HYDROLOGICAL IMPACT ASSESSMENT FOR THE HANNUKAINEN IRON ORE-COPPER-GOLD PROJECT, PHASE 2

Prepared For

Northland Mines OY

Report Prepared by

SRK Consulting (UK) Limited

UK4970

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EXECUTIVE SUMMARY
HYDROLOGICAL IMPACT ASSESSMENT FOR THE HANNUKAINEN IRON ORE-COPPER-GOLD PROJECT, PHASE 2

1 INTRODUCTION

The Hannukainen project is located in the Kolari district of Finnish Lapland, approximately 100 km north of the Arctic Circle. Rivers in the vicinity of the site comprise a known habitat for the endangered Sea Trout (*Salmo truter*) and are within a Natura 2000 protection area under the 1992 EU Habitats Directive.

Earlier in 2012 SRK completed a 'Phase 1' Hydrological Impact Assessment (HIA) for the proposed Hannukainen mine and its associated infrastructure (open pits, waste rock dumps, dry stacked tailings and process plant). The study identified potential negative impacts to local rivers, both in terms of quality and quantity. Consequently, the project has progressed to Phase 2 in which the feasibility of depositing tailings in an existing tailing facility at Rautuvaara is being assessed as an alternative to deposition of the tailings at the Hannukainen site itself.

The proposed Phase 2 Rautuvaara tailings management facility (TMF) infrastructure (dry stacked tailings and process plant) will be located in the Niesa Basin, approximately 10 km south of the proposed Hannukainen pits, in the headwaters of the Niesajoki River. The area is also within the catchment of the Kylmäoja Stream, which is a tributary of the Äkäsjoki River.

Both the Äkäsjoki and Niesajoki are tributaries of the Muonionjoki River which forms the national boundary between Finland and Sweden along part of its length. Treated mine water will be discharged directly from the Rautuvaara TMF to the Muonionjoki River via a pipeline.

The Rautuvaara TMF is located in an area with a long history of mining activities. There is an existing tailings pile that covers 85 hectares and contains approximately 6.6 million tons of waste. Drainage outlets from the existing facility are located in the south and enable water to flow into the Niesajoki River, which discharges into the Muonionjoki River about 12 km downstream. As a result there are existing residual impacts of historical mining on both surface water and groundwater quality.

Renewed deposition of tailings at the site has the potential to adversely impact surface water flows and quality, as well as affecting local groundwater conditions close to the facility. Hence, it is important to define existing conditions within the study area and to assess potential impacts of the development on the environment.

This report outlines an HIA for the expansion of the Rautuvaara TMF and alterations to mine infrastructure at the Hannukainen mine site in support of the Environmental and Social Impact Assessment (ESIA) for the development.

2 CURRENT CONDITIONS

Baseline surface water hydrology within the study area was assessed through analysis of regional stream flow data from Finland's environmental administration OVIA database, supplemented by on-site stream flow measurements. The analysis produced estimates of annual runoff, average monthly flow conditions and low flows for the key rivers potentially impacted by the development. There are marked seasonal variations in flows within rivers close to the site, with high flows following snow melt in spring and low flows in winter when precipitation is held within catchments as snow and ice. These seasonal variations affect the amount of natural dilution available in the river systems through the year.

Baseline surface water quality in rivers close to the development has been characterised through an extensive water quality monitoring program undertaken by Northland Mines Oy. Baseline water quality in the Niesajoki River is negatively affected by historical tailings deposited in the existing Rautuvaara TMF, situated in the Niesa Basin, and uncontrolled releases of surface water from the South Pond of the existing TMF to the river. Water quality improves downstream in the Niesajoki River.

Elsewhere, the water quality within most rivers is good. Site-specific Water Quality Objectives (WQOs) for river water quality have been developed using the ANZECC methodology, an internationally recognised standard. For each chemical parameter 'Trigger Values' (TVs) and 'Action Values' (AVs) have been derived. The TV acts as a warning level, but if the AV is exceeded there is an expectation that the mine operator would undertake immediate remedial work as there is a risk for significant impacts on aquatic life. Under existing conditions, only rare exceedances of AVs for selected parameters are observed within the baseline water quality datasets and analysis of the water quality data identified no exceedances of AVs for median observed concentrations.

There has been very limited monitoring of the groundwater environment at the existing Rautuvaara TMF. A multi-level monitoring network has been designed and installed as part of the investigation associated with this study and provides the majority of the information for defining the current groundwater conditions.

The overburden geology and hydrology is currently being further investigated by the University of Helsinki. A more established groundwater monitoring network exists at Hannukainen comprising both shallow wells in the overburden sediments and multi-level piezometers installed in both the overburden and bedrock. Groundwater investigations began at Hannukainen in November 2007 and regular water levels have been collected since June 2011.

Monitoring indicates that the groundwater surface is generally 0 - 25 m below ground surface (bgs) throughout the project site, broadly following topography, and the local groundwater system discharges to the wetlands and rivers, supporting base flows in these streams.

The site data was used to calibrate a 3-D numerical groundwater model of the site area. The model was used to characterise the hydrogeological regime, including the interaction between groundwater and surface water bodies, and to estimate a water balance for the Rautuvaara TMF ponds under different climatic conditions.

3 POTENTIAL IMPACTS ASSESSMENT

An impacts assessment was undertaken evaluating impacts during the construction, operations and closure periods. The assessment is based on detailed groundwater, geochemical and surface water modelling.

3.1 CONSTRUCTION PHASE

There are no planned releases to the local river network during dewatering of the existing pits, and therefore there are no predicted impacts on water quality and flow associated with pre-dewatering.

During the construction phase of the Rautuvaara TMF there will be excavation of new stream diversion channels, re-development of the water impoundment structure to the north of the TMF, construction of a new impoundment structure to the south of the TMF and construction of other site infrastructure including a clarification pond at Hannukainen and a pipeline from the TMF to the Muonionjoki River. If construction works are undertaken adhering to best practise, including effective sediment control and implementation of environmental management plans, it is anticipated that impacts on water quality in the local rivers will not be significant.

3.2 OPERATIONAL PHASE

Overall there are limited impacts due to the Hannukainen development on surface water flows in any of the main streams located downstream of mining infrastructure (i.e. the Äkäsjoki, Kuerjoki and Valkeajoki Rivers). There will be small (<5% during average year) decreases in flows in the rivers due to a decrease in baseflows and a reduction of catchment area flowing to the rivers. However, hydraulic calculations indicated that these changes will result in a negligible change in channel wetted area, important for the maintenance of aquatic life.

During the operational phase there will be no uncontrolled releases of surface water from the South Pond of the Rautuvaara TMF to the Niesajoki River as water will be pumped directly from the South Pond to the Muonionjoki. Consequently there is potential for a significant decrease in flow within the upper reaches of the Niesajoki River. Immediately downstream of the Rautuvaara TMF flows may tend to zero during winter months (December to April), with very small volumes of surface runoff supporting groundwater-fed base flows in the streams. However, there is the potential for augmentation of flows in the Niesajoki with water from the South Pond (if shown to be of a sufficiently high quality) and the reduction of surface water flows from the Rautuvaara TMF to the Niesajoki River should result in a marked improvement in the quality of water in the Niesajoki.

Groundwater and geochemical modelling were employed to predict the quality of water seeping from the mine infrastructure and reporting to the local groundwater system, TMF ponds and nearby rivers. Negligible or no impacts on water quality are predicted for the Valkeajoki and Kuerjoki during operations. Predictions for the Äkäsjoki River indicate that there are no exceedances of AVs for key parameters during operational mining. No key parameter concentrations are predicted to rise >16% over baseline during the spring thaw, apart from chloride. During winter months exceedances of TVs for cadmium, chromium, mercury and uranium are predicted.

Modelling of the Kylmäoja Stream indicates negligible changes in water quality for key parameters during the operational phase.

During operations an improvement in water quality in Niesajoki River over baseline conditions is predicted, as uncontrolled runoff from the existing Rautuvaara TMF ceases and excess water from the new TMF is controlled and piped to the Muonionjoki.

During operations, treated mine water will be discharged from the TMF to the Muonionjoki River via a pipeline. The discharge will comprise less than 1% of the total flow in the river, even in winter months, and is not predicted to have a significant impact on the flow of the river.

Modelling work indicates that there will be a dilution zone downstream of the outfall to the Muonionjoki within which there is a risk of exceedance of AVs for key parameters. Further modelling work, field studies and discussions with regulators will be required in order to better define the extent of the dilution zone downstream of the outfall. Within 1 – 2 km downstream of the outfall the effluent plume is predicted to have fully mixed with river water. At this point modelling predicts no exceedances of AVs within the Muonionjoki. However, exceedances of TVs for cadmium, cobalt, copper, molybdenum, nickel and uranium are predicted near the end of mine life. For most parameters the main impacts are during winter months when flows in the river are at their lowest.

A number of mitigation options are available including improvements to proposed water treatment and optimisation of the site water management plan to reduce winter discharges to the Muonionjoki. In addition, there are limitations with the ANZECC method (used to derive WQOs) for good quality rivers such as the Muonionjoki. TVs are defined as a statistic of the baseline water quality and in rivers with very low baseline concentrations, exceedances of TVs indicate a change from baseline conditions, but they may not indicate the potential for negative effects on aquatic life. In the Muonionjoki many TVs are significantly lower than AVs.

3.3 CLOSURE PHASE

On cessation of mining operations the open pits will be allowed to fill to form pit lakes and the waste rock dumps will be covered. The closure plan for the Rautuvaara TMF has not been fully developed, leading to uncertainties in predictions of water quality in the TMF and downstream post-closure. However, it is expected that surface exposed High-S tailings will be covered and treatment of runoff from the High-S tailings will cease, as will discharge of water from the Hannukainen mine to the South Pond of the TMF. Excess water in the South Pond will be allowed to flow into the Niesajoki River and the pipeline to the Muonionjoki will be decommissioned.

It is predicted that both the Hannukainen and Kuervitikko pit lakes may overtop to the Äkäsjoki and Kuerjoki respectively once fully recovered. There is negligible impact predicted on river flow. Calculations indicate that following the first over-spill of water from the full pit lake to the rivers, TVs are predicted to be exceeded for a number of key parameters. Copper predictions are predicted to exceed AVs under some flow conditions. Steady state predictions highlight the potential for exceedances of some AVs with exceedance of TVs for the majority of key parameters. Water quality can be significantly improved by the addition of alkaline rock (limestone, $CaCO_3$) to PAF rock dumps and / or addition of alkaline amendment (such as lime, CaO) to the Kuervitikko pit lake to correct initial poor water quality.

Upon closure, seepage from the tailings will continue to report to the TMF ponds and local rivers. It is assumed that water quality of the South Pond will be monitored and water treated until it is of sufficiently high quality to be discharged directly to the Niesajoki without treatment, as per the current arrangement. At that time flow rates in the Niesajoki River would be expected to return close to present day conditions. The water quality of the Niesajoki River is predicted to deteriorate due to this release, with exceedances of TVs for a number of parameters, and the potential for exceedance of AVs for copper, in the Niesajoki.

Seepage calculations indicate, that for many parameters, post-closure concentrations in the Kylmäoja stream will be lower than under baseline conditions. However, for some parameters (mostly metals), concentrations are predicted to increase post-closure compared with baseline conditions.

Overall a number of potential water quality issues have been identified at closure of the Hannukainen mine site and Rautuvaara TMF. At present a number of conservative assumptions have been made within water quality predictions, based on information available to date and the present mine closure plan. A number of mitigation options are available which are expected to improve water quality (e.g., addition of alkaline loadings to WRDs and pit lakes, on-going treatment at Rautuvaara TMF or Hannukainen post-closure); however, additional work will be required to assess the impact of these options.

4 RECOMMENDATIONS

A number of recommendations are made within the study report. Key recommendations are outlined below.

Monitoring of existing surface water flow and stage level, and groundwater level and water quality should continue. The report makes recommendations for the improvement of the existing monitoring program.

Further modelling and site investigation work related to the proposed outfall to the Muonionjoki is required, including additional flow surveys, field dilution surveys and revised plume modelling. Discussions with regulators should be initiated to discuss requirements related to dilution zones downstream of the outfall.

A review of the site water management plan is recommended to assess whether discharge rates from the Hannukainen mine to South Pond can be reduced and/or whether on-site storage during winter could reduce winter discharge rates to Muonionjoki.

Additional work on pit lake water quality is recommended, especially work related to the potential of neutralising WRD runoff and pit lake water quality through the addition of lime or limestone. Refined pit lake modelling is also recommended to identify if stratification in the pit lakes has the potential to improve surface layer water quality in the pit lakes, limiting the need for other mitigation options.

Finally, a review of potential passive and active treatment options for closure of the Rautuvaara tailings facility is recommended to optimise mitigation of any potential impacts post-closure.

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Abbreviations

Abbreviation	Meaning
°C	Degrees Celsius
%	Percent
<	Less than
>	More than
2D	Two dimensional
ADCP	Acoustic Doppler Current Profiler
ANZECC	Australian and New Zealand Environment Conservation Council
AV	Action Value
C	Concentration
CaO	Calcium oxide, commonly known as Lime
CCME	Canadian Environmental Quality Guidelines
cm	Centimetre
CMA	Catchment Management Area
Co	Cobalt
Cu	Copper
DFS	Definitive Feasibility Study
EC	Electrical conductivity
EPA	Environmental Protection Agency
EPD	Government of British Columbia
EQS	Environmental Quality Standards
ERM	Environmental Resources Management
ESA	Environmental Site Assessment
ESIA	Environmental Social Impact Assessment
EU	European Union
Fe	Iron
FHT	Falling Head Test
GMS	Groundwater Modelling System
GPR	Ground Penetrating Radar
GTK	Geological Survey of Finland
GW	Groundwater
HDPE	High-density polyethylene
HIA	Hydrological Impact Assessment

High-S	High Sulphur
HTC	Humidity Test Cell
IN	Inert (waste rock)
IOCG	Iron Ore-Copper-Gold
K	Hydraulic conductivity
km	Kilometre
km^2	Square kilometre
L	Litres
L/s	Litres per second
LDPE	Low-density polyethylene
LIMS	Low intensity magnetic separation
LOM	Life of Mine
LVT	Lapin Vesitutkimus Oy
m	Meter
m mol/L	Millimols per litre
m/d	Meters per day
m^2	Square meter
m^3/d	Cubic meters per day
m^3/s	Cubic meters per second
masl	Meters above sea level
mbgs	Meters below ground surface
mg	Milligram
mg/L	Milligram per litre
mm	Millimetre
mm/yr	Millimetres per year
Mm^3	Million cubic meters
mS/m	Millisiemens per meter
N	Nitrogen
NAG	Net-Acid Generation Test
Ni	Nickel
NOPEX	Northern Hemisphere Climate Processes Land Surface Experiment Project
OB	Overburden
OIVA	Ympäristö- ja paikkatietopalvelusta or Environmental and Spatial Information Service
P	Phosphorus

PAF	Potentially Acid Forming (waste rock)
pH	pH
PJKSZ	Pajala-Kolari Shear Zone
Q1	Quarter 1 [of a calendar year]
RAU12HYD- (D)	Hydrogeological well screened in the bedrock
RAU12HYD- (S)	Hydrogeological well screened in the overburden sediments
RKTL	Finnish Game and Fisheries Research Institute
RMS	Root mean square
RSZ	Rautuvaara Shear Zone
s	Second
SAC	Special Areas of Conservation
SMHI	Swedish Meteorological and Hydrological Institute
SO_4	Sulphate
SPA	Special Protection Areas
SW	Surface Water
SWL	Static Water Level
SYKE	Finnish Environment Institute
T	Temperature
TDS	Total dissolved solids
TMF	Tailings Management Facility
TOC	Total organic carbon
TSS	Total suspended solids
TV	Trigger Value
µg/L	Micrograms per litre
WFD	Water Framework Directive
WQO	Water Quality Objective
WRD	Waste Rock Dump

Glossary of Terms

Aquitard: A confining strata of significantly lower permeability than the aquifer.

Blow testing: Air injected in to the well at a constant rate to provide a measure of volume of water ejected from the well in a given time. Repeated at multiple depths down the length of the well.

Chemocline: A layer within a water body caused by a strong chemical gradient resulting in clear stratification.

Confined aquifer: An aquifer, overlain by a confining stratum of significantly lower permeability than the aquifer and where piezometric level is above the base of the confining stratum. A confined aquifer is saturated throughout.

Constant head boundary: A boundary defined in a model to be at a constant groundwater head.

Eutrophic: Used to describe a lake, pond, or stream rich in mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

Eutrophication: The process by which a lake, pond, or stream becomes eutrophic, typically as a result of mineral and organic runoff from the surrounding land. The increased growth of plants and algae that accompanies eutrophication depletes the dissolved oxygen content of the water and often causes a die-off of other organisms.

Falling head test: If a slug cannot be used, e.g. water table too deep, then a volume of water can be introduced in to the hole to perform a falling head test.

Hydraulic conductivity (K): The rate at which water flows through a unit area of aquifer under a unit hydraulic gradient. Hydraulic conductivity values are expressed in cubic metres per day per square metre of aquifer under a hydraulic gradient of 1 i.e. m3/m2/day or m/day.

Leaky/Semi-confined aquifer: An aquifer overlain by an aquitard in which groundwater flow occurs, albeit at a lower rate than the aquifer itself. When the aquifer is pumped groundwater may flow from the overlying aquitard and recharge the aquifer.

Limnology: The scientific study of the life and phenomena of fresh water, especially lakes and ponds.

Meromixis: Describing the mixing regime of a meromictic lake where no mixing occurs, i.e. the lake is stratified.

Oligotrophic: Used to describe a lake, pond, or stream lacking in plant nutrients such as phosphates, nitrates, and organic matter, and consequently having few plants and a large amount of dissolved oxygen throughout.

Penetration rate: Time required to drill a specified length of borehole.

Piezometer: A small diameter well used to measure groundwater head at a specific interval in an aquifer.

Piezometric surface: The groundwater level at which the pore-pressure is equal to atmospheric pressure i.e. the water table under unconfined conditions and a theoretical surface under confined conditions.

Slug test: A rise in water level induced in the well by the introduction of a solid cylinder (or slug) beneath the static water table. A data logger is then used to monitor the subsequent fall of water level (this procedure is also known as a falling head test). Once the water level has recovered to within 95% of the original static water level the slug is removed to induce a fall in the water level, followed by monitoring of the rise in water (also known as a rising head test);

Source-pathway-receptor model: This model is used as a risk assessment tool to identify the **source** of any contamination, what the source may affect (**receptor**) and how the source may reach the receptor (**pathway**). The three components must be present for the potential for contamination to exist.

Specific yield (S_y): The volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table, also referred to as effective porosity (%).

Specific Storage (S_s): The volume of water released from storage per unit surface area of a confined aquifer (or aquitard) per unit decline in hydraulic head due to release of water from elastic storage only. Values are expressed as length^{-1}.

Storativity (S): The volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in head. Values are dimensionless.

Surface water catchment: Total surface area draining to a specified river.

Unconfined aquifer: An aquifer which is not fully saturated to an overlying confining stratum and where a water table exists which is exposed to the atmosphere.

Unsaturated zone: The zone between the land surface and the water table where pores are not fully saturated with water

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HYDROLOGICAL IMPACT ASSESSMENT FOR THE HANNUKAINEN IRON ORE-COPPER-GOLD PROJECT, PHASE 2

1 INTRODUCTION

1.1 Objectives

SRK Consulting (UK) Limited ("SRK") is an associate company of the international group holding company, SRK Consulting (Global) Limited (the "SRK Group"). SRK has been requested by Northland Mines Oy ("Northland" hereinafter also referred to as the "Company" or the "Client") to undertake an assessment of potential hydrological impacts for the proposed Hannukainen Iron Ore-Copper-Gold Project ("Hannukainen project"), including the associated Rautuvaara tailings management facility (TMF), located in Finland.

The principal objectives of this Hydrological Impact Assessment (HIA) are to:

- Characterise the current water resource status;
- Assess the potential impacts of the proposed mining operation at Hannukainen and Rautuvaara on surrounding groundwater and surface water resources, including;
    - Construction, operational and closure phases;
    - Impacts on the groundwater regime;
    - Impacts on surface water hydrology;
    - Impacts on water quality;
    - Impacts on other water users; and
- Inform the Environmental Social Impact Assessment (ESIA).

This HIA is a standalone document that will be used by Ramboll to write the relevant sections of the Finnish ESIA. The Ramboll document will consider the potential impact of changes to the surface water environment on local ecology. The potential impact to river ecology is not within the scope of this HIA. The Hannukainen HIA and Finnish ESIA will then be used by ERM in preparing the Definite Feasibility Study (DFS) ESIA. A full explanation of the parties involved in the Hannukainen project is given below in Section 1.3.

1.2 History

There is a long history of mining activities in the Hannukainen area with the most recent historical mining at the Hannukainen site between 1975 and 1996. Northland acquired a licence for the area in 2005 and completed explorations in 2008 (Pöyry, 2010).

Exploration and mining was first undertaken at Rautuvaara by Otanmäki Oy in 1962 and continued until 1999, when the plant lease expired. There has been a progression in the type of tailings deposited in the facility, from iron ore through iron-copper to copper-gold (GTK, 2010a). More details are provided below in Section 1.4.6.

1.2.1 Phase 1 Study

In 2008 Northland began to engage a number of consultants, named below in Section 1.3, to complete a DFS and an ESIA for the Hannukainen project. The ESIA included an HIA, undertaken by SRK, for the proposed Hannukainen mine and its associated infrastructure. The HIA study is referred to in this document as the 'Phase 1' Hannukainen HIA.

The Phase 1 Hannukainen HIA (SRK, 2012a) comprised:

- Characterisation of the current water resource status at Hannukainen in terms of both water quantity and water quality, including:
  - The Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki and Muonionjoki rivers;
  - Classified aquifers in the vicinity of the Hannukainen mine site;
  - Other potential receptors in the vicinity of the Hannukainen mine site, e.g. groundwater users, nature reserves, wetlands and springs;
- Assessment of the potential impacts of the proposed Phase 1 infrastructure on surrounding groundwater and surface water resources by means of:
  - Numerical groundwater modelling;
  - Geochemical modelling;
  - Surface water catchment analysis;
  - Water quality predictions; and
- Production of a Hannukainen HIA Report providing details of the data, methodologies and findings for use by Northland and other consultants involved with the project.

The Phase 1 Hannukainen HIA study did not consider the deposition of tailings at the Rautuvaara site, the proposed Phase 1 TMF location being close to the Hannukainen mine complex, approximately 11 km north of Rautuvaara (SRK, 2012a). The Rautuvaara site was discounted in Phase 1 due to the economic risks associated with the acquisition of a potentially contaminated brownfield site (Northland, pers. comm.).

The Phase 1 Hannukainen HIA (SRK, 2012a) identified limited impacts to the nearby Äkäsjoki and Kuerjoki rivers. However, potential negative impacts to the Valkeajoki River, a breeding ground for the critically endangered Sea Trout (*Salmo truter*), and the Niesajoki River were predicted as follows:

- Average monthly flows in the Valkeajoki were predicted to reduce by up to 12% in the winter months as a result of decreased recharge in the river catchment caused by the constructed bottom structure beneath the Phase 1 TMF at Hannukainen and the associated surface water management system;

- Seepage water from the TMF and waste rock dumps (WRDs) had the potential to raise concentrations of selected parameters (nitrate, cadmium, chromium, mercury and uranium) above water quality objective (WQO) Action Values (AVs) in the Valkeajoki during both the operational and post-closure phases;
- It was predicted that average monthly flows in winter would increase by over 100% in the Niesajoki River due to treated mine water discharge;
- For some parameters the quality of treatment plant effluent exceeded WQOs for the Niesajoki and the discharge resulted in significant increases in concentrations of selected parameters (iron, mercury, nickel, sulphate and uranium) in the river, with concentrations exceeding the WQO AVs; and
- Water quality of the pit lakes deteriorated post-closure while the pits flooded due to reactions with acid generating material in the pit walls. The pit lake water quality improved once the pits were fully flooded and this material was submerged.

1.2.2 Phase 2 study

Due to the potential negative impacts identified by the Phase 1 study the feasibility of depositing tailings at Rautuvaara was reassessed as an alternative to deposition of the tailings at the Hannukainen site. This development of the HIA is referred to as 'Phase 2'.

The Phase 2 study will comprise:

- An HIA study at Rautuvaara and an update of the Phase 1 Hannukainen HIA study, as outlined previously in Section 1.1. These two studies are combined in this report to develop one HIA document for the proposed Phase 2 project; and
- Refinement of the Hannukainen DFS document. The reader is referred to the DFS document (SRK 2012c) for more detail.

During the Phase 1 Hannukainen HIA, SRK undertook an assessment of pit water management requirements for the Hannukainen project (SRK, 2011) and the associated impacts (SRK, 2012a), which required conceptual and numerical groundwater flow modelling for the originally proposed site. SRK has extended this work for the Phase 2 HIA to include the newly proposed tailings area at Rautuvaara. The resultant predictive groundwater model has been used to inform hydrological and geochemical modelling and hence predict potential flow, level and quality impacts.

It was proposed in Phase 1 that water from the existing pit lakes be discharged to the Äkäsjoki River, via the Laurinoja Stream. In Phase 2 this water will be stored in the Hannukainen clarification pond and then used throughout the site during the construction phase, i.e. there are no planned discharges to the Laurinoja Stream or Äkäsjoki River in the Phase 2 plan.

During Phase 1 excess mine water was treated and discharged directly to the Niesajoki River. However, due to predicted impacts on water quality in Niesajoki, Phase 2 considers the option where excess mine water (including water from the Rautuvaara TMF) is piped to the Muonionjoki River, bypassing the Niesajoki. Hence, the Phase 2 study includes dilution modelling to predict water quality impacts within the Muonionjoki River.

The work undertaken during Phase 2 also includes updates and improvements to the pit lake water quality predictions for the management of the Hannukainen and Kuervitikko pits at closure. This work included detailed water balance modelling and the assessment of the impact of augmenting pit lake infilling with pumped river water.

The assessment of potential impacts to water quality will rely heavily upon comparison with site specific WQOs developed by Ramboll. The methodology employed to calculate these WQOs is discussed in Section 3.2 where potential issues regarding use of these WQOs are also highlighted.

1.3 Role Players

The principal role players involved in the HIA are SRK and their sub-consultants Kaya Consulting Ltd ("Kaya"):

- SRK has been commissioned by Northland to complete an HIA at Hannukainen. The study will be used by Environmental Resources Management ("ERM"), who is compiling the DFS level ESIA on behalf of Northland.
- Kaya was commissioned by SRK to undertake an assessment of the effects of the Phase 1 Hannukainen mine development on surface water quantity (hydrology) and quality in the key watercourses potentially impacted by the mine development. They have been retained to complete the Phase 2 works. Their work is incorporated into this HIA report.

The key parties involved at Hannukainen and a summary of their roles with respect to water studies for the ESIA and DFS are summarised in Table 1-1.

Table 1-1: Key role players at Hannukainen

Company	Project role
SRK	• Input to DFS; geology and resources, geotechnical studies, water management, mining studies (including cost estimates), WRD design, pit lake modelling • Compilation of the HIA; including numerical groundwater modelling, TMF and tailings lake source terms, and geochemical modelling. • 43-101 technical reviews and reporting
Kaya	• Hydrological aspects of HIA; including surface water baseline, modelling and impact assessment
ERM	• Compilation of the DFS ESIA (drawing from the Finnish ESIA by Ramboll)
Lapin Vesitutkimus Oy ("LVT")	• Baseline studies (surface water and groundwater)
Nils Eriksson	• Review of SRK geochemical modelling work
Pöyry	• Site wide mine water balance • Mine site infrastructure; including surface water management, mine water treatment, and tailings facility design
Ramboll	• Development of WQOs for receiving waters • Compilation of the Finnish ESIA • Closure plan
University of Helsinki	• Quaternary deposits study; including Ground Penetrating Radar (GPR), stratigraphic logging, thermal imaging and hydrological studies

1.4 Project Setting

1.4.1 Location

The Hannukainen Project is located in the Kolari district of Finnish Lapland, approximately 100 km north of the Arctic Circle, 25 km north-northeast of Kolari and 20 km east of the border with Sweden (Figure 1-1). The Rautuvaara TMF is located in the Niesa Basin approximately 11 km south of the proposed Hannukainen pits.

1.4.2 Topography

The topography of the area is characterised by incised, undulating terrain of low relief. Most of the area is covered by glacial moraine and sands, with variable peat cover in the lower-lying areas. Hills and some valleys are forested, primarily with birch, pine and spruce. Peat-bogs, swamps and numerous shallow lakes cover much of the low-lying areas.

1.4.3 Climate

The Kolari region belongs to the boreal, coniferous-mixed forest zone of Finland. It is characterised by moderate precipitation, cold winters and cool summers.

The average annual precipitation at Hannukainen and Rautuvaara is estimated to be 529 mm (Pöyry, 2012a), based on the data used during the Phase 1 HIA. Most of the precipitation occurs in the period July to August (74 mm/month and 71 mm/month respectively on average), with the lowest precipitation rates from February to March (27 mm/month and 29 mm/month respectively).

The average annual temperature measured at the nearest long-term meteorological station in Pajala, Sweden is -0.1 ºC. However, the average temperature in the winter months, November to February, drops to -11.2 ºC. Between November and April precipitation falls as snow and begins to thaw in May. The snow depth by the end of winter in Kolari reaches 75 cm on average (Pöyry, 2012a).

1.4.4 Hydrology

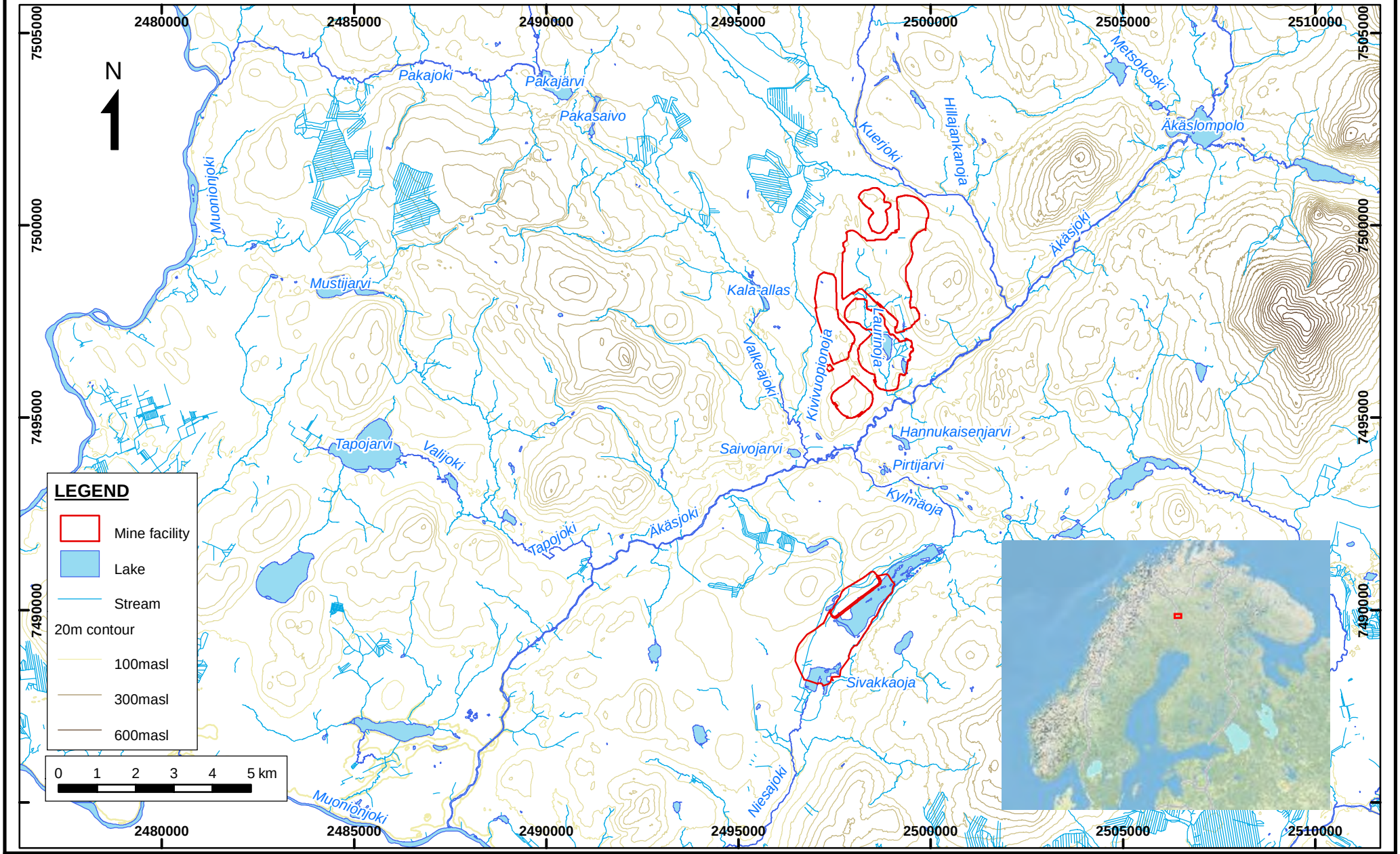
The Hannukainen mine site is bounded to the south by the Äkäsjoki River, to the west by the Valkeajoki River and to the east by the Kuerjoki River. The Valkeajoki and Kuerjoki rivers are tributaries of the Äkäsjoki (Figure 1-1).

The existing Rautuvaara TMF is located within the Niesa Basin and forms the headwaters of the Niesajoki River. Prior to industrial operations in the Niesa Basin the Niesajoki River headwaters were located further upstream in the hills to the northeast of the basin. However, during the development of the Niesa Basin the natural headwaters of the Niesajoki were diverted to the Äkäsjoki by way of a man-made ditch (Kylmäoja Stream). This ditch is still in operation and, as a result, the remaining catchment draining to the Niesa Basin, and therefore the Niesajoki, is small at around 5 km^2 (Figure 1-1).

The Äkäsjoki and Niesajoki rivers discharge into the Muonionjoki, which is itself a tributary of the Tornionjoki River. The Muonionjoki joins the Tornionjoki about 20 km south of the town of Kolari and together they form the national boundary between Sweden and Finland.

The Muonionjoki, Tornionjoki and Äkäsjoki rivers are known to be important for supporting populations of both Baltic Sea Salmon and Sea Trout (Puro-Tahvanainen et al., 2001). However, it is noted in the fish baseline study that “No information is available about the Niesajoki River probably having a sea trout population. There are no electrofishing monitoring points of the Finnish Game and Fisheries Research Institute (RKTL) in the Niesajoki River” (Ramboll, 2012a). All the catchments in the study area lie within a Natura 2000 protection area.

A wetland nature reserve (Saivojärvi) is located a few kilometres to the south-west of the mine site.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Surface Water Features in the Area of the Project	Figure 1.1

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 1-1 Local Hydrology_PH2.mxd

1.4.5 Geology

The Hannukainen and Kuervitikko deposits, which together make up the Hannukainen Project, will be the source of tailings for the Rautuvaara TMF. They are two of a number of Iron Ore-Copper-Gold (IOCG) deposits in this region. However, economically viable grades are known only in a limited number of these deposits and the Hannukainen and Kuervitikko deposits are believed to be one of the most gold-rich IOCG deposits in the Kolari region (Hatch, 2010).

The Hannukainen Project is located within the Fennoscandian shield which is a large, exposed Precambrian crustal domain covering most of Finland and Sweden. The Shield comprises three Archean cratons (Norrbotten, Karelian and Kola) that were amalgamated during a collision event in the early Proterozoic (SRK, 2011).

The structural geology of the area is dominated by the Pajala-Kolari Shear Zone (PJKSZ), a north-northeast to south-southwest trending, crustal-scale fault / shear system. The PJKSZ is situated along, and forms the tectonized contact between, the Norrbotten and Karelian cratons. At Hannukainen, the PJKSZ consists of several shear and thrust zones extending over an area 250 km long by 10 km wide. Thrusting along the PJKSZ structures has generally been towards the northeast, with observed dips generally towards the west and / or southwest (Holma et al, 2008).

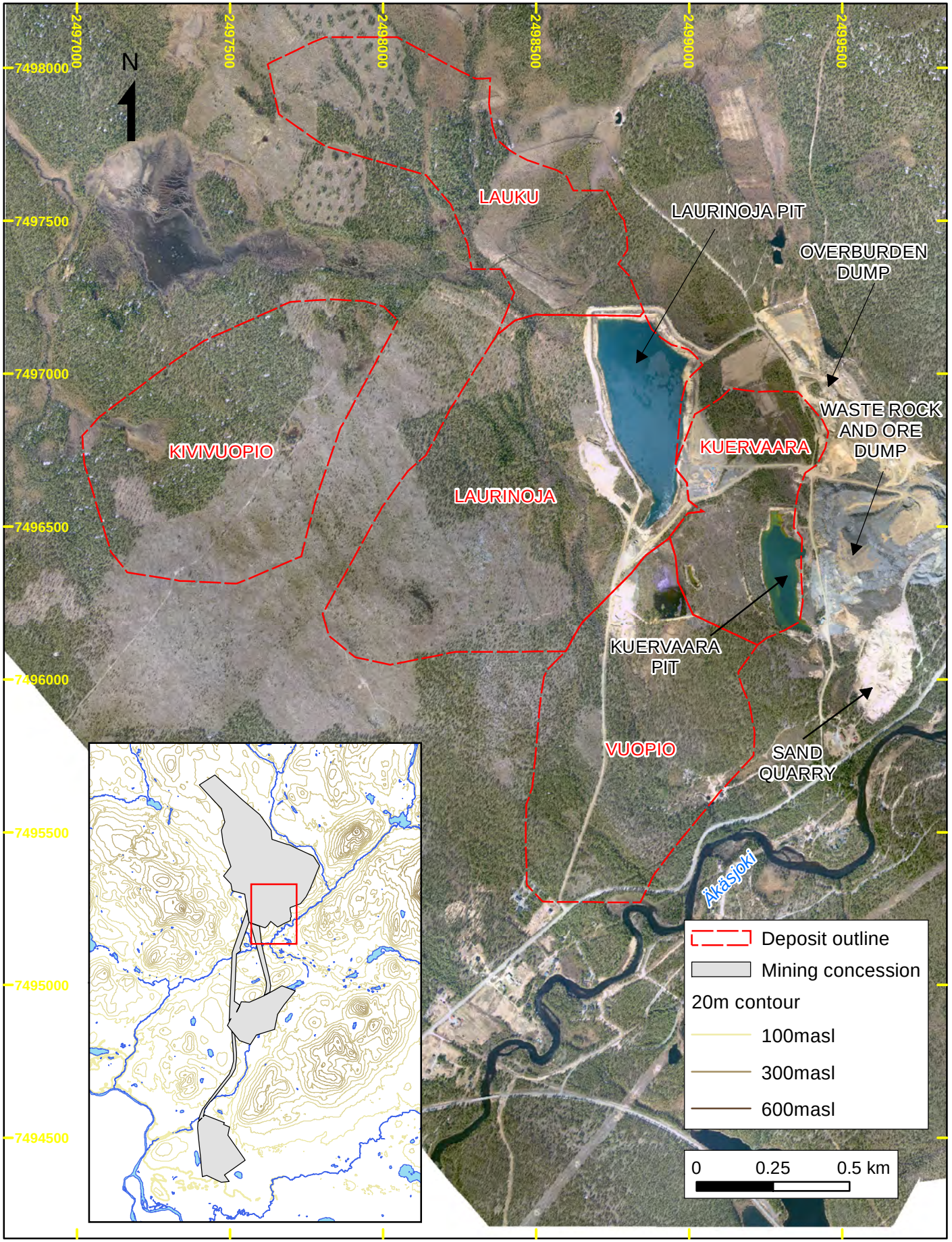
1.4.6 Historical Mining

Mining

The main ore bodies of the Hannukainen area (Laurinoja, Kuervaara, Vuopio, Lauku and Kivivuopio) were acquired by Rautaruukki Oy from 1974 to 1985 and by Outokumpu Oy from 1985 to 1995. At the end of historical mining operations at Hannukainen the open pits at the Laurinoja and Kuervaara ore bodies were allowed to flood and remain as pit lakes within the present site (Pöyry, 2010).

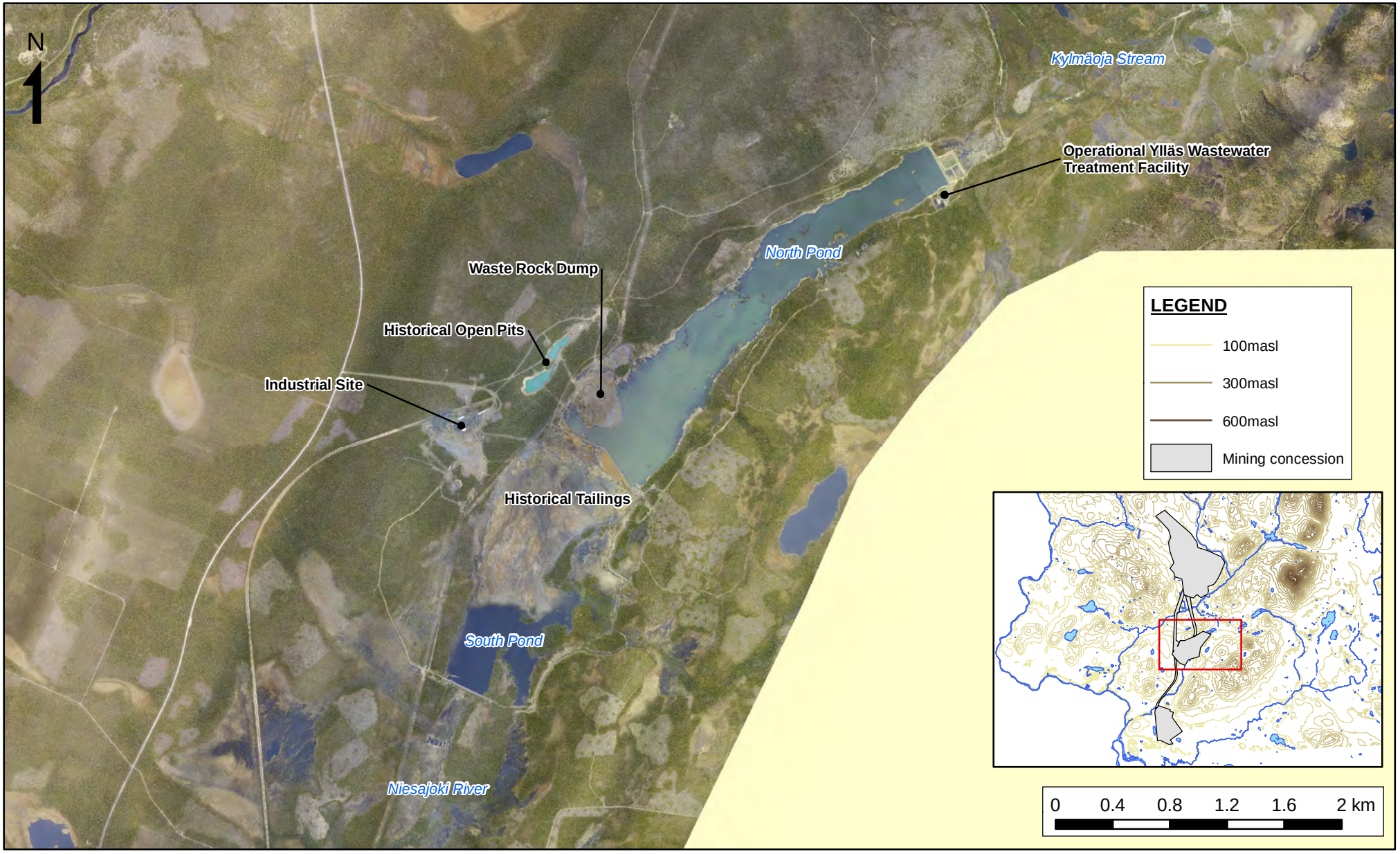
At Rautuvaara, exploration and mining was first undertaken by Otanmäki Oy from 1962 to 1967. Rautaruukki Oy continued operations in 1970 using a pilot processing method. Subsequently a mill and concentrator was constructed to process iron ore from the Rautuvaara mine (1975 – 1988), then iron-copper ores from the Kuervaara (1978 – 1986) and Laurinoja (1982 – 1988) mines, and most recently gold-copper ore from the Saattopora mine (1989 – 1996) and four other smaller gold and copper mines operated by Outokumpu Oyj. The plant lease of Outokumpu Oyj expired in 1999 and the Rautuvaara facility has not been in use since this time (GTK, 2010a).

Historical mining facilities at the proposed Hannukainen mine site and Rautuvaara TMF site are shown in Figure 1-2 and Figure 1-3 respectively.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Hannukainen Historical Mine Workings and Northland Mining Concession	Figure 1.2

P:\U4518 Hannukainen HIA\Project\CAD\Deposit_Outlines_PH2.mxd



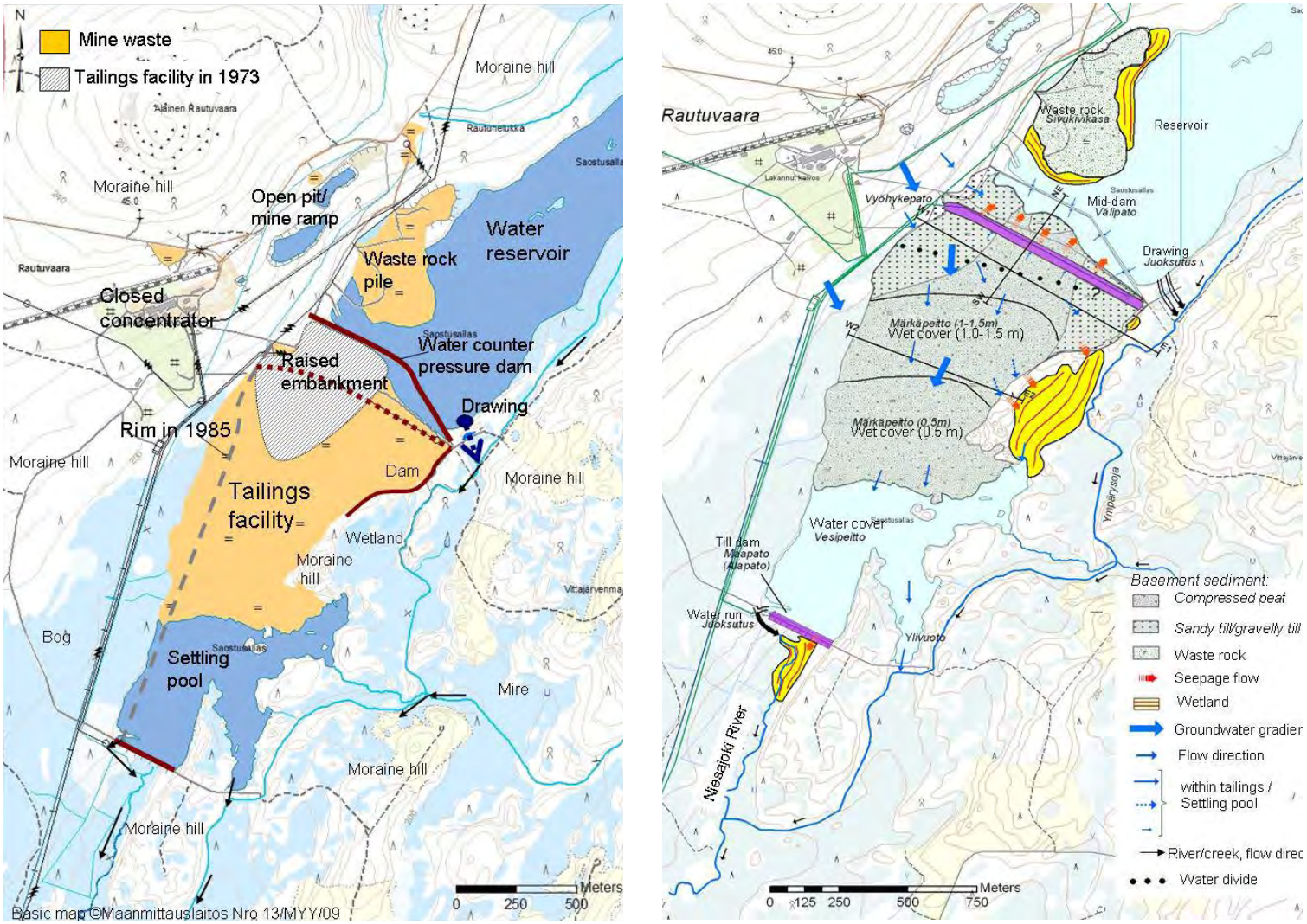
JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Rautuvaara Historical Mine Workings and Remnant Infrastructure	Figure 1.3

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 1-3 Historical infrastructure_PH2.mxd

Tailings Deposition

Tailings deposition in the existing Rautuvaara TMF is described by GTK (2010a) and summarised below and in Figure 1-4:

- Deposition in the Rautuvaara TMF started in 1973 on the northwest side of the river basin. Tailings have progressively been deposited downstream to the south and southeast with the discharge point moving during the lifetime of the TMF but always located along the northern embankment. Consequently, finer tailings material is generally located in the central and southern portion of the TMF while the bulk of the coarse material has settled in the northern part of the tailings dam, close to the discharge points;
- The TMF comprises a single cell. It is contained as follows:
    - To the north by a counter-pressure dam of coarse rock boulders which separates the TMF from the water reservoir further north. An embankment has been constructed 'later' (no date available) which consists of tailings mixed with waste rock aggregates;
    - To the east by a containment dam of waste rock aggregate;
    - To the south by a till core dam with waste rock covers which contains the tailings and also the settling pool located over the southern portion of the tailings; and
    - To the west there is no containment structure.
- There are two ponds associated with the existing Rautuvaara TMF:
    - A water reservoir to the north which was used to supply water for the processing plant during historical mining; and
    - A settling pool to the south of the tailings facility. There are direct discharges from the facility to the surface water system, described below in Section 6.3.4, but it is not clear how these outlets were managed during historical operations.
- The majority of the existing tailings dam is underlain by a layer of compressed peat, which is itself located on top of sandy or gravelly sandy till and crystalline bedrock. There are two known exceptions in the northwest and northeast corners of the facility (Figure 1-4) where the peat is absent and tailings are deposited directly on to sandy or gravelly sandy till with a thin humus layer. It was assumed by GTK (2010a) that the compressed peat would impede movement of potential contaminants to the groundwater while the regions with just a thin humus layer would have relatively permeable foundations and therefore be more susceptible to groundwater contamination; and
- The current tailings pile covers an area of 85 hectares and contains approximately 6.6 million tons of waste. Drainage outlets from the existing facility are located in the south and enable water to flow into the Niesajoki River, which discharges into the Muonionjoki River about 12 km downstream.



(a) **(b)**

Figure 1-4: Existing Rautuvaara TMF showing (a) progressive historical deposition (black arrows refer to flow direction of surface waters) and (b) natural basement sediment beneath the facility (from GTK, 2010a).

1.5 Layout of the report

This Phase 2 HIA report is an amalgamation of the Phase 1 Hannukainen HIA report and the Rautuvaara HIA draft report, as per the request of the client.

A summary of the report structure is given below:

1. Introduction: HIA objectives, regional setting and key role players;
2. Framework: Legal, corporate, and international context of the HIA;
3. Approach: Methodology adopted by the HIA, key assumptions and limitations;
4. Proposed Activities and Scoping assessment: Identification of potential source–pathway–receptor linkages and targets for impact assessment;
5. Approach to Current Conditions Assessment: Data sources and methodologies employed in the current conditions assessment;
6. Current Conditions Assessment: Data describing the current conditions at the site including climate, surface water (SW), groundwater (GW) and geology, and the conceptual hydrogeological model;
7. Project Description: Description of proposed activities that may affect water resources;
8. Approach to Impact Assessment: Description of modelling and impact prediction techniques;
9. Impact Assessment: Description and magnitude of impacts;
10. Impact Management: Mitigation measures and management methods; and
11. Conclusion: Key findings and recommendations.

2 FRAMEWORK

The Project is located in northern Finland, and must comply with both national and international guidelines and standards. A summary of the relevant legislation is given below in order to provide the context in which the HIA has been undertaken.

2.1 Legal Context

On 23rd October 2000, the "Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy" or “EU Water Framework Directive” (WFD) was adopted throughout the European Union (EU).

The objective of the WFD (2000/60/EU) is for all surface water bodies in member states to reach at least ‘good’ status by 2015. The directive requires that member states:

- Manage water resources based on river basins;
- Define what constitutes a “good” status by setting Environmental Quality Standards (EQSs);
- Identify the characteristics of river basin districts;
- Assess existing water quality;
- Identify and implement necessary pollution control measures; and
- Continually monitor and review progress.

In relation to groundwater, the WFD (2000/60/EU) presumes that groundwater is currently unpolluted and therefore setting chemical quality standards is generally not considered the best approach (with the exception of particular parameters, e.g. nitrates, pesticides and biocides). Rather than water quality standards, the WFD prohibits direct discharges to groundwater, and (to protect against indirect discharges) requires member states to monitor groundwater bodies so as to detect changes in chemical composition and reverse any anthropogenic impacts. The directive also requires management of groundwater resources in order to prevent over-abstraction of aquifers (from http://ec.europa.eu).

The WFD is implemented in Finland through three key pieces of legislation:

1. Act on Water Resources Management (1299/2004);
2. Decree on Water Resources Management (1040/2006); and
3. Decree on Water Resources Management Regions (1303/2004).

Finnish water management planning is divided into Catchment Management Areas (CMAs), each of which consists of one or more drainage basins. Hannukainen and Rautuvaara are situated in the Torne river basin district, which belongs to the Tornionjoki CMA. It is an international CMA shared with Sweden. Figure 2-1 presents the Finnish CMAs.

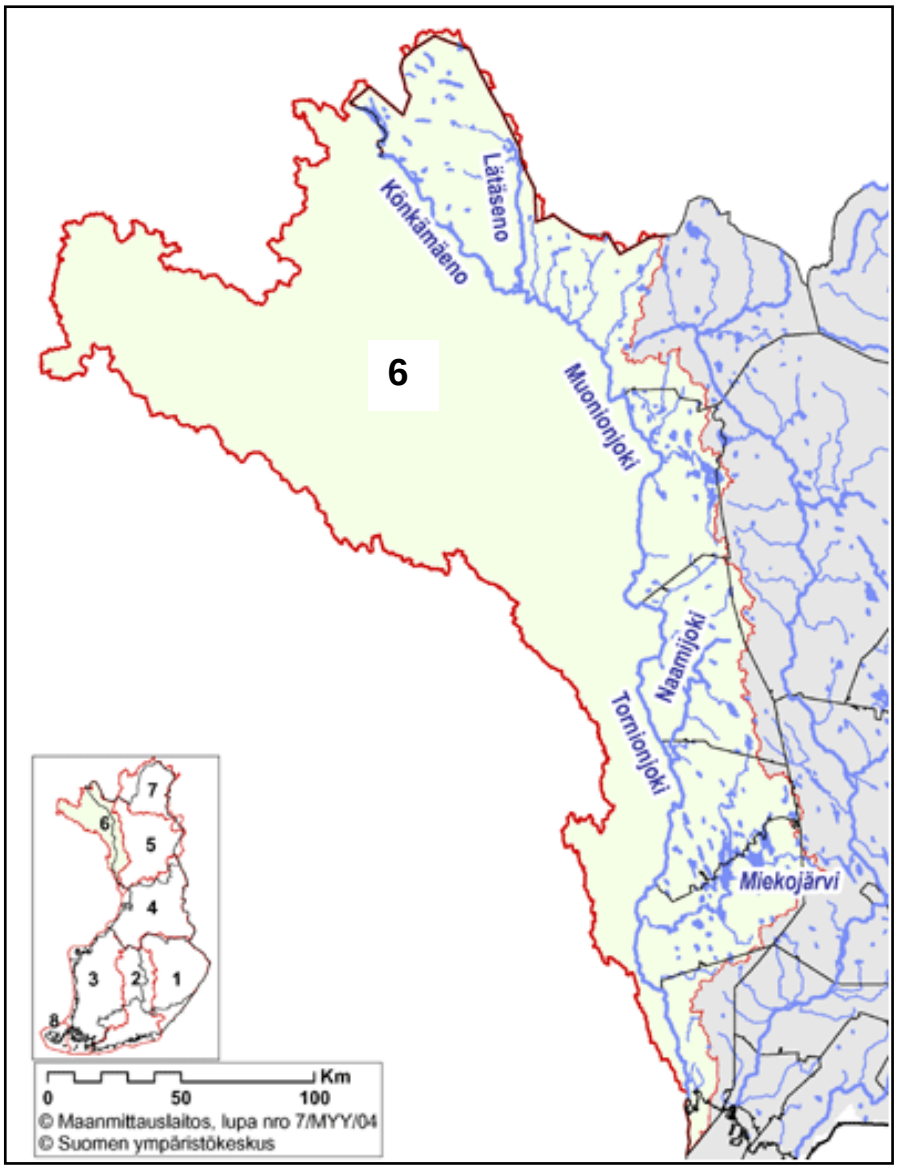


Figure 2-1: Tornionjoki Catchment Management Area (from www.ymparisto.fi, maintained by the Finnish Environment Institute (SYKE))

On the Finnish side, the Torne river basin district belongs almost completely to the Natura 2000 protection network, an EU wide network of nature protection areas established under the 1992 Habitats Directive. The aim of the Natura 2000 protection network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. While the network includes Special Areas of Conservation (SAC), Special Protection Areas (SPAs) and nature reserves, most of the land is privately owned and the emphasis is on ensuring that future management is sustainable, both ecologically and economically (from http://ec.europa.eu, maintained by the European Commission).

2.1.1 Surface Water Classification

Finnish surface waters are classified by the Finnish Environment Institute (SYKE) in terms of their ecological and chemical status, defined by threshold values for a set of variables. A summary of each class is given below. Full details are given in Appendix A.

- **Class I (Excellent):** The watercourse is in a natural state, usually oligotrophic, clear or with some humus. Water use is not restricted by any special occurrence of algae. Highly suitable for all modes of use;
- **Class II (Good):** The watercourse is in a near-natural state, slightly eutrophic or clearly humic. Locally restricted algal blooms can occur occasionally. Water is still suitable for most modes of use;
- **Class III (Satisfactory):** The watercourse is slightly affected by changing activity, or is appreciably eutrophic or humic due to natural causes. Algal blooms can occur repeatedly. Concentrations of harmful substances in water, sediment or biota can be slightly higher than in pristine conditions. The watercourse is usually satisfactory for most modes of use;
- **Class IV (Passable):** The watercourse is strongly affected by changing activity. Algal blooms are common and may restrict water use for a long period. Concentrations of harmful substances in water, sediment or biota can be clearly higher than in pristine conditions. Water is suitable only for modes of use having few water quality requirements; and
- **Class V (Poor):** Wastewaters, diffuse loading or other changing activity extensively pollute the watercourse. Algal blooms occur frequently and are often abundant, restricting water use for a long period. Oxygen concentrations are clearly affected by eutrophication. Concentrations of harmful substances in water, sediment or biota can be at levels that cause a clear risk to the use of water or biota. Poorly suited to any mode of use.

Proposed Finnish EQSs have been derived for some industrial and consumer chemicals and pesticides however these have not yet been fully ratified and are so not considered further in this report.

2.1.2 Groundwater Classification

Groundwater resources are classified by SYKE into three categories; I, II and III:

- **Class I:** An important groundwater area for water intake. Groundwater is or will be utilized within 20 – 30 years or should be reserved for emergency water supply. Water is used by at least 10 households or industry;
- **Class II:** A groundwater area that is suitable for water intake. Groundwater is not currently utilized but the potential exists for supply; and
- **Class III:** A groundwater area that may be utilized for water intake but where available data is insufficient to classify them further. Class III groundwater areas may subsequently be investigated by SYKE and either moved to category I or II or alternatively removed from the groundwater classification system.

At present there are no national EQSs for groundwater in Finland, however data can be compared against “suitable background values”. This study has compared groundwater data against drinking water standards and site specific WQOs developed for local rivers by Ramboll, discussed further in Section 3.2.

2.1.3 ESIA

Under Finnish legislation ESIAs are governed by the Act of Environmental Impact Assessment Procedure (468/1994), which applies to projects that may be expected to have considerable negative environmental impacts. The Act defines an environmental impact as being:

"direct or indirect effects inside and outside Finnish territory of a project or operations on;

- Human health, living conditions and amenities;
- Soil, water, air, climate, organisms and biological diversity;
- The community structure, buildings, landscape, townscape and cultural heritage;
- The utilisation of natural resources;
- And interactions between other factors given in 267/1999."

Finnish regulators will use the ESIA to determine whether the project will compromise targets specified in the WFD, and consequently whether an environmental permit may be awarded to the project.

2.2 Licensing and Permitting

2.2.1 Hannukainen Site

There are currently two pits located at the Hannukainen site; Laurinoja and Kuervaara. These pits were allowed to flood following cessation of mining in 1995 and it was estimated in the Provisional Economic Assessment (PEA) that they contain approximately 3.4 million m^3 of water (Hatch, 2010).

These pits will need to be dewatered before mining operations can commence. The discharge of pit lake water to the Äkäsjoki was permitted (Environmental Permit M12/07) in 2007 by the Finnish – Swedish Transboundary Water Commission (BRC). The permitted discharge rate to the Äkäsjoki is 300 L/s (0.3 m^3/s) in summertime, 100 L/s (0.1 m^3/s) in wintertime and 400 L/s (0.4 m^3/s) in flood season, which will enable the pits to be dewatered in less than a year (SRK, 2012a).

Due to poorer quality water in the Kuervaara pit, the permit stipulates that "the water amount discharged from the Laurinoja pit is at least 90% and in the Kuervaara pit a maximum of 10%".

The original BRC dewatering permit was valid until 31st December 2010 and this permit has been extended to 31st December 2015 (Pöyry, 2012a). The permissible discharge rates are summarised in Table 2-1.

Table 2-1: Summary of permitted dewatering discharge rates

Time of year	Permissible pumping rate (L/s)		
	Total (100%)	Laurinoja (90%)	Kuervaara (10%)
Summer	300	270	30
Winter	100	90	10
Flooding	400	360	40

2.2.2 Rautuvaara Site

No environmental permits are currently held for the Rautuvaara site (Golder, 2012).

The liabilities associated with use of a previously contaminated site have been investigated through an Environmental Site Assessment (ESA) conducted by Golder Associates in 2012. In the case that Northland commences operations at the Rautuvaara site, Northland will assume the liabilities for the historical tailings previously held by Rautaruukki Oy (Golder, 2012).

An active dialogue exists between Northland and Rautaruukki Oy (J. Kuntonen Vant Riet, pers. comm.). There is currently an informal understanding that in the case that Northland assumes liability of the Rautuvaara site, Rautaruukki Oy will place a sum of money into a closure fund equal to their liability as calculated at the time of exchange. This money will contribute towards the cost of closure at the end of operational mining.

It is beyond the scope of this report to discuss these issues further and the reader is referred to the ESA for more detail.

3 APPROACH

Mining operations will impact the local hydrological system. There is potential for both physical and chemical impacts affecting both the surface water and groundwater systems.

Any chemical impacts, caused by contamination from the mining process, are characterised by a source-pathway-receptor model. This model is used as a risk assessment tool to identify the source of any contamination (source e.g. WRD), what the source may affect (receptor, e.g. rivers, groundwater bodies) and how the source may reach the receptor (pathway, e.g. groundwater system). The three components must be present for the potential for contamination to exist. For example, a quantity of toxic material that is fully contained such that it cannot migrate out of its container cannot be described as a source of contamination because there is no pathway or receptor associated with the material.

Physical impacts caused by the mining process, e.g. drawdown of a water resource through dewatering, are also identified. In the case of physical impacts the 'source' (e.g. discharge from a sedimentation pond) may affect the 'receptor' (e.g. a river) directly.

Identification of potential impacts has been investigated in the HIA using the approach described below in Section 3.1.

3.1 HIA Approach

Impact assessment is an iterative process starting with receptor and impact identification during the scoping phase. As the HIA progresses, the emphasis moves to impact definition and evaluation, which consists of the systematic evaluation of each of the identified impacts.

The impact assessment completed in the HIA can be used in the ESIA to establish the significance of the impacts, and for the impacts to be ranked accordingly. As part of this process, management measures are defined to reduce the significance of negative impacts or enhance positive ones. After consideration of the management measures, the significance of the resulting (residual) impacts is re-evaluated in the ESIA using the same criteria.

Table 3-1 summarises the HIA approach employed at Hannukainen to assess impacts arising from mining. The methodologies adopted for impact assessment are discussed in more detail below in Section 8.1.

Table 3-1: Summary of the HIA approach

Work	Description	Reported in Detail
Scoping	• In association with the DFS team understand the proposed project • Identify possible source-pathway-receptors	Section 4
Characterise baseline	• Collect baseline data • Evaluate data using appropriate tools • Identify receptors and possible pathways • Develop a conceptual model	Section 5 and 6
Project description	• Identify and characterise possible sources	Section 6.4.4
Impact assessment	• Use appropriate tools, e.g. numerical models, to make quantitative impact predictions • Describe likely impacts	Section 8 and 9
Impact management	• Identify possible mitigation measures for negative impacts • Suggest management methods and assessment criteria to determine the success of future management • Suggest appropriate monitoring	Section 10

3.2 Water Quality Objectives

The report compares observed and modelled water quality data with site specific WQOs prepared by SRK and agreed with Ramboll (who retain overall responsibility for derivation of WQOs) and Northland.

In the Phase 1 report site specific WQOs were prepared by Ramboll for the Äkäsjoki, Valkeajoki, Kuerjoki, Niesajoki and Muonionjoki rivers (2012b). The Phase 1 WQOs have been recalculated for the purpose of this report so as to be consistent with the revised and updated baseline water quality data sets presented in this report. The updated WQOs were agreed with Ramboll and will be used by all consultants involved in the project. They supersede the WQO values used in the Phase 1 report.

There are no site-specific WQOs for groundwater. Since groundwater is a source of domestic drinking water at Hannukainen, groundwater water quality in this area is compared against Finnish drinking water standards (Finnish SRM 401/2001). At Rautuvaara groundwater is not utilised as a drinking water source and it was agreed that groundwater quality data would be compared to surface water WQOs developed for Niesajoki River.

3.2.1 Methodology

The site-specific WQOs were derived using the Australian and New Zealand Environment Conservation Council (ANZECC) methodology (ANZECC & ARMCANZ, 2000). The ANZECC approach utilises internationally agreed water quality guidelines[1] and water quality baseline data. For each parameter 'Trigger Values' (TVs) and 'Action Values' (AVs) are derived.

For parameters with internationally accepted guideline values the AV is typically set equal to the lowest or most appropriate of the international guidelines, apart from cases where baseline conditions are already above international guidelines. In this case the AV can be set as a statistic of the baseline water quality data (i.e., 99th percentile of observed data plus two standard deviations above the mean). For parameters with no international guidelines an AV can be defined based on a statistic of the baseline water quality data. International guidelines are typically set at a level above which there is a risk for adverse effects on aquatic life. Hence, if an AV is exceeded during the mine life or closure there is an expectation that the mine operator would undertake immediate remedial work to rectify the exceedances as there is a risk of acute impacts on aquatic life.

A TV is the 80th percentile of the baseline data. As the name would suggest a TV typically acts as a warning threshold level, which, once reached, indicates the need for the mine operators to consider additional work that could lead to remedial action, e.g., additional monitoring or toxicological work. To be an effective warning level it would be expected that the exceedance of a TV might indicate either a significant deviation from baseline conditions or a potential future risk of an exceedance of an AV, with associated risks to aquatic life. However, at Hannukainen baseline water quality is generally very good and for some larger rivers (e.g., Muonionjoki) the baseline data shows limited seasonal and inter-annual variation resulting in a low standard deviation within the data set.

Hence, in many cases at Hannukainen TVs can be significantly lower (orders of magnitude) than AVs and relatively close to median baseline conditions. In such cases a relatively small increase in concentrations might result in an exceedance of a TV, even though the increased concentrations were not significantly above baseline, or close to the relevant AV. Hence, there are question marks over the use of TVs for the Hannukainen site and care should be taken in the study to compare the TV to the baseline concentrations and the AV. The TV does remain useful in indicating parameters where calculations suggest that they could

1Guidelines considered in development of WQO's

1) CCME, Canadian council of Ministers of the Environment. Canadian Environmental Quality Guidelines. Water Quality Guidelines for the Protection of Aquatic Life. Freshwater.

2) EPA, United States Environmental Protection Agency. National Recommended Water Quality Criteria for the protection of aquatic life and human health in surface water. Freshwater.

3) EPD, Government of British Columbia, Canada. Environmental Protection Division. Water Quality Guidelines. Fresh Water Aquatic Life.

4) ANZECC, Australian and New Zealand Environmental Conservation Council. Water Quality Guidelines for Aquatic Ecosystems.

5) EU, DIRECTIVE 2006/44/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life.

6) EU, DIRECTIVE 2008/105/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council

exceed the normal range of baseline conditions and, in many cases, it should be viewed as indicating a change from baseline conditions rather than indicating a potential risk to aquatic life.

It should also be noted that in some circumstances (molybdenum for instance) the AV may be relatively high in comparison to the TV and may require toxicological re-evaluation of the AV value so that a more sensitive value can be assigned.

To be consistent with the ANZECC approach selected for this study, TVs are calculated for all parameters and exceedances of TVs are highlighted in the effects assessment section of the report. However, for the final project EIA, the use of TVs and the interpretation of an exceedance of a TV may need to be re-assessed. A more suitable limit may need to be defined to act as an intermediate threshold which lies above baseline conditions, but below AVs, e.g., a percentage (50%) of the AV might be considered as such an intermediate threshold.

AVs and TVs are derived for 29 parameters. However, within the full data set two groupings of parameters are identified:

1. 'Key' Parameters: Those which have AVs based on internationally agreed guideline limits. If a parameter has an existing internationally agreed guideline value it is assumed that this has been identified as a parameter which has the potential to cause adverse impacts on aquatic life; and

2. 'Other' Parameters: Those with no internationally agreed guideline limits and where AVs are based on analysis of baseline data. If a parameter does not have an existing guideline value it is assumed that this parameter has a lesser impact on aquatic life than those parameters with a guideline value.

Parameters are identified as 'Key' or 'Other' Parameters in Table 3-2 and Table 3-3 respectively.

As WQOs are defined by comparison with baseline data, they were calculated for specific water quality sampling points, namely:

- FS09 on the Äkäsjoki adjacent to the Hannukainen mine site;
- FS10 on the Äkäsjoki downstream of the confluence with the Valkeajoki;
- FS40 near the mouth of the Kuerjoki;
- FS08 near the mouth of the Valkeajoki;
- FS15 on the Niesajoki downstream of the existing TMF;
- FS12 at the mouth of the Niesajoki;
- FS03 at the mouth of the Kylmäoja Stream; and
- FS23 on the Muonionjoki just upstream of the confluence with the Niesajoki.

These sites were selected as locations where the impacts of development on surface water quality are to be assessed. Values for TVs and AVs at these sites are presented in the relevant sections in Section 6 where existing conditions at each of the rivers considered in this assessment are discussed.

It should be noted that, as TVs and AVs have been developed for different sites and using water quality data at each site, TVs and AVs vary across the study area. For many parameters AVs are the same across the study area as they are based on limits set by international guideline limits. However, some AVs and all TVs are set based on site-specific water quality data, so will vary between locations.

Values were based on analysis of all observed data at each site with the following assumptions and exclusions:

- Samples with concentrations that were below detection limits were included in the data set with a concentration set equal to half the detection limit;
- Historic sampling data (pre-Northland sampling program) with excessively high detection limits were excluded from the analysis as the detection limit strongly influenced the calculation of TVs and AVs; and
- Selected outliers were removed from the data where observed concentrations were orders of magnitude above the median of the remaining samples. In total only 4 outliers were removed as they strongly influenced the calculation of TVs and AVs. The ANZECC methods allow for the removal of outliers if they are thought to result in inappropriate (too high) TVs or AVs.

Table 3-2: 'Key' parameters for surface water quality assessment

Parameter	Unit
Suspended solids	mg/l
Ammonium	mg/l
Nitrite	mg/l
Nitrate	mg/l
Chloride	mg/l
Sulphate	mg/l
Iron	mg/l
Aluminium	mg/l
Arsenic	mg/l
Cadmium	mg/l
Cobalt	mg/l
Chromium	mg/l
Copper	mg/l
Mercury	mg/l
Manganese	mg/l
Molybdenum	mg/l
Nickel	mg/l
Lead	mg/l
Uranium	mg/l
Zinc	mg/l

Table 3-3: 'Other' Parameters for surface water quality assessment

Parameter	Unit
pH	-
Electrical Conductivity	mS/m
Calcium	mg/l
Potassium	mg/l
Magnesium	mg/l
Sodium	mg/l
Sulphur	mg/l
Silicon	mg/l
Barium	mg/l
Strontium	mg/l
Antimony	mg/l

3.2.2 Comparison with WQOs in Phase 1 study

WQOs should be developed in consultation with local regulators. Since the Muonionjoki is an international river, discussions will need to be held with both Swedish and Finnish regulators. Discussions with regulators regarding appropriate WQOs for the site had not been undertaken at the time of this report. As a result, there is potential that the WQOs may be subject to change following discussion between these parties.

There were some issues pertaining to the WQOs that were highlighted in the Phase 1 study (SRK, 2012a) and subsequently to Northland and Ramboll:

- There was a single set of WQOs for the Niesajoki River based on analysis of a combined data set of all water quality data for the monitoring stations along the river. Due to the influence of the existing Rautuvaara TMF in the headwaters of the Niesajoki, which produces a clear spatial trend in the observed data (Section 6.3.4), the use of a single set of WQOs for the whole river resulted in WQOs that were too low for baseline conditions in the upper reaches of the Niesajoki (i.e. baseline water quality exceeds objectives) and too high for baseline conditions in the lower reaches of the Niesajoki (i.e. baseline conditions are well below objectives); and
- The most recent baseline water quality data were not available, and therefore were not used in the development of WQOs for Phase 1. As a result, there were discrepancies between the WQOs and baseline data that needed to be resolved for Phase 2, to allow the most recent baseline data to be incorporated into the assessment.

Given the sensitivity of this study to WQO values, SRK has worked alongside Ramboll during Phase 2 to re-calculate the WQOs and ensure both studies use the same dataset. The refined TVs were approved by Ramboll (Ramboll, pers. comm.). The AV for iron was adjusted by Ramboll on SRK's recommendation as part of this process.

Following these refinements the main concerns regarding the WQOs have been addressed.

The WQOs are based on analysis of the full water quality data set and there are no seasonal variations in objectives defined for rivers in the study area. As a result, the surface water quality calculations presented in this study are based on median concentrations of the full

water quality data sets at each sampling location.

3.3 Key Assumptions and Limitations

As with many impact assessments, this HIA is reliant upon inputs from independent parties in order to complete a full assessment. Generally all of the necessary information has been calculated during the Phase 1 Hannukainen study. Some of this information has required updating to incorporate the modified Phase 2 project layout and mining methods.

Due to the tight project deadline it has not been possible to accommodate all the Phase 2 modifications into the HIA, particularly for Rautuvaara. Instead a number of assumptions have been made regarding the use of Phase 1 data as inputs to the current study. The Phase 1 inputs that have been included are as follows:

- Water treatment plant data from Pöyry (2013) is based on Phase 1 geochemical modelling data;
- For the calculation of the WRD source terms (Section 8.1.3), total tonnes of WRD material have been updated to reflect the Phase 2 tonnages, however the proportion of different rock types within each waste type are assumed to be the same as calculated during Phase 1;
- During the calculations of pit lake water quality (Section 8.1.3), the pit wall areas have been updated to reflect the Phase 2 pit shells however, it is assumed that the proportion of rock types is the same as calculated during Phase 1; and
- Phase 1 loadings, calculated for the LIMS and High-S tailings, have been used in the Phase 2 study to calculate tailings source terms (Section 8.1.3).

The key assumptions and limitations of the HIA are given below. Specific issues, for example related to modelling work, are highlighted within the report in the relevant sub-section.

Key assumptions:

- Mining schedule, including closure plan, is as described in Section 6.4.4;
- Mine infrastructure is as per the base case described in Section 7.1;
- Baseline and predicted post-development water quality values are compared to WQOs described in Section 3.2; and
- The mine water balance is as described by Pöyry, described in Section 7.2.

Key limitations:

- Baseline surface water flow, surface water level, groundwater quality and groundwater level data is limited and does not comprise a full, seasonal record. Long term monitoring is not within the SRK scope of work and SRK are reliant on Northland for the provision of long term monitoring data;
- Groundwater information was extremely sparse at Rautuvaara and so, as part of the HIA study, SRK recommended drilling locations for a monitoring network at the proposed TMF site. SRK also specified procedures for collecting hydrogeological information during drilling and provided installation designs. Supervision of the drilling programme was undertaken primarily by Northland staff, in close communication with

SRK. SRK undertook direct supervision of the early stages of the piezometer installation and reviewed the drilling programme, which was on-going. Despite repeated requests and explanation by both Northland and SRK staff, some test procedures, e.g. blow yield testing and penetration rate, were not always completed or recorded;

- Borehole construction details are only available for the Pöyry (suffix SP-) and SRK (suffix -HYDR-) boreholes at Hannukainen and SRK (suffix RAU12HYD-) boreholes at Rautuvaara;
- The site-based meteorological station has one year of record only so was not able to be used to determine long-term average meteorological conditions at the site;
- Current closure plans are not well developed at the Rautuvaara site and assumptions have had to be made related to water management at closure. It has been confirmed by Ramboll that the Phase 1 closure plan at the Hannukainen site for WRDs should be used for Phase 2;
- The Phase 2 TMF design and associated parameters, e.g. seepage, are calculated for life of mine (LOM) only; and
- The site is located in a fractured, hard rock environment and therefore groundwater flow is likely to be significantly structurally controlled. Fractures may act as both conduits and barriers to groundwater flow. Structural data is limited and it is not possible to map the location and hydrological significance of every structure. Currently unmapped structures may act as highly conductive pathways between a source and receptor but conversely, a fracture may contain a source or divert groundwater flow away from the receptor. As a consequence it is not possible to predict potential impacts with the accuracy that might be possible in an isotropic, porous-medium environment where granular flow is the dominant flow mechanism (e.g. uniform sandstone aquifer).

4 PROPOSED ACTIVITIES AND SCOPING ASSESSMENT

The proposed Hannukainen mine site is located in a north-south valley at approximately 200 m above sea-level (asl) with hills to the west (Kivivuopionvaara; 245 masl) and east (Kuervaara; 325 masl). The project comprises two pits – Hannukainen to the south and Kuervitikko to the north.

Associated infrastructure broadly comprises:

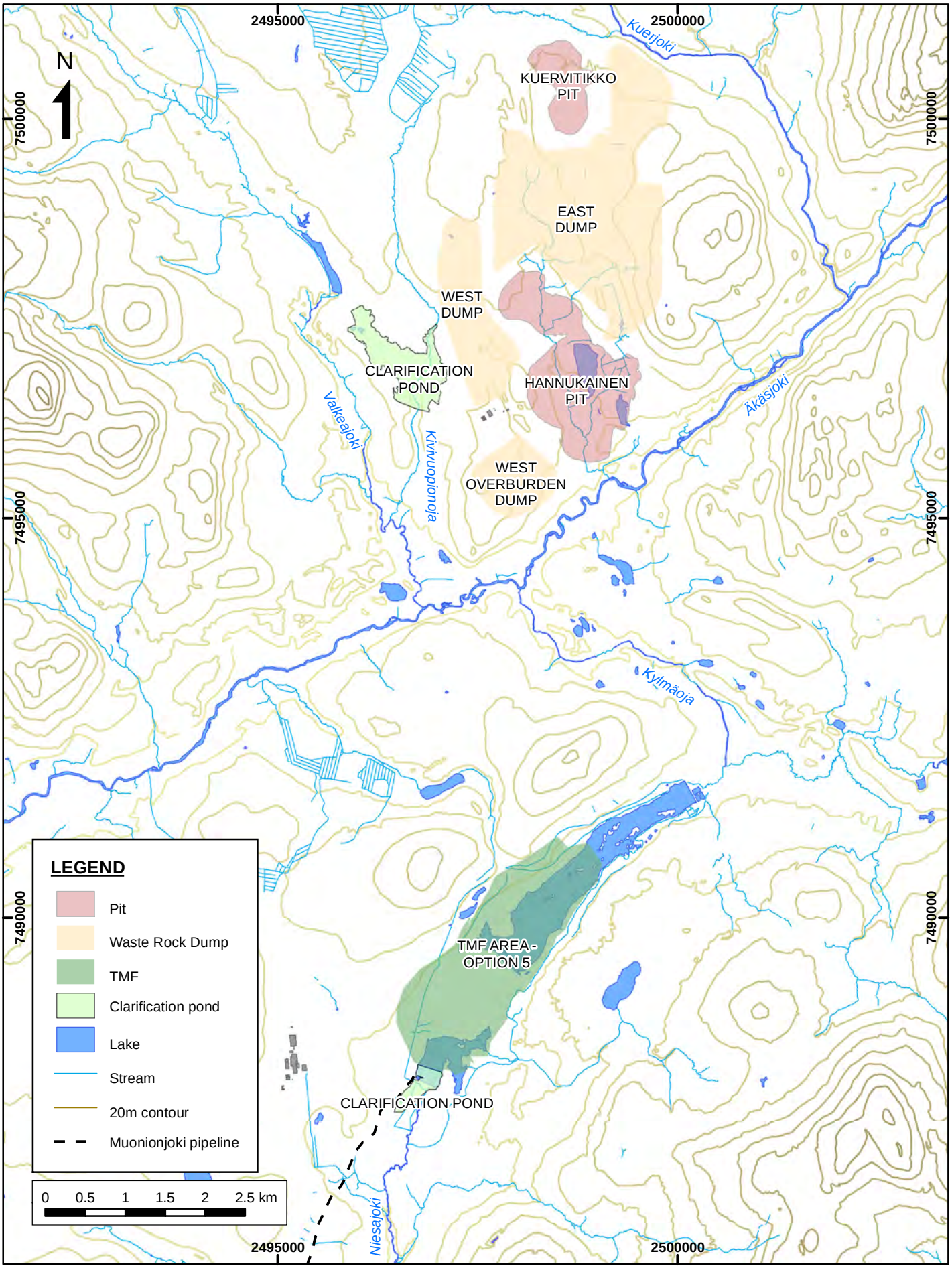
- Hannukainen site: Three WRD areas, clarification pond, crusher and water treatment plant;
- Niesa Basin: TMF, two clarification ponds (Northern and Southern), processing plant and water treatment plant; and
- New road, rail and pipeline network.

The proposed site layout is presented in Figure 4-1.

Within the vicinity of the proposed site there is limited human use of surface water or groundwater as a resource (Northland, 2011a). However, baseline studies (Northland, 2011a) and discussions with regulators have shown that rivers potentially impacted by the project (particularly Äkäsjoki and Muonionjoki) are critical breeding rivers for the Sea Trout (*Salmo truter*), an endangered species.

Baseline studies undertaken by Lapland Water Research Ltd Oy in summer 2007 identified trout in the Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki and Muonionjoki. However, it is noted in the fish baseline study (Ramboll, 2012a) that “No information is available about the Niesajoki River probably having a sea trout population. There are no electrofishing monitoring points of the Finnish Game and Fisheries Research Institute (RKTL) in the Niesajoki River.” In addition, the Saivojärvi wetland nature reserve lies close to the site.

In the absence of population centres or use of surface waters or groundwater as a resource, the main receptors are key fish species and the general health of the surface water aquatic ecosystem downstream of the site.



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srk consulting		Hannukainen Proposed Site Layout	Figure 4.1

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 4-1 Site_Layout_PH2.mxd

4.1 Surface Water

The construction, operation and closure of the mine infrastructure (including open pits, WRDs, TMF and mine water management plan) has the potential to affect surface water flows and water quality in a number of catchments close to the facility (i.e. Äkäsjoki, Kuerjoki, Valkeajoki, Kylmäoja and Niesajoki) as well as larger rivers lying downstream of the site (i.e. Muonionjoki).

Hence, there is a need to define the current conditions within the river systems and to identify impacts on flows and water quality that could impact key receptors downstream of the site.

While the north-west of Finland is generally unaffected by human activity, the Hannukainen area has been the site of historic mining and tailings deposition. These previous activities will impact baseline conditions within the study area.

The key surface water parameters to be considered in the assessment are outlined in Table 4-1.

Table 4-1: Outline of key parameters for surface water

Key Hydrological Parameter	Reason for Study
Flow paths and drainage areas	Flow paths define the hydrological network in any catchment and describe linkages between different streams and river systems. Changes to flow paths or drainage areas can impact downstream flow rates, access to upper reaches of the watercourse and downstream supply of nutrients.
Annual Flow Volumes	The annual flow volume is a measure of the total volume of water flowing through a site of interest. An assessment of the impact of development on the annual flow volume will indicate the large-scale effects on the project on the water available for aquatic and terrestrial life.
Monthly flows	Within the study area stream flows vary throughout the year. The monthly flow distribution reflects the annual cycle of temperature and precipitation within the study area and is in balance with the natural life cycle of many aquatic organisms.
Low Flows	A minimum flow is required to maintain the health of aquatic ecosystems. A decrease in low flow conditions can impact aquatic life and water quality.
High Flows	Peak (i.e. flood) flows have impacts on human and natural environments. Floods can result in damage and loss of life, but also provide a natural source of sediment and water to sustain wetland and floodplain areas along river valleys. They also help clear the rocky stream beds of excess sediment that accumulates in low flows periods. This rocky substrate is critical for fish spawning.
Water Quality	Local river have been identified as critical breeding rivers for the Sea Trout (*Salmo truter*), an endangered species. Changes in water quality could impact the capability of the rivers to support indigenous aquatic organisms, particularly the Sea Trout.

For the maintenance of aquatic life it is considered that the key flow parameters are those related to low flow conditions in fish bearing streams (i.e. Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki and Muonionjoki) as low flows are crucial for maintaining quality and quantity of habitat in winter and summer months, as well as protecting spawning grounds from exposure (Northland, 2011b).

Depending on the channel shape, relatively small changes in low flow conditions can impact habitat. In addition, the introduction of new infrastructure can result in attenuation of flow resulting in a more constant flow throughout the year so seasonal variability in flow is also an important consideration.

In contrast, although high flows are also important for a healthy river system, small changes at high flows may not produce as significant an impact to aquatic life. Thresholds at which significant impacts will occur will be defined through the ESIA process following consultation with aquatic biologists and other professionals.

Local rivers surrounding the mine site have been identified as critical breeding grounds for the Sea Trout (*Salmo truter*), an endangered species. Changes in water quality could impact the capability of the rivers to support indigenous aquatic organisms, particularly the Sea Trout, and therefore it is essential to assess the potential impact of the Project on the water quality of the local hydrology.

It should be reiterated that the objectives of this HIA are to assess the potential impacts of the proposed mining operation on surface water resources, and to inform the ESIA. The HIA considers the surface water system to be the key receptor rather than local ecology. The ESIA will assess the potential impact of changes to surface water flow and water quality on the local ecology.

An initial scoping assessment for mining activities with the potential to significantly impact surface water quantity or quality was undertaken with results presented in Table 4-2 and Table 4-3 respectively. Additional potential impacts were identified during the development of the Project description and baseline characterisation and were added to Table 4-2 and Table 4-3 such that these tables provide a comprehensive list of all potential impacts that have been identified by the study.

Where a potential impact is beyond the scope of the HIA, or where quantitative impact assessment is not required, the issue is scoped out at this stage and is not considered for quantitative analysis in this report. The other key issues are considered in detail in subsequent sections of this report.

Table 4-2: Initial Scoping of Effects Related to Surface Water Quantity and Flows

Mine Component	Potential Impact	Potential for Effect on Key Hydrological Parameter				Assessed in Detail or Scoped Out
		Annual runoff and flow pathways	Monthly flows	Low flows	Flood Flows	
Construction						
Construction of clarification pond and diversion structures at Hannukainen	Change in flows in Kivivuopionoja Stream and consequently the Valkeajoki River	√	√	√	√	Effects expected to be similar to changes during operations. As a result, changes during construction are not assessed separately and are considered in sections related to mine operations.
Construction of new dams and diversion structures within Niesa Basin	Changes in flows in Niesajoki and Kylmäoja streams	√	√	√	Changes too small to impact flood flows significantly	Effects expected to be similar to changes during operations. As a result, changes during construction are not assessed separately and are considered in sections related to mine operations.
Mine Operations						
Dewatering of open pits	Potential for decrease in baseflows to rivers adjacent to mine site due to reduced baseflow from groundwater (i.e. Äkäsjoki, Kuerjoki, Valkeajoki)		√	√		Section 9
Construction of mine components over streams within mine site area and water management plan	Excess runoff from disturbed areas of the mine site to be pumped to Niesajoki catchment potentially decreasing flows in rivers adjacent to mine site (i.e. Äkäsjoki, Kuerjoki, Valkeajoki).	√	√	√	Unlikely as area of catchments too small	Section 9
Construction of mine components over streams within mine site area and water management plan	Removal of natural streams within small catchments within mine footprint	√	√	√		Small catchments will be removed and streams completely altered due to mine development. No quantitative analysis required.

Mine Component	Potential Impact	Potential for Effect on Key Hydrological Parameter				Assessed in Detail or Scoped Out
		Annual runoff and flow pathways	Monthly flows	Low flows	Flood Flows	
Construction of mine components over streams within mine site area and water management plan	Potential for changes in flows in Äkäsjoki and Valkeajoki to impact water levels in Saivojärvi wetlands. Changes in Äkäsjoki and Valkeajoki flow due to reduced catchment size.	√	√	√		Section 9
Tailings deposition into Niesa Basin	Expansion of Rautuvaara TMF for tailings deposition will change local flow pathways around the basin and tailings will bury south pond and some areas of wetland to the south-west of the existing TMF.	√	√	√	Changes too small to impact flood flows significantly	Section 9
North and South Clarification Ponds	Clarification ponds will be constructed in the north and south of the Niesa Basin. There is the potential for seepage of water from these ponds to Kylmäoja Stream and Niesajoki River.	√	√	√	Seepage rates too low to impact flood flows	Section 9
Water Treatment Plant	The water treatment plant will treat water from the collection system at the High-Sulphide (High-S) cell of the TMF and discharge it to the Southern clarification pond. Water from this pond will be discharged to Muonionjoki River, impacting flows to Niesajoki and Muonionjoki	√	√	√	Discharge rates too low to affect flood flows	Section 9
All mining activities	Potential for change in flows in Muonionjoki River	√	√	√	Increase in flows too small to impact flood flows	Section 9

Mine Component	Potential Impact	Potential for Effect on Key Hydrological Parameter				Assessed in Detail or Scoped Out
		Annual runoff and flow pathways	Monthly flows	Low flows	Flood Flows	
Failure of water management dams on site	Potential for increased flows to Valkeajoki and Äkäsjoki Rivers		√	√	√	Not part of this assessment
Failure of Niesa dam	Potential for increased flows to Niesajoki River				√	Niesa Dam is an existing dam facility with an ongoing maintenance and inspection program. Assessment of failure of dam is not part of this assessment.
Closure						
Infilling of pit lakes	Continued impact on baseflow to rivers until pit lake has been filled		√	√		Section 9
Reclamation of WRDs, TMF and clarification pond	Potential changes in runoff from site compared to baseline conditions	√	√	√		Section 9
Rautuvaara TMF	Layout of the Rautuvaara TMF at end of operations is expected to be maintained into closure period, with effects on hydrology similar to those described for operations period	√	√	√	Seepage rates too low to impact flood flows	Section 9
Water Treatment Plant	Depending on the quality of water during closure the treatment plant may need to be operated through the end of operations. Flow rates at closure are likely to be lower than during operations.	√	√	√	Discharge rates too low to affect flood flows	Section 9

Table 4-3: Initial Scoping of Effects Related to Surface Water Quality

Mine Component	Potential Impact	Assessed in Detail or Scoped Out
Construction		
Pumping of water from Laurinoja and Kuervaara pit lakes to the clarification pond	Potential for increased erosion in the vicinity of the aeration cascade leading to increased sediment load and a decrease in water quality in the downstream catchments	The aeration cascade will be an artificial channel and can therefore be engineered to avoid significant erosion. Control measures may include lining vulnerable sections of the channel with matting and / or placing boulders in the channel bed. Since an engineered solution can be designed to mitigate any negative impact it is not considered further in this report.
Construction of new dams and diversion structures around the Rautuvaara TMF	Potential for releases of sediment or disturbance to existing tailings, with impacts on water quality in Niesajoki	Section 9
Mine Operations		
Seepage from waste dumps and other mine infrastructure	Potential for release of untreated mine seepage water to Äkäsjoki, Kuerjoki or Valkeajoki Rivers	Section 9
Tailings deposition into Niesa Basin	Potential for seepage of poor quality water from Niesa Basin through tailings into local groundwater system. This seepage water could enter Niesajoki or Kylmäoja Stream downstream of the Rautuvaara TMF.	Section 9
North and South Clarification Ponds and water management dams	Uncontrolled release of untreated water from ponds into Niesajoki or Kylmäoja Stream.	Section 9
Water Treatment Plant	Treatment plant effluent will be discharged into Muonionjoki River, resulting in potential for change in water quality in Muonionjoki River	Section 9
Failure of water management dams on site	Potential for discharge of untreated water to Valkeajoki, Äkäsjoki and Niesajoki Rivers	Not part of this assessment
Failure of Niesa dam	Potential for discharge of water and / or tailings from dis-used mines to Niesajoki River	Niesa Dam is an existing dam facility with an ongoing maintenance and inspection program. Assessment of failure of dam is not part of this assessment.
All mining activities	Potential for change in water quality in Muonionjoki River	Section 9

Mine Component	Potential Impact	Assessed in Detail or Scoped Out
Closure		
Infilling of pit lakes	Potential for release of poor quality water from pit lakes to groundwater or surface water	Section 9
Seepage, runoff or discharges from mine infrastructure at closure	Potential for release of poor quality water from mine site infrastructure to receiving environment	Section 9
Rautuvaara TMF	Seepage from the Rautuvaara TMF to groundwater system likely to continue into closure period. This seepage water could enter Niesajoki or Kylmäoja Stream downstream of the Rautuvaara TMF.	Section 9
Water Treatment Plant	Depending on the quality of water during closure the treatment plant may need to be operated through the end of operations, with on-going effects on water quality in Muonionjoki	Section 9

4.2 Groundwater

Although key fish species and the general health of the surface water aquatic ecosystem downstream of the site have been identified as the key receptors, it is still necessary to consider impacts to the groundwater system.

The groundwater at Hannukainen is generally unconfined, allowing interaction between the groundwater and surface water systems. A proportion of precipitation (rainfall, snow melt) migrates through the unsaturated zone into the groundwater system as groundwater recharge. Conversely groundwater supports the surface water system via springs and wetland areas and, more broadly, as baseflow to rivers.

Northwest Finland has a low population density and close to the site there are no towns or villages; however, local maps indicate a number of holiday cottages adjacent to the Äkäsjoki and Niesajoki Rivers:

- Pöyry (2010) notes there are 15 households and 45 holiday homes close to the Hannukainen development, with the nearest houses roughly 100 m from the historic mine facilities. Groundwater wells, which are connected to the local groundwater system, have been identified at three of these properties and provide a source of water for these households. Similar extraction of the groundwater may occur in the other houses; and
- Local maps identify one building adjacent to the Niesajoki River approximately 5 km downstream of the current TMF and an additional four buildings approximately 4 km further downstream. SRK identified a permanent residence within 250 m of the existing TMF during their site visit.

Mining activities have the potential to impact classified aquifers located within the proposed Project site (full details given in Section 6.4.3). However, the aquifers are subject to very limited human use and all of the private wells will be purchased by Northland prior to the start of mining (M.Smith (Northland), pers. comm.).

Groundwater is the principal pathway connecting potential sources (e.g. the WRD) with the most significant receptors in the area (i.e. the rivers). Therefore, while there is only limited use of the groundwater system as a resource, the groundwater quantity and quality are still important because of the interaction of groundwater with the surface water system.

The key parameters to be considered in the assessment of groundwater are outlined in Table 4-4.

Table 4-4: Outline of key parameters for groundwater

Key Hydrogeological Parameter	Reason for Study
Piezometric surface	The piezometric surface, or groundwater level, controls the interaction between groundwater and surface water, e.g. baseflow to rivers. It also determines the position of wetland areas and springs. Modification of the piezometric surface, e.g. drawdown due to pit dewatering, can impact local wetland eco-systems, groundwater abstractions and springs.
Hydraulic conductivity	Combined with groundwater level, the hydraulic conductivity of the groundwater-bearing formation determines the flow rate of the groundwater. Therefore, hydraulic conductivity is a key parameter when predicting contaminant transport.
Water Quality	There are a number of classified aquifers in the vicinity of the Project site. However, perhaps more importantly groundwater is a potential pathway between mine infrastructure (e.g. WRD, TMF) and the local river network. Therefore changes in water quality of the groundwater could impact the water quality of the rivers and therefore capability of the rivers to support aquatic life.

An initial scoping assessment for mining activities with the potential to significantly impact groundwater quantity or quality was undertaken with results presented in Table 4-5. Additional potential impacts were identified during the development of the Project description and baseline characterisation and were added to Table 4-5 such that the table provides a comprehensive list of all potential impacts that have been identified by the study.

Table 4-5: Initial Scoping of Effects Related to Groundwater

Mine Component	Potential Impact	Potential for Effect on Key Hydrological Parameter		Assessed in Detail or Scoped Out
		Piezometric surface	Water Quality	
Construction				
Dewatering of existing pits	Potential for drawdown around pits to affect wetlands, springs, well abstractions and baseflow to rivers	√		Section 9
Clearance of vegetation and superficial material to prepare High-S cell site for bottom structure	Potential for changes to infiltration rates, affecting the local groundwater regime	√		Effects expected to be similar to changes during operations. As a result, changes during construction are not assessed separately and are considered in sections related to mine operations
Mine Operations				
Pit dewatering	Potential for drawdown around pits to affect wetlands, springs, well abstractions and baseflow to rivers	√		Section 9 Note, private wells to be purchased by Northland and will not be operated therefore not classified as a receptor.
Excavation of pit through classified aquifers	Removal (partial or complete) of classified aquifers as pit is excavated	√		Section 9
Construction of WRD above, or up-gradient of, classified aquifers	Potential for derogation of classified aquifers due to WRD seepage reducing the water quality of the groundwater	√	√	Section 9
Seepage from WRD, TMF and other mine infrastructure	Potential for changes in water quality of the groundwater, affecting classified aquifers and river baseflow	√	√	Section 9
High-S cell bottom structure	Potential for changes in the local groundwater regime due to reduced groundwater recharge beneath the liner	√		Section 9
North and South Clarification Ponds	Potential for deterioration of classified aquifers due to seepage reducing the water quality of the groundwater	√	√	Section 9

Mine Component	Potential Impact	Potential for Effect on Key Hydrological Parameter		Assessed in Detail or Scoped Out
		Piezometric surface	Water Quality	
Deposition of High-S tailings in to the existing flooded pits at Rautuvaara	Potential for changes in water quality of the local groundwater		√	The pits will be unlined but since the tailings will be entirely submerged under water it is anticipated that the tailings will not oxidise significantly and that generation of leachate from the tailings will be restricted to a narrow reaction front. Prediction of water quality within the pit lakes themselves is not specifically calculated in the current study, however, prediction of water quality impacts to the wider Rautuvaara catchment is taken into account in the catchment water quality prediction model
Closure				
Flooding of pits	Pit lake levels dictate surrounding groundwater levels and change the natural groundwater surface	√		Section 9
Flooding of pits	Potentially contaminated pit lake water seeps into the groundwater system		√	Section 9
Rautuvaara TMF	Potential for changes in water quality of the groundwater due to seepage, affecting classified aquifers and river baseflow		√	Section 9

5 APPROACH TO CURRENT CONDITIONS ASSESSMENT

This section presents the approach taken to baseline data collection at the Rautuvaara site. It includes:

- Climate data;
- Surface water data (flow, water quality); and
- Groundwater data (water level, water quality).

The information has been collated in order to describe the current conditions observed at the Project site, which are described in Chapter 6. The report aims to describe the current conditions observed at the site but it does not constitute a full baseline characterisation which was not within SRK's scope of work and was included in the study conducted by LVT (2008).

Throughout the text the following terms are used to describe the study area:

- 'Hannukainen mine site' – Proposed open pits, WRDs, clarification pond and associated infrastructure located north of the Äkäsjoki River;
- 'Existing Rautuvaara TMF' or 'existing TMF' – Existing tailings pile that is a remnant of historic operations at Rautuvaara;
- 'Proposed Rautuvaara TMF' or 'proposed TMF' – New TMF as proposed by Northland;
- 'Niesajoki catchment' – Whole catchment of the Niesajoki River from the headwaters to the confluence with the Muonionjoki River; and
- 'Niesa Basin' – Region of the Niesajoki catchment immediately surrounding the existing and proposed Rautuvaara TMF.

5.1 Climate

5.1.1 Data Sources

There is no site specific climate data at Rautuvaara, however a weather station has been installed by Northland at the Hannukainen mine site, shown in Figure 5-1. It has been named informally as Kuervitikko weather station (A.Haaparanta (Northland) pers.comm.). Monitoring began at the station on 20 December 2011. Hourly measurements have been recorded since 22 December 2011. The Kuervitikko weather station has been in place for less than one year so it is not yet possible to derive seasonal trends from this station and it cannot provide a long term climate record.

Climate records (temperature, precipitation and snow fall) are available from the Swedish Meteorological and Hydrological Institute (SMHI) for the nearby Kaunisvaara weather station (18381) between 1961 and 2007. The monitoring station is located about 30 km south west of the Project site and is considered sufficiently representative of the climate in the area around Hannukainen and Rautuvaara, being located in a region of similar altitude and terrain.

Figure 5-2 shows the monthly average rainfall and temperature data collected at Kaunisvaara weather station, plotted alongside the available monthly data from Kuervitikko weather station from 2012. There is good correlation between the temperature records measured at each station, however there is significant disparity in the precipitation records, which will require further assessment by Northland staff as it may indicate a problem with the Kuervitikko gauge.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Regional Hydrological and Climate Monitoring Stations	Figure 5.1

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 5-1 Site_Layout and Weather Station_PH2_GT.mxd

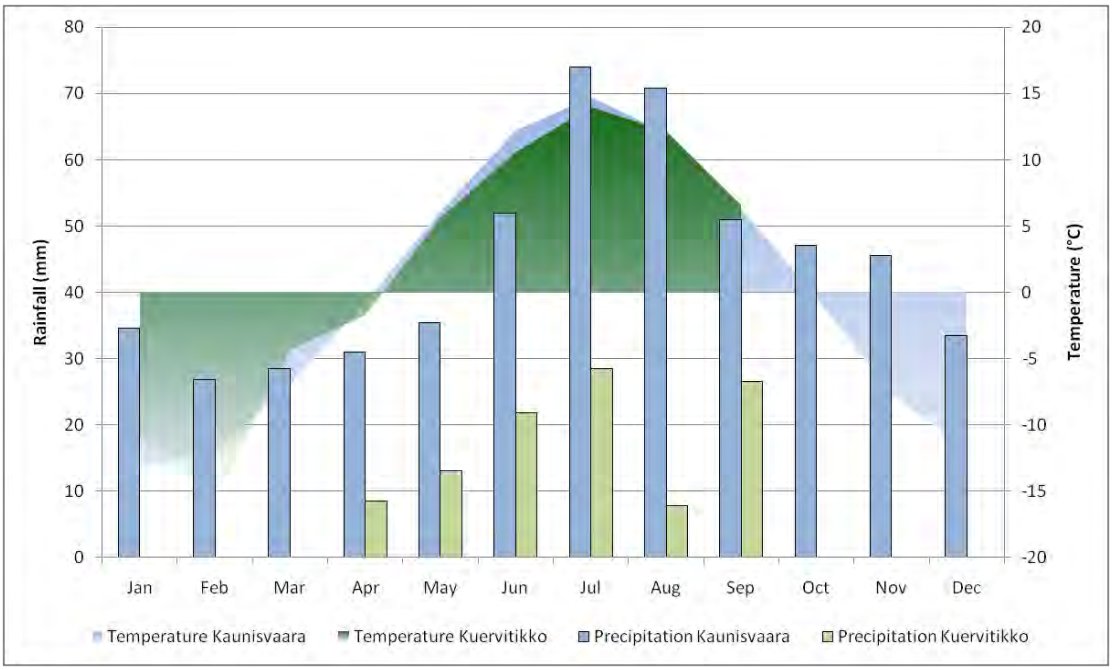


Figure 5-2: Correlation between monthly temperature and precipitation at the Kuervitikko (2012 by Northland) and Kaunisvaara ((1961 to 2007) by SMHI) weather stations

Data for the Kaunisvaara weather station for 2012 was not available at the time of writing of this report. Hence, at this stage it is not possible to determine whether the inconsistency in precipitation data is due to different precipitation regimes between the weather station locations or an atypical year in 2012.

In lieu of climate data, 2012 stream flow data was obtained from two stream flow gauging stations; one located 85 km south of Hannukainen on the Naamijoki; and the other 70 km north-east of Hannukainen on the Ounasjoki at Kongas. Comparison of the 2012 data with 1971 – 2011 monthly averages (Table 5-1) produced contradictory results. At the gauging station on the Ounasjoki stream flows in 2012 were significantly higher than average in most months of the year suggesting higher than average rainfall. However, on the Naamijoki stream flows in the summer months were either average or below average, suggesting average or dry climate conditions. Anecdotal evidence (Northlands staff) would suggest that stream flows in early summer 2012 were significantly above average; however, more detailed analysis of regional precipitation and stream flow data would be required to allow firm conclusions to be made.

Nevertheless, in lieu of a long term site specific record, the long term climate record at the Kaunisvaara weather station has been used to characterise the climate at Hannukainen. Data from the Kaunisvaara weather station was used as the basis for precipitation values in Pöyry (2012a) and this report aims to be consistent with the Pöyry approach as Pöyry have developed the mine site water balance.

Other data sources used to estimate other important climate data are:

- Average snow depth data measured at the SMHI monitoring station at Kolari, from data presented in Pöyry (2012a);
- Ice thickness data for Jerisjarvi near Muonio, 40 km to the north of Hannukainen, from data presented in Pöyry (2012a); and
- Evaporation data predicted by the Finnish Environment Institute SYKE model, for lakes in the Hannukainen area, from data presented in Pöyry (2012a).

Table 5-1: Comparison of 2012 flow data at regional flow monitoring stations

	Observed stream flow data for Naamijoki River (m^3/s)											
	January	February	March	April	May	June	July	August	September	October	November	December
2012 average	3.8	2.9	2.3	2.0	43.2	36.1	14.1	4.3	8.0	17.3	-	-
Return Period	**Monthly average flows for period 1971 – 2011 (m^3/s)**											
1 IN 100 DRY	2.6	2.0	1.9	1.3	38.6	13.0	6.4	4.2	4.2	6.8	4.3	3.3
1 IN 50 DRY	2.9	2.3	2.1	1.6	42.4	14.7	7.3	5.0	5.0	7.8	5.0	3.8
1 IN 10 DRY	3.9	3.0	2.9	2.9	55.1	20.5	10.5	8.0	8.0	11.3	7.6	5.3
AVERAGE	6.3	4.9	4.7	7.7	85.1	35.7	19.3	17.7	17.5	21.0	15.0	9.5
1 IN 10 WET	10.4	7.9	7.8	20.0	131.5	62.1	35.3	39.1	38.5	39.1	29.7	16.9
1 IN 20 WET	11.9	9.0	9.0	26.3	148.8	72.6	41.9	48.9	48.1	46.6	36.1	19.9
1 IN 50 WET	13.9	10.5	10.5	35.7	171.0	86.7	50.8	62.9	61.8	56.8	45.0	24.0
1 IN 100 WET	15.5	11.7	11.7	43.8	187.6	97.6	57.7	74.5	73.1	64.8	52.0	27.1

Shaded return periods indicate which return period 2012 data would lie within

	Observed stream flow data for Ounasjoki River (m^3/s)											
	January	February	March	April	May	June	July	August	September	October	November	December
2012 average	18.6	15.0	14.3	12.7	239.8	113.9	45.3	27.5	63.1	71.8	-	-
Return Period	**Monthly average flows for period 1971 – 2011 (m^3/s)**											
1 IN 100 DRY	4.9	4.2	4.3	2.8	36.3	16.3	8.5	6.0	7.5	8.6	4.3	4.5
1 IN 50 DRY	5.2	4.4	4.6	3.1	40.8	18.9	9.8	7.1	8.7	9.8	5.1	4.9
1 IN 10 DRY	6.1	5.2	5.3	4.4	57.0	29.0	14.2	11.4	13.1	14.0	7.9	6.6
AVERAGE	8.0	6.6	6.8	7.8	99.2	58.9	26.7	25.2	25.8	25.6	16.3	10.6
1 IN 10 WET	10.4	8.5	8.8	13.6	172.7	119.8	50.0	55.7	51.0	46.6	33.9	17.1
1 IN 20 WET	11.2	9.1	9.4	16.0	202.1	146.5	59.8	69.8	61.8	55.3	41.7	19.6
1 IN 50 WET	12.2	9.9	10.2	19.1	241.1	183.6	73.1	89.8	76.7	67.0	52.6	22.9
1 IN 100 WET	13.0	10.4	10.8	21.5	271.3	213.6	83.5	106.3	88.6	76.1	61.5	25.3

Shaded return periods indicate which return period 2012 data would lie within

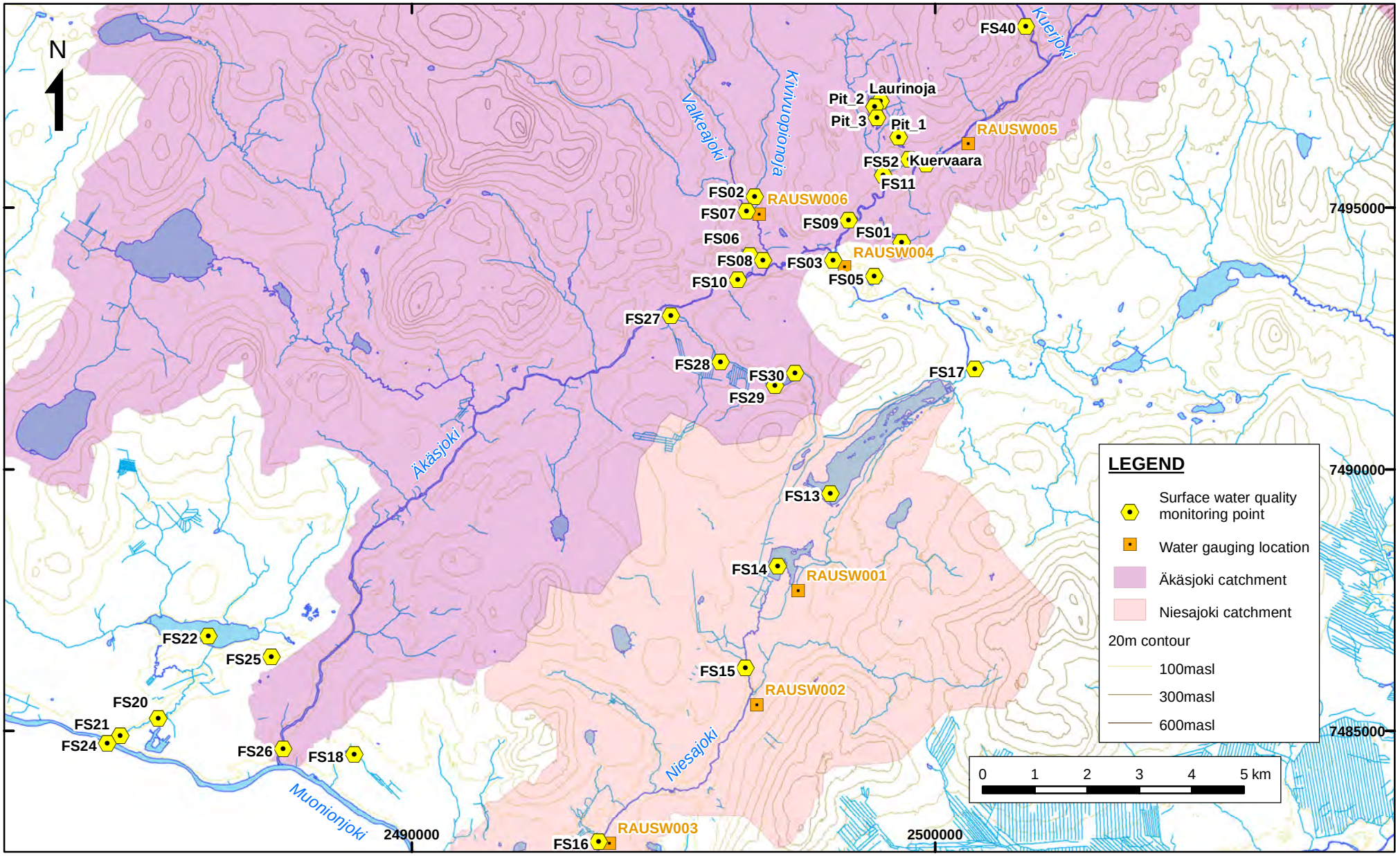
5.2 Surface Water

5.2.1 Data Sources

Hydrology and water quality data has been collected from several sources:

- Spot flow gauging: Conducted by SRK in May 2011;
- Flow records from hydrological monitoring stations installed in June 2012 by Northland: Continuous flow records are available for the period July to end-October, with rating curves for each site developed based on available spot flow measurements undertaken by Northland staff, included in Appendix B;
- Regional gauged flow data: Collected by the Finnish Environment Institute (Suomen Ympäristökeskus) and regional environment centres (ELY-keskus) since June 1960, available online from the OIVA database operated by Finland's environmental administration;
- Water quality data: Sampled by Northland since May 2007 (approximately monthly during the summer months); and
- Additional water quality data: National Finnish database since May 1975 for selected sites (approximately monthly during the summer months). Site wide conductivity survey undertaken by Northlands staff in October 2012.

Figure 5-3 shows the positions of these surface water monitoring locations.



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srk consulting		Surface Water Monitoring Stations	Figure 5.3

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The surface water quality of water bodies within the Hannukainen development area (including Rautuvaara) and receiving environment has been monitored since the first mining activities within the area in the 1970s.

A water quality sampling program in support of the Hannukainen project was undertaken by Lapin Vesitutkimus (LVT) in 2007 and 2008, spring sampling in 2009 was undertaken by WSP Environmental Ltd and subsequent sampling (summer 2009 to summer 2012) was undertaken by Northland. In each sampling period one sample was typically taken during winter months, two or three samples during spring snowmelt in May and June and one or two samples the late summer and autumn. A summary of the sampling program is provided in Table 5-2.

Table 5-2: Frequency of sampling 2007-2012

Period	No of samples	Sampling periods	Sampled by
08.05.2007 -16.07.2008	5	2 x May, August, September-October and March	Lapin Vesitutkimus
29.03.2009 -17.06.2009	3	April, May and June	WSP Environmental Ltd
18.06.2009 - 16.10.2009	2	July and October	Northland
2010	5	January, 2 x May, July and September	Northland
2011	5	February-March, 2 x May-June, July and September-October	Northland
2012	4*	February-March, 2 x May-June and July	Northland

** Note that an additional monitoring round was completed in September-October 2012 increasing the total number of samples to 5 in 2012. However the analysis was not completed in time for inclusion in this study and so it has not been included in this table.*

Table 5-3: Detection limits applied by Lapin Vesitutkimus and the accredited laboratory of Ambiotica of University of Jyväskylä and Luleå laboratory of ALS Scandinavia AB

Parameter	Unit	Detection limits	
		Lapin Vesitutkimus	University of Jyväskylä and ALS Scandinavia AB
Suspended solids	mg/L	-	1
Electrical Conductivity	mS/m	0.05	0.05
Ammonia	µg/L	3	3
Nitrite	µg/L	4	4
Nitrate	µg/L	-	1
Chloride	mg/L	0.1	0.1
Sulphate	mg/L	2	2
Calcium	µg/L	0.5	0.5
Total Iron	µg/L	10	10
Total Potassium	mg/L	0.1	0.1
Total Magnesium	mg/L	0.1	0.1
Total Sodium	mg/L	0.1	0.1
Total Sulphur	mg/L	-	-
Total Silicon	mg/L	-	-
Total Aluminium	µg/L	-	10
Total Arsenic	µg/L	1	0.05
Total Barium	µg/L	-	-
Total Cadmium	µg/L	1	0.002
Total Cobalt	µg/L	4	0.005
Total Chromium	µg/L	3	0.01
Total Copper	µg/L	3	0.1
Total Mercury	µg/L	0.1	0.001
Total Manganese	µg/L	3	3
Total Molybdenum	µg/L	-	0.05
Total Nickel	µg/L	3	0.05
Total Lead	µg/L	4	0.01
Total Strontium	µg/L	-	-
Total Zinc	µg/L	40	0.2
Total Antimony	µg/L	3	3
Total Uranium	µg/L	-	-

Data from 20 key sampling locations were considered in this baseline assessment. The locations are listed in Table 5-4. Locations in the immediate vicinity of the proposed mine site are shown in Figure 5-3, while more regional sampling locations are presented on Figure 5-4.

Table 5-4: Water quality sampling points considered in baseline assessment

Site No	Location (coordinates Y X)*	River	Period of Sampling Record	No of Samples	Location	Sampled by
FS02	7498477 3368656	Kivivuopionoja	2007-2012	19	Upstream the confluence with Valkeajoki	Northland Resources
FS03	7497191 3370098	Kylmäoja	2007-2012	24	Upstream the confluence with Äkäsjoki	Northland Resources
FS04	7498757 3371132	Laurinoja	2007-2012	19	Laurinoja	Northland Resources
FS06	7497361 3368509	Saivojärvi	1982-1984, 1988 & 2007-2012	94	Saivojärvi	Rautaruukki Oyj, Outokumpu Mining & Northland Resources
FS07	7498210 3368495	Valkeajoki	2007-2012	24	At confluence with Kivivuopionoja	Northland Resources
FS08	7497256 3368759	Valkeajoki	1992 & 2007-2012	44	Upstream the confluence with Äkäsjoki	Outokumpu Mining & Northland Resources
FS09	7497936 3370435	Äkäsjoki	1981-1984 & 2007-2011	49	Downstream the confluence with Kuerjoki	Rautaruukki Oyj, Outokumpu Mining & Northland Resources
FS10	7496907 3368263	Äkäsjoki	1983-1984 & 2007-2012	45	Downstream the confluence with Valkeajoki	Rautaruukki Oyj, Outokumpu Mining & Northland Resources
FS11	7498931 3371965	Äkäsjoki	2007-2012	23	Upstream the confluence with Kuerjoki	Northland Resources
FS12	7484130 3361390	Niesajoki	1999-2001, 2003-2011 & 2007-2012	22	Mouth of Niesajoki	Northland Resources
FS13	7492738 3369832	Niesa Basin	2007-2012	22	Niesa Basin; North Pond	Northland Resources
FS14	7491395 3368754	Niesajoki	2007-2012	22	Niesa Basin; South Pond	Northland Resources
FS15	7489480 3368050	Niesajoki	1999-2001, 2004-2011 & 2007-2012	21	Immediately downstream of Niesa Basin	Northland Resources
FS16	7486310 3365090	Niesajoki	1999-2001, 2004-2011 & 2007-2012	22	Mid-reach of Niesajoki	Northland Resources
FS17	7494976 3372701	Old Niesajoki	2007-2012	20	Upstream of Kylmäoja and Niesa Basin	Northland Resources
FS23	7484843 3361019	Muonionjoki	2007-2012	22	Upstream the confluence with Äkäsjoki	Northland Resources

Site No	Location (coordinates Y X)*	River	Period of Sampling Record	No of Samples	Location	Sampled by
FS24	7488640 3355795	Muonionjoki	1996,1999-2001 & 2007-2012	22	Upstream the confluence with Niesajoki	Outokumpu Mining & Northland Resources
FS26	7488368 3359146	Äkäsjoki	1978, 1981-2001 & 2007-2012	156	Mouth of Äkäsjoki	Rautaruukki Oyj, Outokumpu Mining & Northland Resources
FS30	7495068 336964	Rautuoja	2008-2011	13	Rautuoja Upstream of Rautujärvi	Northland Resources
FS40	Exact location not known	Kuerjoki	2010-2012	11	Upstream the confluence with Äkäsjoki	Northland Resources

** Finland Zone 3*

5.2.2 Methodology

Surface Water Flow

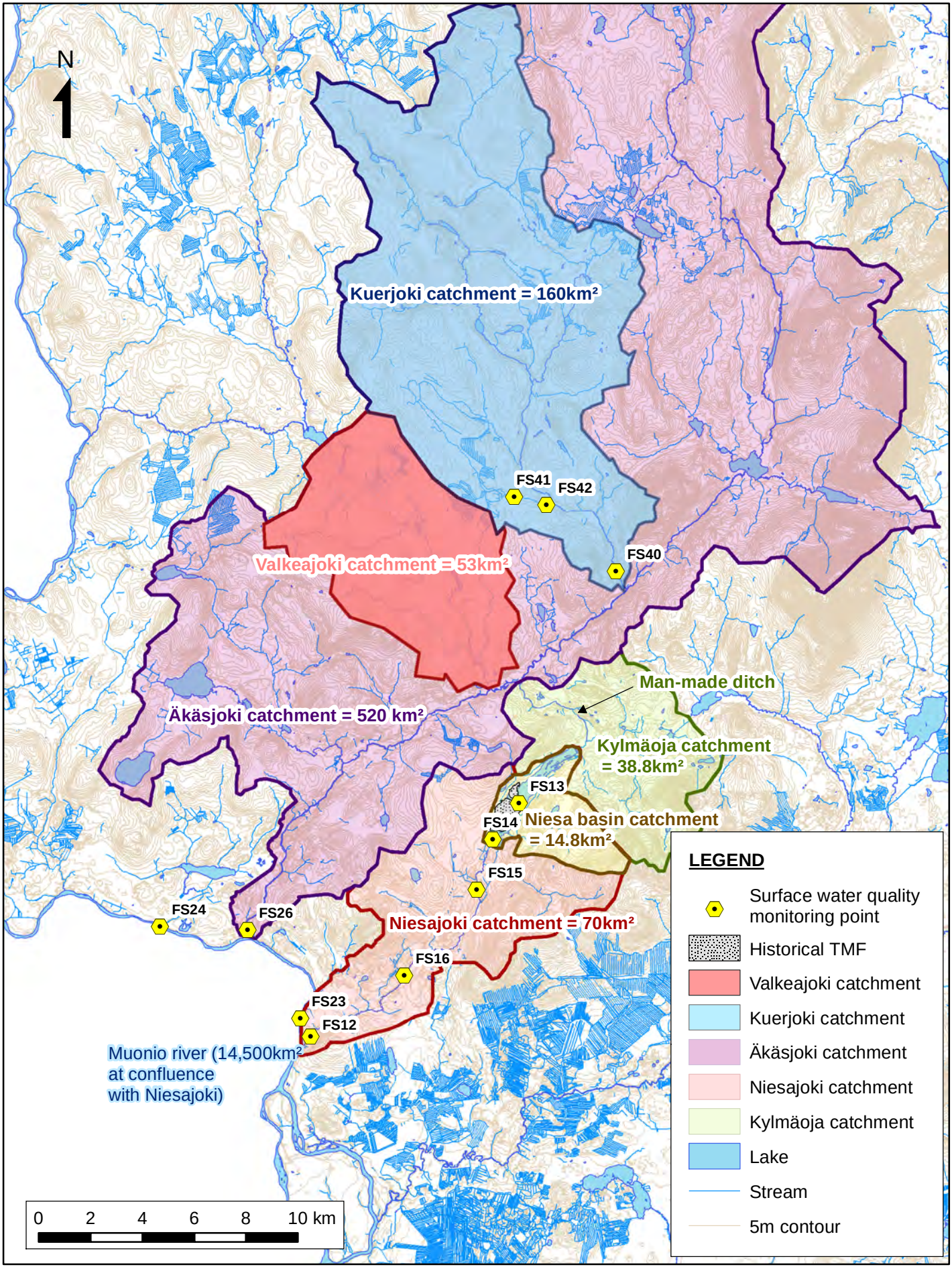
The impact assessment focuses on surface water flows and water quality in six key rivers potentially impacted by the mine development:

- Äkäsjoki River;
- Kuerjoki River;
- Valkeajoki River;
- Niesajoki River;
- Kylmäoja Stream; and
- Muonionjoki River.

The key catchments and watercourses considered in this assessment are shown in Figure 5-4 with catchment areas outlined in Table 5-5.

Table 5-5: Catchment areas for key catchments considered in the assessment

Catchment	Catchment Area (km^2)	Method used to derive key hydrological parameters
Äkäsjoki at confluence with Kylmäoja stream	520	Regional analysis as outlined in Appendix C
Äkäsjoki at its mouth	650	Regional analysis as outlined in Appendix C
Kuerjoki at its mouth	160	Regional analysis as outlined in Appendix C
Valkeajoki at its mouth	53	Regional analysis as outlined in Appendix C
Niesajoki at its mouth	70.	Regional analysis as outlined in Appendix C
Kylmäoja Stream at its mouth	40	Regional analysis as outlined in Appendix C
Muonionjoki at its confluence with Niesajoki	14,500	Analysis of gauged data at SMHI flow monitoring station at Kallio



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srk consulting		Key Catchments and Water Courses	Figure 5.4

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As outlined in Section 5.2.1, six stream flow monitoring stations were installed on watercourses located within the Hannukainen and Rautuvaara study areas in late June 2012. Hence, although these stations will provide a long period of records in years to come, at present there is only a short period of record at these gauged sites. Although short-term records can provide some information on stream flow conditions, they may not provide an accurate reflection of average or typical flow conditions in the watercourse. For this longer-term flow records are required.

Within the study area there are long-term flow records for the Muonionjoki River only, with the Muonionjoki gauged records at Kallio some 20 km downstream of its confluence with Äkäsjoki River and close to the confluence with the Niesajoki River. There are over 100 years of flow records at this site. Other smaller watercourses (Niesajoki, Äkäsjoki, Kuerjoki, Valkeajoki and Kylmäoja Stream) do not have long term flow records.

In the absence of long-term stream flow measurements within the smaller watercourses in the study area, average flow conditions for the watercourses are based on a regional hydrological analysis using available gauged flow data collected by the Finnish Environment Institute (Suomen Ympäristökeskus), regional environment centres (ELY-keskus) and the Swedish Meteorological and Hydrological Institute (SMHI). Details of the regional analysis are provided in Appendix C. In brief, key hydrological parameters for watercourses in the study area (Table 4-1) are derived based on extrapolation of gauged data from relevant nearby sites to the study catchments. This is a standard method of estimation of hydrological parameters for ungauged watercourses.

As there is a good flow record for the Muonionjoki River, hydrological estimates for this river are based on analysis of the flow data from the Kallio gauge.

The key hydrological parameters considered in this assessment were:

- Annual runoff and flow volume totals: Annual runoff is a measure of the hydrological response of a catchment. If is presented as runoff depth in millimetres (mm) over an entire watershed, allowing direct comparison with precipitation totals. Runoff is calculated by dividing the total flow volume (m^3) observed at a monitoring station with the area of land (m^2) draining to the site;
- Monthly runoff totals and monthly averaged flows: Monthly average flows provide an indication of the seasonal variation in flows at a site. The impact assessment will focus on comparing pre- and post-development monthly averaged flows in watercourses downstream of the Project site. Monthly flows are a useful basis for an impacts assessment, as they allow an assessment of the impact of the development at different times of the year and under different flow conditions (e.g., higher flows in snow melt and lower flows in summer months); and

- Low flow conditions, such as annual and July to September 7-day minimum flow: Predictions of low flow conditions are vital for managing water resources and assessing impacts on aquatic life, as it is often the low flow periods that are critical for maintaining life in any stream. Different indices exist that are used to characterise low flows, with the most common measure being the 7-day low flow. The 7-day low flow is the minimum average seven day flow that occurs over a specified period, such as a year or a season. The 7-day Q_{10} flow is often used in water use planning and it is defined as the seven day average minimum flow that is expected to occur with a probability of 10% in any one year.

Although regional flow estimates are taken as the basis of the key hydrological parameters for the watercourses in the study area, the regional data are compared to the flow data obtained from the on-site hydrological monitoring stations within the current conditions assessment in Section 6.3.

Water balance calculations for the existing TMF at Rautuvaara are presented in Section 6.3.4. These calculations predict flows from the catchment surrounding the TMF, as well as precipitation on, and evaporation from, the North and South Ponds. In addition, flow estimates are also made at key locations along the Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki, Kylmäoja rivers. These flow estimates are based on a series of equations based on annual runoff totals, monthly flow distributions (percentage of flow occurring in every month of the year) and catchment areas. Annual runoff totals and monthly flow distributions are calculated for each catchment in Appendix C. Catchment areas are measured using available topographical maps of the area.

Monthly flow rates are calculated using the following equation:

$$\textit{Average Monthly Inflow } (m^3/mon) = \textit{Total Annual Runoff } (m) \times \textit{Watershed Area } (m^2) \times \textit{Percentage of Annual Flow Occurring in Month } (/mon)$$

For the North and South Ponds annual net inflows due to precipitation on, and evaporation from, the surface of the ponds are based on:

$$\textit{Annual Net Input to Lake Surface } (mm) = \textit{Total Annual Precipitation } (mm) - \textit{Total Annual Evaporation } (mm)$$

Monthly contributions are modelled as:

$$\textit{Average Monthly Inflow/Outflow } (m^3/mon) = ((\textit{Total Annual Precipitation } (m) \times \textit{Percentage of Effective Precipitation Occurring in Month } (/mon)) - (\textit{Total Annual Evaporation } (m) \times \textit{Percentage Evaporation Occurring in Month } (/mon)) \times \textit{Lake Area } (m^2)$$

The source for annual precipitation, annual evaporation and monthly distributions of these data are discussed in Section 5.1, with values provided in Section 6.1.

Surface Water Quality

A detailed baseline water quality assessment was reported in '*Surface Water Baseline Study of Sahavaara, Tapuli, Hannukainen, Rautuvaara and Äkäsjokisuu Project Area, 2011'* (Northland, 2011a). This report does not attempt to repeat or replace this work. However, this assessment does go further than Northland (2011a) in that it includes water quality data collected in 2012.

All samples were taken in accordance with the Finnish environmental administration's water sampling guidelines (Mäkelä et al 1992) and all samplers employed in the program were certified by the Finnish Environment Institute and / or Swedish Naturvardsverket. Water samples in rivers were taken manually from the depth of 0.1 m – 0.2 m from the streambed. Samples taken by LVT were analysed at their own accredited laboratory. Samples taken by WSP Environmental Ltd and Northland were analysed in the accredited laboratory of Ambiotica at Jyvaskyla University's Institute of Environmental Research and the Lulea laboratory of ALS Scandinavia AB. Detection limits applied by the laboratories are listed in Table 5-3. All samples from metals were analysed for total metals only, i.e., there was no data for dissolved metals (i.e. from filtered samples).

The water quality assessment presented in this report provides a summary of water quality data relevant to the key watercourses considered in this assessment (Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki, Kylmäoja and Muonionjoki) and calculates suitable average or median[2] concentrations to be used in the effects assessment. The analysis also compares baseline data (maximum and median concentrations) to site-specific WQOs developed by Ramboll (2012b) (discussed in Section 3.2), to identify key parameters of concern that will be included in the effects assessment.

Generally, it would be expected that there would be seasonal variability in response to flow conditions, with higher total metals concentrations during high flows as a result of increased suspended sediment loads and surface water runoff. In contrast salts (e.g. sulphate), which are generally observed to be present in higher concentrations in groundwater than surface water, would tend to have higher concentrations in streams during low flow periods when groundwater is a dominant source of flow in the streams.

Analysis of seasonal variability in the available data confirmed the presence of some general patterns of the type outlined above, but the differences were not consistent and were not borne out in quantitative analyses of the data. This may be due to the frequency of sampling; while there is bi-monthly or monthly sampling during the summer months sampling during

[2] Generally the median concentration was used in the analysis rather than the mean. The water quality data set at Hannukainen and Rautuvaara is not large, samples span a range of hydrological conditions and often parameters have one or two outliers (high and low). In this case outliers can distort the mean value, making the median value a more appropriate representation of the data. Hence, this study generally presents medians and maxima in the tables to try and capture the range of values seen at a site. The median could bias samples with a high number of below detections; however, for such samples the average is often controlled by the choice of how to deal with below detection limit samples (i.e., whether to take half or full detection limit). The potential bias will depend on the number of values below detection limits versus total sample size as to whether the mean deviates substantially from the median. Consequently, the choice of median or mean values was considered on a parameter basis in order to select the most appropriate statistical method. In all cases the median value was deemed to be more representative of the data than the mean.

winter and spring conditions is limited to one sample per year and consequently there are insufficient water quality samples to undertake a robust statistical analysis of seasonal variability in surface water quality.

In addition to the rivers, the historic pit lake water quality data has been assessed at Hannukainen and Rautuvaara:

- Depth sampling in both pit lakes at Hannukainen has been undertaken approximately annually between 2005 and 2008 and subsequently in 2011. Water quality is compared against WQOs for Äkäsjoki River. It should be noted that WQOs are for comparison purposes only and are not developed for specifically pit lakes, therefore pit lake water quality is compare to AVs only; and
- At Rautuvaara, depth sampling from the smaller (Eastern) pit lake was undertaken on the 16/01/2012 and from the larger (Western) pit on the 06/03/2012. Water quality is compared with the Niesajoki River WQOs for monitoring location FS15.

Due to no seasonal water quality data being available, it has not been possible to make an assessment of temporal variation in pit lake water quality or limnological characteristics.

5.3 Groundwater

Groundwater monitoring has been undertaken since 2007 at Hannukainen but prior to this study there had been relatively little investigation into the groundwater conditions at Rautuvaara. Therefore a key aim of the Phase 2 study was to establish a groundwater monitoring network at Rautuvaara in order to characterise the baseline groundwater conditions and develop a conceptual hydrogeological model of the site.

The overburden and weathered bedrock are referred to the shallow and deep aquifers respectively throughout the ensuing text.

5.3.1 Data Sources

Hannukainen

Hydraulic properties of the overburden and bedrock at Hannukainen were investigated primarily in May 2011 during fieldworks for the DFS study (SRK, 2011); these investigations provide the primary source of hydraulic data used in this report.

Groundwater monitoring has been undertaken since 2007, as summarised in Table 5-6, at locations shown in Figure 5-5. Further details of the groundwater water quality sampling programme are provided in

Table 5-7.

Table 5-6: Groundwater monitoring at Hannukainen mine site

Date	Description of monitoring / works	Collected by
November 2007	Single round of water level and water quality monitoring. Installation of shallow standpipes drilled in the overburden as part of a site investigation for the initial soil and groundwater baseline study.	Pöyry (Pöyry, 2008a)
May 2011	Single round of water level monitoring and hydraulic testing. Installation of multi-level wells in overburden and bedrock during field work for Open Pit Water Management Study and manual dipping of available boreholes across the site.	SRK (SRK, 2012c)
June 2011 onwards	Four rounds of water quality sampling (June 2011, April / June / August 2012). Water level monitoring at boreholes across the site since October 2011. Approximately 6 rounds of monitoring, irregular frequency, generally in spring and autumn months.	Northland
September 2011	Single round of water level and water quality monitoring, and hydraulic testing. Installed temporary piezometers in the river bed of the Äkäsjoki and took water quality samples from boreholes around the site but data not available for this study.	University of Helsinki (Salonen et al., 2012)

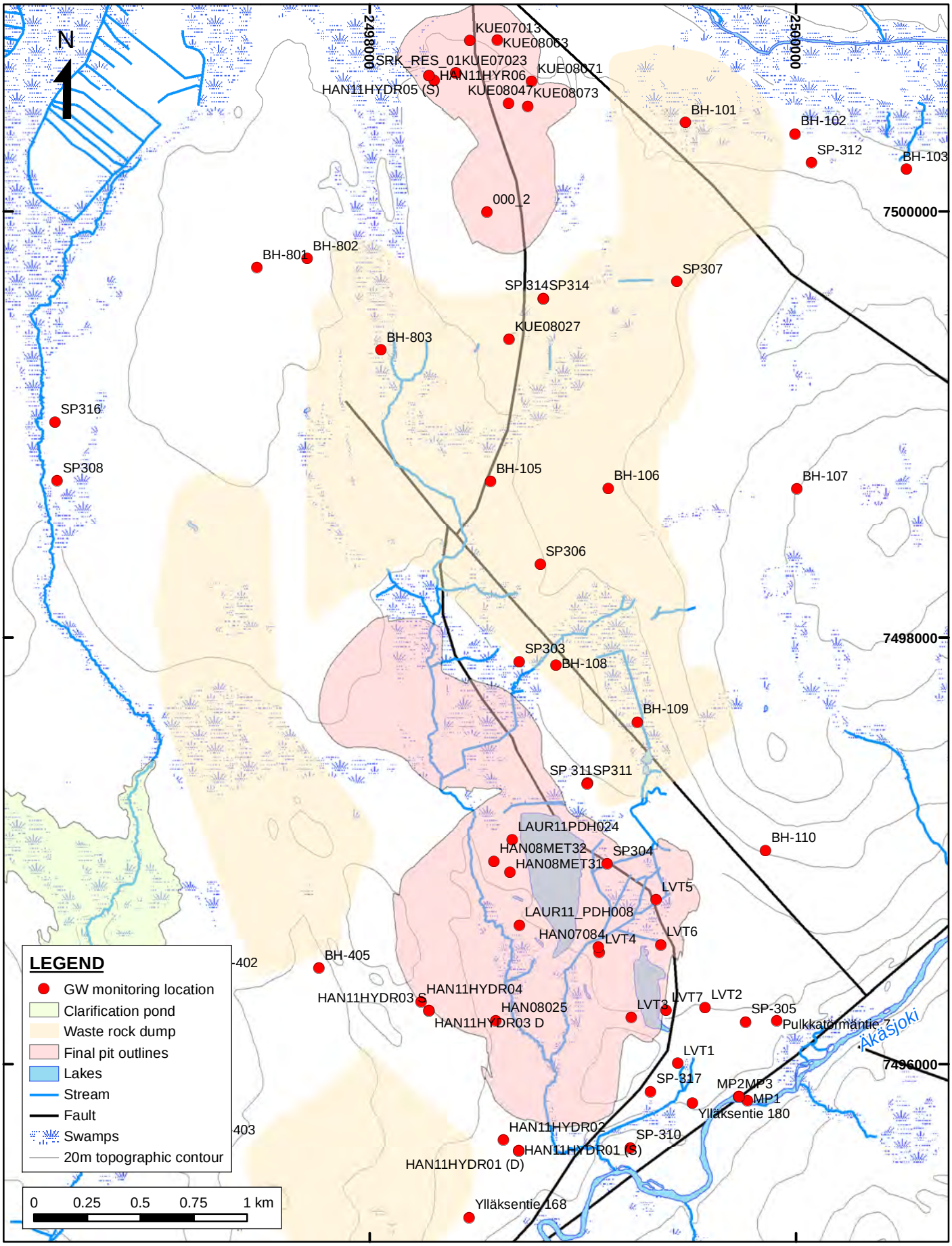
Table 5-7: Groundwater water quality sampling and analysis at Hannukainen

Sample Location	Number of Samples	2007	2008	2011	2012		
		December	June	June	April	June	August
BH 101	5			1	1	2	1
BH 103	4			1		2	1
BH 109	4			1	1	1	1
BH 803	5			1	1	2	1
HAN OW 02D	4			1		2	1
HAN OW 02S	4				1	2	1
HAN OW 08D	5			1	1	2	1
HAN OW 08S	2					2	
KUE_OW_01D	5			1	1	2	1
KUE_OW_01S	4				1	2	1
KUE11GT04	5			1	1	2	1
LVT 6	4				1	2	1
LVT2-OW2s	1				1		
LVT3 30.6	1			1			
SP 303	1		1				
SP 304	1		1				
SP 305	6		1	1	1	2	1
SP 306	6		1	1	1	2	1
SP 307	1		1				
SP 308	1		1				
SP 310	6		1	1	1	2	1
SP 311	2		1	1			
SP 312	6		1	1	1	2	1

Sample Location	Number of Samples	2007	2008	2011	2012		
		December	June	June	April	June	August
SP 314	6		1	1	1	2	1
SP 316	1		1				
SP 317	1		1				
Pulkka-törmäntie 7	1	1					
Ylläksen-tie 168	1	1					
Ylläksen-tie 180	1	1					

Key:

X	= number of analyses undertaken
	= full analytical suite conducted
	= full analytical suite conducted but potential error in results as major cations are all reported as below detection limit and reflected in poor ion balance
	= relatively high cations reported resulting in poor ion balance
	= chloride and sulphate not reported
	= chloride, sulphate and bicarbonate not reported
	= uranium not reported
	= major ions only reported
	= major ions only reported, excluding sodium
	= potential error in sulphate results reflected by poor ion balance
	= full suite excluded silicon, strontium and uranium



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srk consulting		Groundwater Monitoring Locations at Hannukainen	Figure 5.5

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Rautuvaara

Baseline monitoring of groundwater levels and groundwater quality at Rautuvaara has been very limited and was initially restricted to three GTK holes located in the vicinity of the current tailings deposit. As a result SRK were requested by Northland to recommend suitable locations for groundwater monitoring wells at Rautuvaara. The purpose of these additional piezometers was twofold:

1. To enable collection of baseline data and characterisation of the site; and
2. To establish a monitoring network that could be utilised during operational mining for ongoing groundwater monitoring.

The groundwater monitoring programme at Rautuvaara is primarily for environmental purposes with contaminant transport a particular focus of the programme. It was anticipated that bedrock would be more weathered in the upper portion than at depth and that the weathered portion of the bedrock would be more permeable than the more competent rock below, i.e. groundwater can flow more easily through the weathered bedrock than the competent bedrock. Therefore the weathered bedrock is likely to transport potential contamination from the TMF to nearby receptors.

The groundwater monitoring wells at Rautuvaara were designed to target the overburden, existing tailings pile and the upper 20 m of the bedrock, which were identified as the most likely pathways for contamination transport. SRK oversaw the installation of 24 multi-level piezometers located around the proposed TMF. The borehole installations are summarised in Table 5-8. A full description of the rationale behind the design of the monitoring network is provided in SRK (2012b).

Table 5-8: Summary of piezometer and pumping well target intervals

Station ID	X	Y	Z (masl)	Drilled length (m)	Gravel pack (S)			Gravel pack (D)		
					From (m)	To (m)	Geology	From (m)	To (m)	Geology
RAU12HYD01	2496723.45	7489436.22	206.65	53	25.0	31.0	Overburden	48.0	54.0	Bedrock
RAU12HYD02	2497594.3	7490110.37	197.6	48	21.0	27.0	Overburden	42.0	48.0	Bedrock
RAU12HYD03	2497702.18	7489449.97	196.52	36	7.0	13.0	Tailings	30.0	36.0	Monzonite / monzodiorite/ granite
RAU12HYD03 (Mid)	2497702.18	7489449.97	196.52	21	14.5	17.5	Overburden: Peat and gravel	-	-	-
RAU12HYD04	2500246.55	7491790.59	189.73	26	2.3	4.5	Overburden	20.0	26.0	Bedrock
RAU12HYD05	2497757.67	7490570.32	215.87	28	3.0	7.0	Overburden	22.0	28.0	Diorite
RAU12HYD06	2497147.17	7488641.9	190.76	34	5.5	11.5	Tailings	26.0	32.0	Diorite
RAU12HYD07	2497278.4	7488956.49	192.17	37	6.5	12.5	Overburden: Clay rich till	28.0	34.0	Pegmatite
RAU12HYD08	2496221.29	7488412.12	197.97	36	9.0	15.0	Overburden Broken rock	30.0	36.0	Bedrock
RAU12HYD09	2497006.78	7487815.61	193.99	43	16.0	22.0	Overburden: Gravel and sand	37.0	43.0	Bedrock
RAU12HYD10	2497891.37	7487612.12	201.8	37	10.0	16.0	Overburden: Sand and gravel	31.0	37.0	Intermediate volcanic
RAU12HYD11	2497580.42	7487075.61	196.41	52	25.0	31.0	Overburden: Sand	46.0	52.0	Skarn
RAU12HYD12	2496607.03	7485775.64	176.52	46	19.0	25.0	Overburden	40.0	46.0	Amphibole
RAU12HYD13	2496908.34	7487703.67	194.36	47	20.0	26.0	Overburden	41.0	47.0	Amphibole
RAU12HYD14	2500604.31	7492299.72	190.35	26	2.5	5.5	Overburden: Sand and gravel	10.5	26.0	Granodiorite / diorite
RAU12HYD15	2500698.65	7491694.19	192.99	32	5.0	11.0	Overburden	26.0	32.0	Volcanic
RAU12HYD16	2499159.67	7491477.67	205.09	32	5.0	11.0	Overburden	26.0	32.0	Diorite / monzodiorite
RAU12HYD17	2498832.9	7491057.76	196.06	35	8.0	14.0	Overburden	29.0	35.0	Diorite
RAU12HYD18	2498009.13	7489134.52	194.28	23	1.8	4.0	Overburden: Monzodioritic fragments and clay	17.0	23.0	Amphibole
RAU12HYD19	2498535.48	7488601.15	213.95	51	34.0	40.0	Overburden: Sand	45.0	51.0	Overburden/ bedrock contact, granitic
RAU12HYD20	2498843	7489433.58	223.45	66	36.0	44.0	Overburden: Sand	52.0	66.0	Diorite
RAU12HYD21	2498465.7	7489613.27	194.69	40	12.0	18.0	Overburden: Sand	25.0	40.0	Diorite
RAU12HYD22	2495560.73	7488316.43	204.79	44	17.0	23.0	Overburden	38.0	44.0	Diorite
RAU12HYD23	2499409.68	7490429.7	215.43	63	36.0	42.0	Overburden	57.0	63.0	Diorite
RAU12HYD24	2495594.87	7486760.62	199.13	25	2.0	4.5	Overburden	19.0	25.0	Diorite / monzodiorite

Four pressure transducers have been installed in the RAU12HYD- series boreholes by EHP in order to generate a better understanding of seasonal groundwater trends, the response of the groundwater system to climatic events, groundwater recharge and the interaction between the surface water and groundwater systems.

Loggers were installed in RAU12HYD12(S)[3], RAU12HYD12(D)3, RAU12HYD18(D)[4] and RAU12HYD20(D)[5] in June 2012 (Figure 5-7). The rationale behind these locations is provided in SRK (2012b).

The frequency of monitoring is insufficient at the deep wells for any comparison between manual and automated monitoring, however a comparison has been made at RAU12HYD12(S), shown in Figure 5-6.

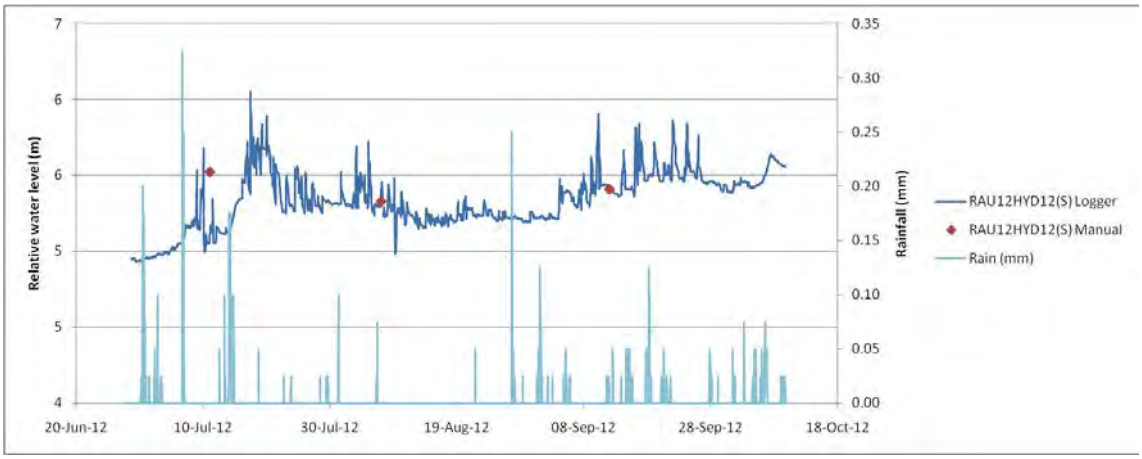


Figure 5-6: Comparison of Manual and Logger Water Level Records at RAU12HYD12(S)

The water level record in September 2012 was used to correlate the manual and logger data because this was the most stable period of the logger record. It can be seen that there is a reasonable correlation between the monitoring records in August but some inconsistency in the July readings. It is also clear to see that the logger record provides substantially more information about variations in groundwater level and the response of the groundwater system to rainfall events than the manual readings.

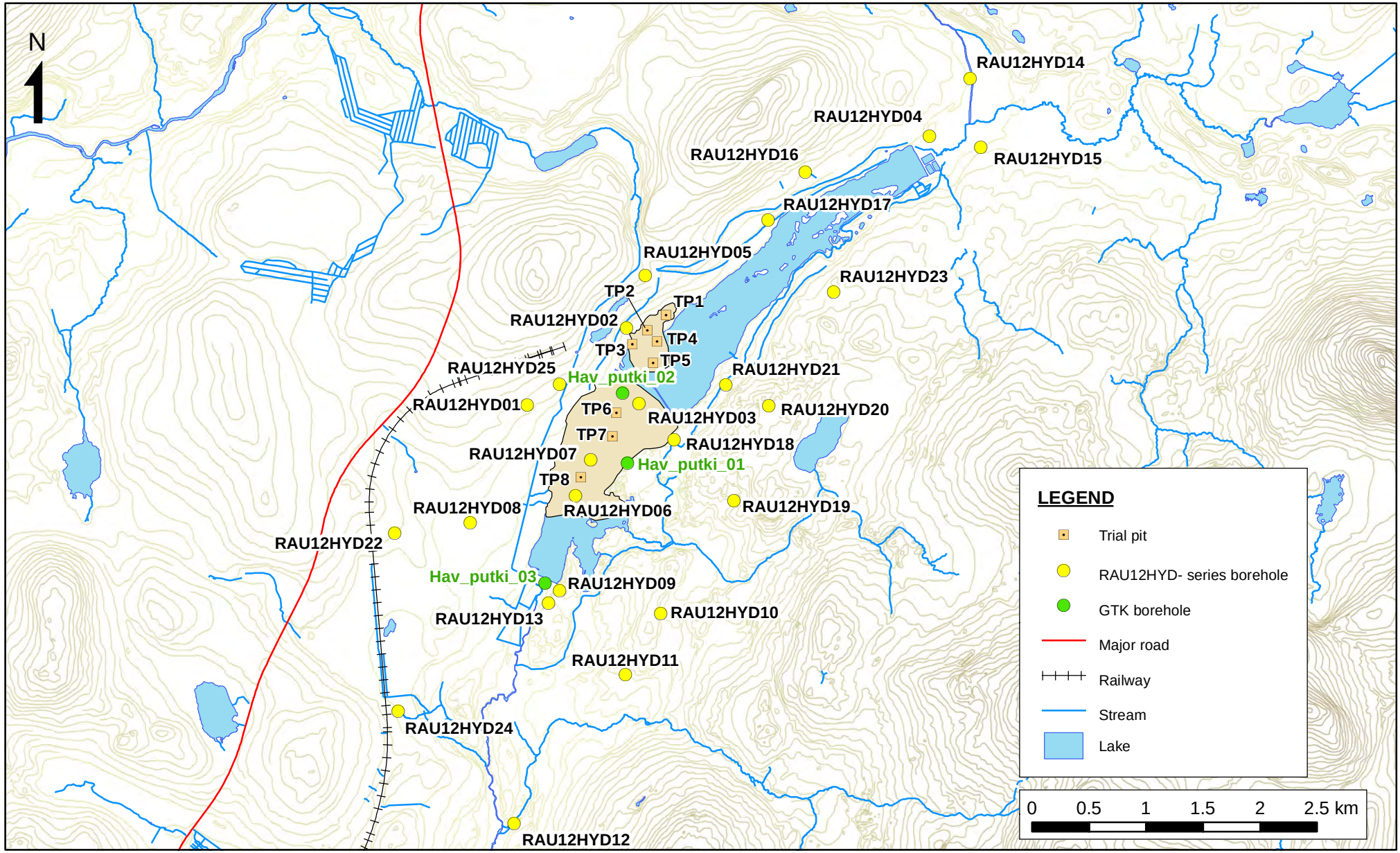
In September 2012 an additional borehole, RAU12HYD25, was drilled at Rautuvaara. It was recommended that this borehole should penetrate the bedrock to approximately 100 m, believed to be beyond the weathered horizon. However, the borehole was only drilled to a depth of 35.4 mbgs and therefore cannot be used to characterise the nature of the bedrock at depth or substantiate the assumption of a weathered bedrock horizon.

3 RAU12HYD12 is located in marshy ground less than 20 m from a tributary of the Niesajoki River and approximately 100 m east of surface water monitoring station SW002, located on the Niesajoki River
4 RAU12HYD18 is located in slightly raised ground, surrounded by marshy ground to the east of the existing tailings and has less than 3 m of overburden material
5 RAU12HYD20 is located in marshy ground on the top of a hill to the east of the tailings facility where the overburden thickness is approximately 46 m

Groundwater monitoring at Rautuvaara is summarised below in Table 5-9 and the monitoring locations are shown in Figure 5-7.

Table 5-9: Groundwater Monitoring Locations at Rautuvaara

Suffix	Description	Monitoring Record
Hav_putki-	• 3 wells • Installed by GTK, installation in 2005 – 2006 • Depth (measured on site) 9 – 14 mbgs • Construction details unknown	Water Level: • Recorded in March 2012, then monthly since June 2012 Water Quality: • Samples collected in March, May and July / August 2012
RAU12HYD-	• 25 wells • Majority drilled and installed in April / May 2012, one additional well drilled in September 2012 • Depth 21 – 66 m, all drilled 20 m into the bedrock located beneath the tailings • Construction details provided in Appendix D	Water Level: • Recorded monthly since June 2012 in shallow piezometers • Recorded in June and September 2012 in deep piezometers • Data loggers installed in 3 deep piezometers and 1 shallow piezometer in June 2012, recording data every hour Water Quality: • One sampling round in July / August 2012
SW-	• 2 TMF surface seepages locations	Water quality sample collected during field visit in July 2012
SWS-	• 2 WRD surface seepage locations	Water quality sample collected during field visit in July 2012
TP-	• 7 Trial pits o 3 pits in the TMF (TP6, TP7, TP8) o 4 pits in the WRD (TP2, TP3, TP4, TP5)	Water quality sample collected during field visit in July 2012



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srk consulting		Groundwater Monitoring Locations at Rautuvaara	Figure 5.7

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 5-6 Borehole_locations_PH2.mxd

5.3.2 Methodology

Aquifer Properties

The aquifer properties at Hannukainen were investigated during the DFS study and are described in detail in SRK (2011). Test work included impellor flow logging, pumping tests and falling head tests. The reader is referred to the glossary for a brief summary of the techniques and SRK (2011) for more details.

Aquifer properties of the shallow overburden and underlying weathered bedrock at Rautuvaara were investigated by means of blow testing and penetration rate during drilling and subsequently through groundwater level monitoring, slug tests and falling head tests in the piezometer installations. The reader is referred to the glossary for a brief summary of the techniques and the interim Phase 4 report (SRK, 2012a) for further detail. It should be noted that:

- Blow testing was only undertaken for approximately one minute at each depth. This is not sufficient to stress the surrounding rock and achieve a sustainable yield. The test duration was only sufficient to evacuate water from the hole and this is evident in the results, which show an increase in blow test yield with increasing depth. Therefore the blow yield tests undertaken during the drilling programme cannot be used to estimate the hydraulic properties of the rock and have not been considered further in this investigation; and
- A total of 40 slug tests were performed in shallow and deep piezometers in RAU12HYD01 to RAU12HYD24. It was important to filter the data to remove poor quality test results. Nine of the forty slug tests conducted at Rautuvaara were deemed unreliable. Details of the methods used to analyse the quality of the slug tests are provided in Appendix E.

Hydraulic conductivity was estimated from the slug tests and falling head tests using AQTSOLV, an industry standard software for analysis of hydraulic tests[6].

Groundwater Quality

Baseline analysis focuses on water samples taken by Northland that were collected following manual purging of the boreholes. Purging ensures that the groundwater samples represent the quality of the local groundwater, rather than the condition of stagnant water in the borehole. Details of purging methods are given in SRK (2011).

Laboratory analyses of the water samples are included in full in Appendix F. The locations of the sampling points are shown on Figure 5-7.

Available groundwater quality data and site surface seepage data was analysed in order to determine the concentrations of key parameters observed during the sampling period. Water quality data was compared to the following standards:

[6] All data was analysed using the Cooper et al. (1967) straight line method, followed by either the Bower-Rice (1976), KGS (1994), Hvorslev (1951), Springer-Gelhar (1991) or Butler-Zhan (2004) methods as appropriate. Full details are provided in Appendix E.

- At Hannukainen water quality data has been compared to drinking water quality standards, as set out in government regulation STM 401/2001. These standards were chosen due to the presence of a Class II groundwater aquifer at the site and the close proximity of the site to private wells; and
- At Rautuvaara the data was compared against the Niesajoki River WQOs for sampling site FS09, described in Section 3.2.

There is historical contamination at Rautuvaara due to the existing tailings facility. Therefore, in order to distinguish between impacted and non-impacted groundwater quality, the results from Rautuvaara were separated into groundwater data (deep and shallow) and surface seepage. The results were further sub-divided according to whether the sampling location was within or outside the zone of influence for the existing TMF.

Shallow boreholes within the current TMF zone of influence reflect samples taken from tailings whereas shallow boreholes outside the current TMF zone of influence reflect samples taken from the overburden; the deep boreholes represent samples taken from the bedrock (Table 5-9). The borehole and trial pit localities are shown on Figure 5-7.

Since only one round of groundwater sampling has been undertaken at the Rautuvaara site it has not been possible to make a statistical assessment of water quality variation.

6 CURRENT CONDITIONS ASSESSMENT

This section presents the baseline data collected at the Rautuvaara site. It includes:

- Climate data (meteorological data);
- Geological information (geology, structures, aquifer hydraulic properties);
- Surface water data (flow, water quality); and
- Groundwater data (water level, water quality).

This information has been collated together to develop a conceptual hydrogeological model of the site, which is described in Section 6.4.4.

6.1 Climate

Figure 5-2 illustrates the annual variation in precipitation and temperature as recorded at Kaunisvaara between 1961 and 2007. Temperature data at the weather station indicates cold, wet winters (November to April) with average temperatures of between -5°C to -15°C, contrasting with summer months (June to August) with temperatures of 10°C to 15°C.

Data from the Kaunisvaara weather station was used as the basis for project precipitation values by Pöyry (2012a) who have developed a water balance for the mine site infrastructure at Hannukainen and Rautuvaara. To be consistent with Pöyry (2012a) the same precipitation values are used in this assessment. Average and return period precipitation values are shown in Table 6-1. The data indicates average annual precipitation of 528 mm, with the minimum recorded annual precipitation of 369 mm (1968) and a maximum recorded value of 695 mm (1992).

Average snow depth data measured on the last day of each month at Kolari is shown in Table 6-2, based on data presented in Pöyry (2012a). The data indicates average snow depths peaking in February and March at around 0.7 m – 0.8 m. Data from the Kaunisvaara weather station indicates an average of 183 days per year snow cover, with around 250 mm average snowfall per year and maximum snow depth between 0.6 m – 1.2 m (with maximum depth typically occurring in March).

Ice thickness data was obtained by Pöyry (2012a) for Jerisjarvi near the town of Muonio, 40 km to the north of Hannukainen. Monthly ice thickness is shown in Table 6-2, illustrating ice thickness peaking in March and April at around 0.7 m. Ice thickness is dependent on a number of factors such as elevation of the site and depth of water and as a result the values in Table 6-2 may not be exactly reflect conditions within the Hannukainen site. However, the data provides an indication of likely ice thicknesses and the trend and timing of ice growth would be expected to be similar at Hannukainen and Jerisjarvi due to their proximity to one another.

As a result of the cold temperatures, surface water features (bogs, lakes and rivers) are all frozen over throughout the winter and remain frozen for about four to six months annually, between November and April.

Evaporation data relevant to the study area was obtained from the Finnish Environment Institute SYKE model and reported in Pöyry (2012a). This data set was obtained for the current study, with monthly and annual average evaporation totals outlined in Table 6-2. The results indicate the key months for open water evaporation are May to September, with the highest evaporation rates in July (79.2 mm).

Monthly distributions of precipitation, effective precipitation, evaporation and runoff used in water balance estimates are summarised in Table 6-3. 'Effective precipitation' is used to calculate the timing of inputs from precipitation to water bodies, taking into account that precipitation during winter months within the study area will fall as snow and will not contribute to the lake water balance until it melts in spring. Hence, in defining Effective Precipitation it is assumed that all precipitation falling in the winter months is assumed to be snow, and that this snow melts during May and June. Hence, in Table 6-3 the winter monthly percentages for effective precipitation equal zero (i.e., precipitation is stored as snow) and the total precipitation during this period is then distributed in May to represent the water held in the snow pack being released as snowmelt.

6.1.1 Groundwater Recharge

No site specific data are available for groundwater recharge. Therefore, SRK has developed a simple monthly water balance for the area around Äkäsjoki catchment in order to estimate groundwater recharge. Since the terrain and ground cover at Rautuvaara are similar to those at Hannukainen the values have been applied across the Project site.

The model predicted a groundwater recharge value of 74 mm/yr. The value represents the rainfall that infiltrates past the capillary zone (i.e. effective precipitation minus runoff).

Full details are given in Appendix G and SRK (2011a).

Table 6-1: Average monthly precipitation totals from Kaunisvaara weather station used for the present study

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average precipitation (mm)	34.5	26.7	28.5	31	33.9	52	74	70.8	50.9	47.1	45.5	33.5	528.4
20 year dry (mm)	20.7	16	17.1	18.6	20.3	31.2	44.4	42.5	30.6	28.3	27.3	20.1	317.1
20 year wet (mm)	48.4	37.4	40	43.4	47.4	72.8	103.6	99.1	71.3	66	63.7	46.9	740
50 year dry (mm)	17.3	13.4	14.3	15.5	16.9	26	37	35.4	35.5	23.6	22.8	16.8	274.5
50 year wet (mm)	51.8	40.1	42.8	46.5	50.8	78	111	106.2	76.4	70.7	68.3	50.3	792.9

Table 6-2: Average monthly ice thickness, snow depth and evaporation totals used for present study

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
[a]Ice Thickness (mm)	520	600	680	690	0	0	0	0	0	0	230	400	3120
[b]Snow depth (mm)	625	760	749	287	0	0	0	0	0	68	246	424	3159
[c]Evaporation (mm)	0	0	0	0.9	31.4	67.8	79.2	65.5	29.9	10.9	1.0	0	286.6

[a] Obtained by Pöyry from Finnish Environmental Institutes HERITA database from Jerisjarvi near Muonio, 40 km to the north of Hannukainen. Data is from 1990 - 1990.
[b] For last day in each month, for Kolari. Data in Pöyry (2012)
[c] Data provided to Pöyry by Finnish Environmental Institute

Table 6-3: Monthly distributions used in water balance calculations

	Percentage of annual total in each month												
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Precipitation	6.5	5.1	5.4	5.9	6.4	9.8	14.0	13.4	9.6	8.9	8.6	6.3	100
[a]Effective Precipitation	0.0	0.0	0.0	0.0	44.2	9.8	14.0	13.4	9.6	8.9	0.0	0.0	100
Evaporation	0.0	0.0	0.0	0.3	11.0	23.7	27.6	22.9	10.4	3.8	0.4	0.0	100
Catchment Runoff	2.7	2.0	2.0	4.1	32.6	15.0	7.7	7.3	7.5	8.7	6.5	3.9	100

[a] See text for definition

6.2 Geology

The local bedrock geology at Hannukainen comprises mainly intrusive igneous rocks, metasediments and metavolcanics and has been subject to a large amount of structural deformation. The bedrock geology is overlain by Quaternary overburden. The key geological units and structural deformation are described in more detail in the sections below.

6.2.1 Bedrock

Hannukainen

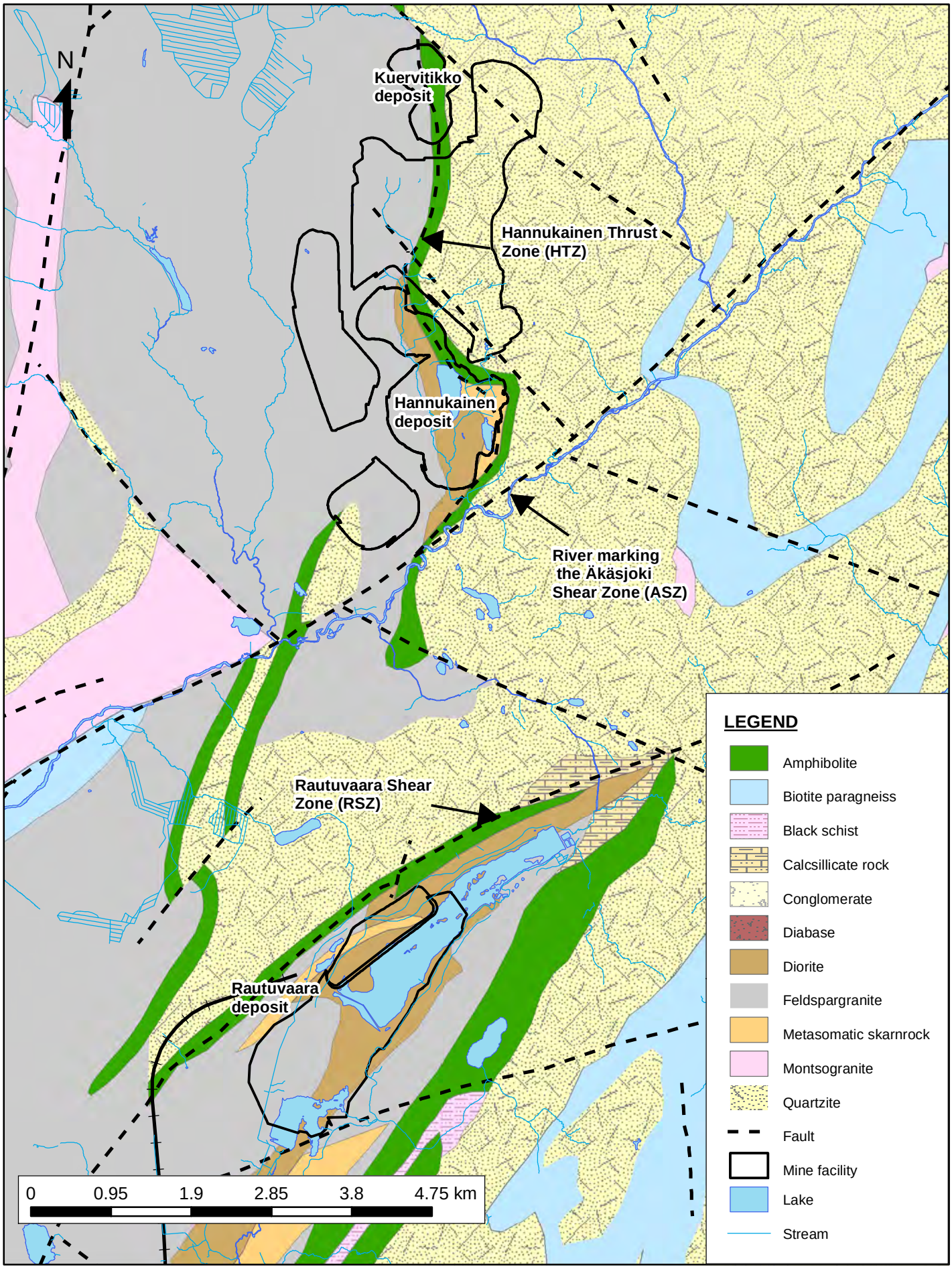
At Hannukainen the eastern section of the licence area (footwall) is underlain by Paleoproterozoic supracrustal rocks of the Karelian Craton. These predominantly comprise gently west-dipping quartzites, phyllites and mica schists belonging to the Sodankylä Group, overlain by younger metasediments including dolomitic marble and black schists belonging to the Savukoski Group.

The western section of the licence area (hanging wall) is underlain by the younger Haparanda Suite of the Norbotten Craton which is made up of monzonite and diorite intrusions. The Kolari Thrust Zone (KTZ) (known locally as the Hannukainen Thrust Zone (HTZ)) is located between the Norbotten and Kalerian Cratons and comprises IOCG mineralisation within the overlying and underlying cratonic rocks. Rocks are strongly foliated and sheared within, and adjacent to, the mineralised zones. A skarn was formed through the metasomatic alteration of host rocks near to this faulted contact. The IOCG mineralisation is hosted within this skarn.

Rautuvaara

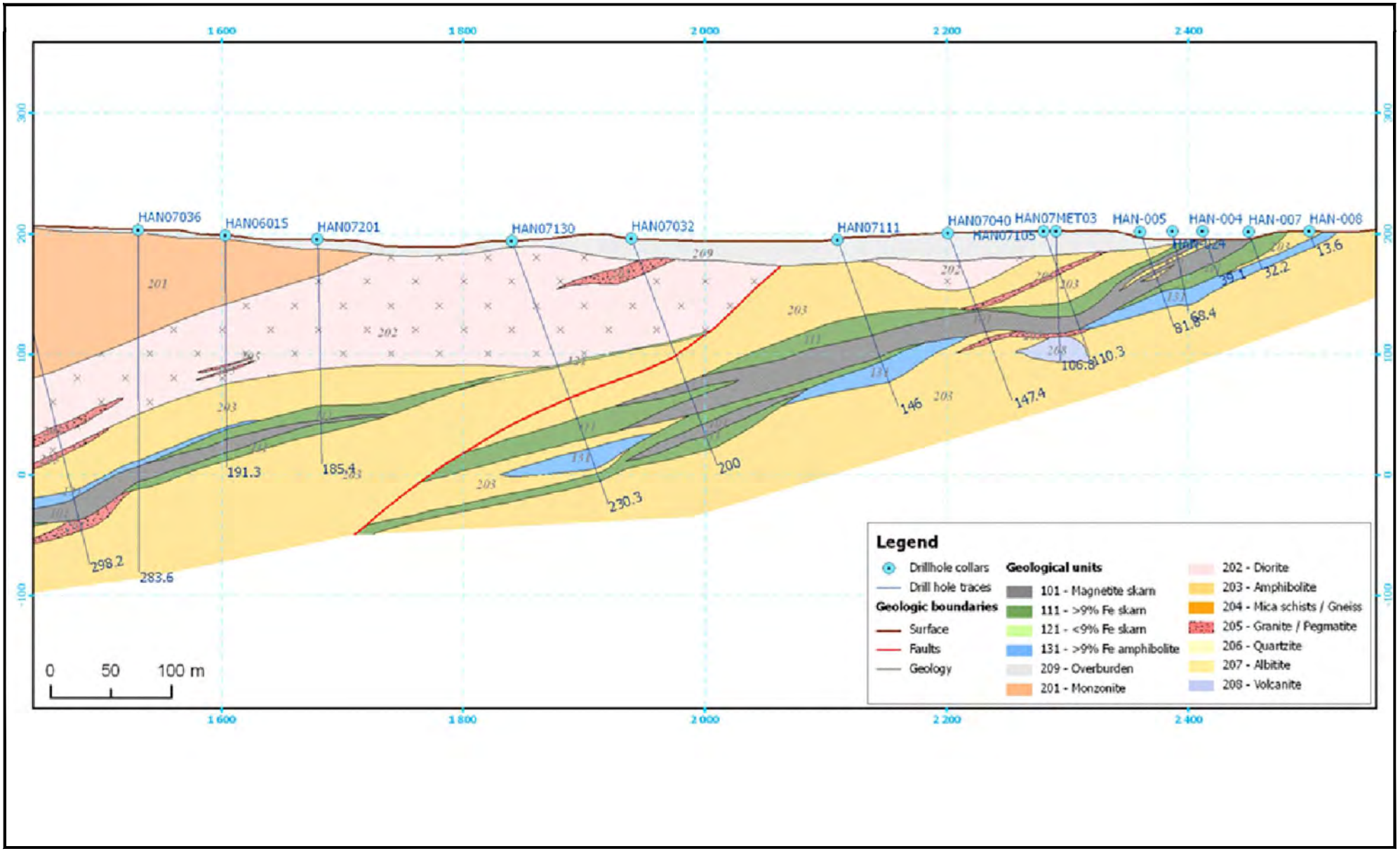
At Rautuvaara, the oldest bedrock is located to the southeast of the facility and comprises rocks of the Karelian Craton (Niiranen et al. 2007). The central and western portions of the Niesa Basin are dominated by the Norbotten Craton. The Rautuvaara ore body (comprising Cu–Au mineralisation) is hosted in clinopyroxene-dominated skarn rocks within this sequence (GTK, 2010a). The ore body outcrops in the hillside to the northwest of the existing TMF.

Local bedrock geology across the site is shown in Figure 6-1. A conceptual cross-section through the Hannukainen and Rautuvaara deposits is included in Figure 6-2 and Figure 6-3 respectively.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Local Bedrock Geology	Figure 6.1

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JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Cross-Section XS6300 Showing the Geological Units and Mineralisation (Source: Northland October 2010)	Figure 6.2

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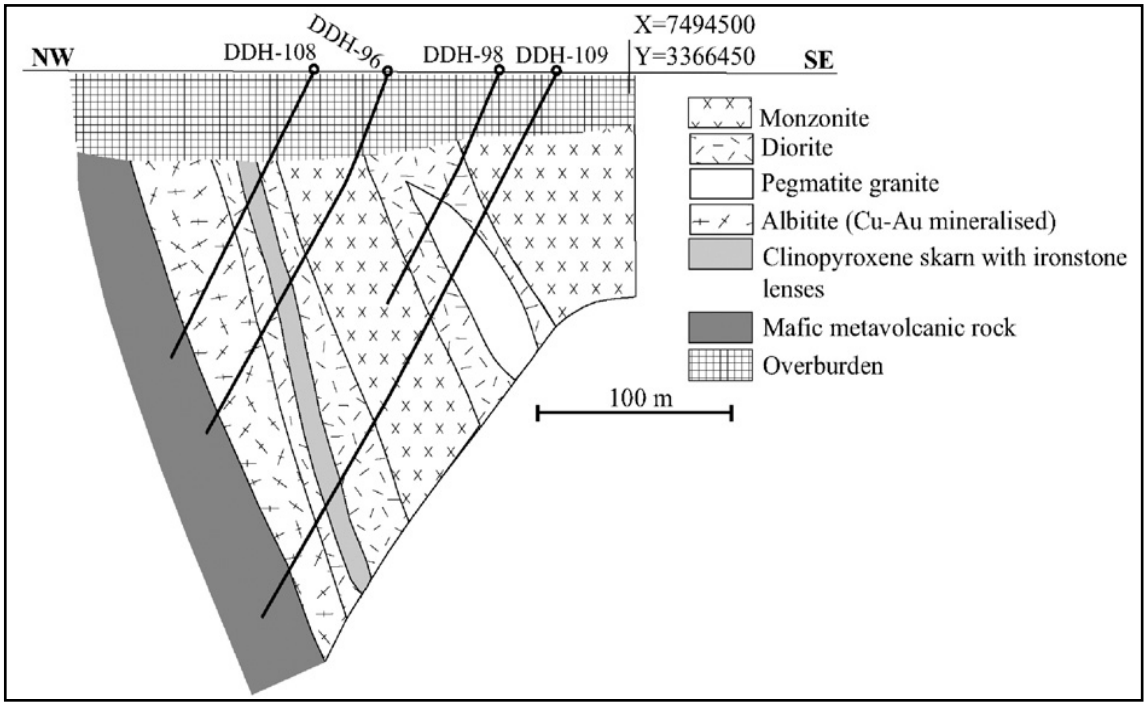


Figure 6-3: Cross-section Through the Cu-Rautuvaara Deposit (Source: Hiltunen (1982))

6.2.2 Overburden

Hannukainen

The characteristics of the overburden at the Hannukainen site were investigated in detail by the University of Helsinki in 2011. The field work comprised stratigraphic logging, overburden thickness estimation and groundwater level monitoring.

The study concluded that the Quaternary deposits are a result of at least three separate glacial cycles, and predominantly comprise sands and gravels related to fluvial and glaciofluvial activities. Figure 6-4 shows the Laurinoja open pit stratigraphic section, which comprises approximately 16 m of Quaternary sediments extending from the bedrock to the present ground surface. The logs contain 10 sedimentary units which are thought to represent four glacial / non-glacial sequences, named as the Oldest (A), Old (B), Middle (C) and Youngest (D) glacial sequence.

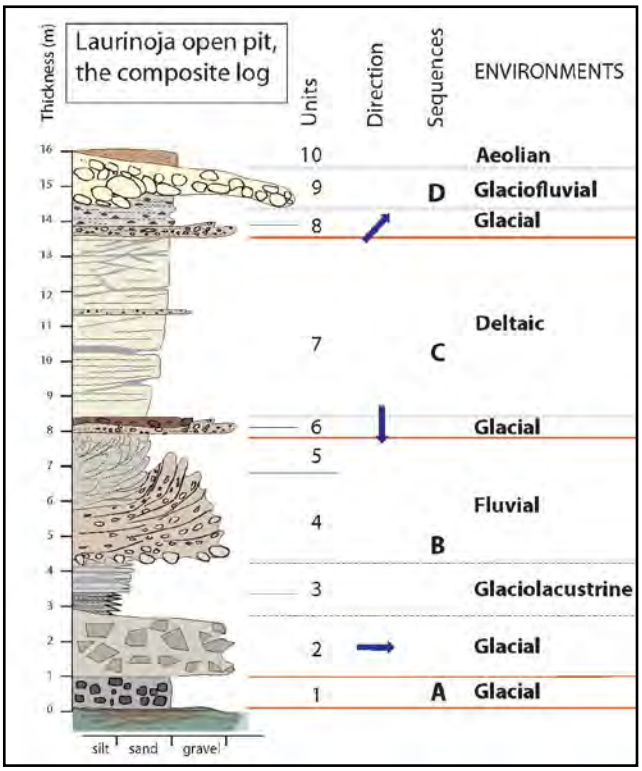


Figure 6-4: Quaternary sediments log from the Laurinoja pit section (Salonen, 2012).

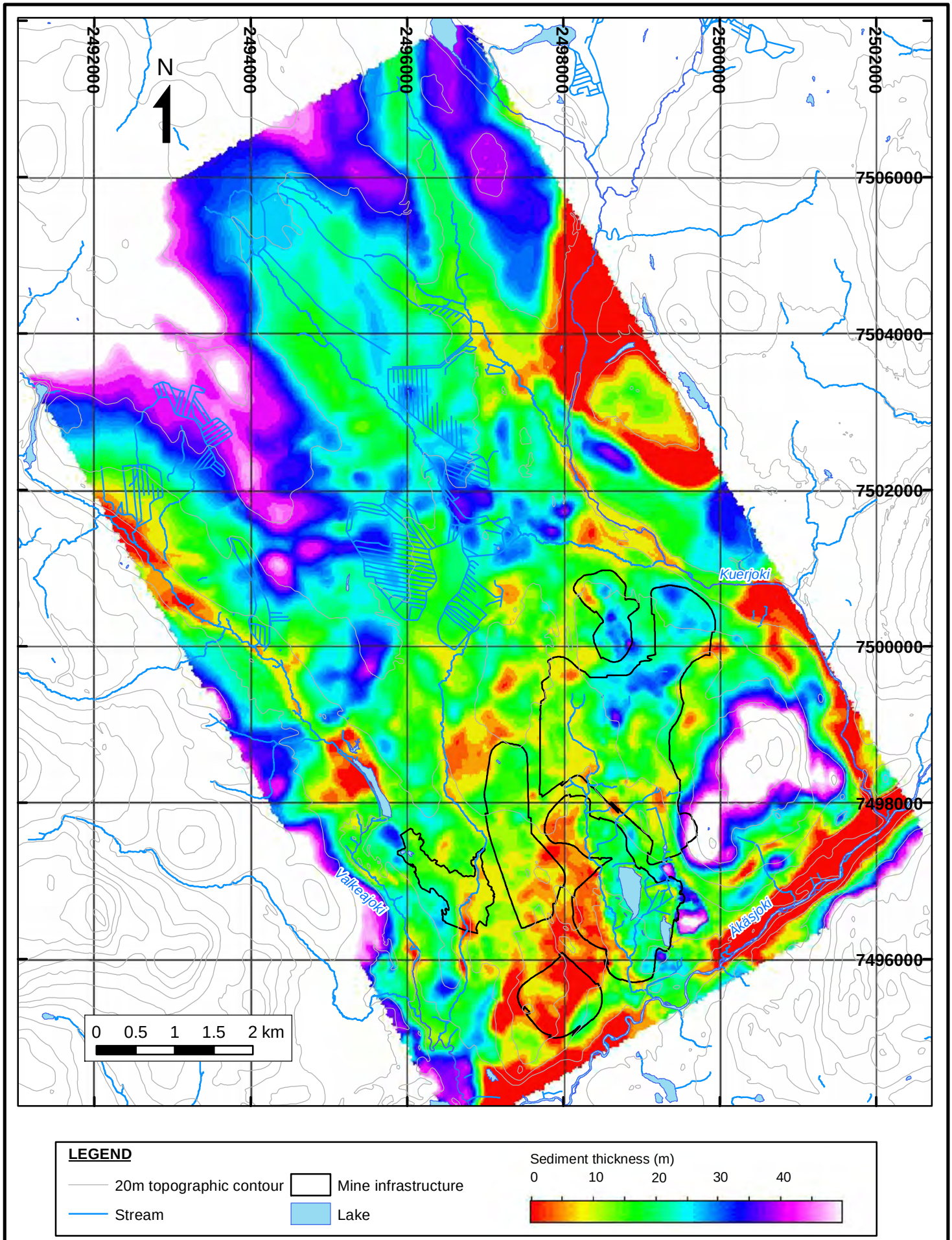
The University analysed ground penetrating radar (GPR) data acquired by the Geological Survey of Finland (GTK) in March 2011, and subsequently by the University of Helsinki during two campaigns (July 2011, September 2011), in order to generate a map of overburden thickness at Hannukainen.

The modelled Quaternary thickness is shown in Figure 6-5. Sediment thickness ranges from 0 to 102 m; the median thickness is 17.65 m, the mean is 20.38 m and the standard deviation is 14.65 m. These deposits are substantially thicker than the average measured in Lapland (i.e. 5.7 m (Maijanen et al. 2008)). There is no apparent correlation between geomorphology, bedrock elevation and sediment thickness.

A number of buried valleys have been identified in the area (Figure 6-5). Most of the buried valleys are expressed at the surface by north-south striking depressions filled with bogs and small brooks. However, the scale of the current topography of these valleys is often significantly less than the original geometry of the fluvial incision (> 30 m). The buried valleys may connect groundwater basins in the Hannukainen area and influence the hydrogeological flow regime.

In addition to buried valleys a number of 'highs' have been identified. These are locations where historically there has been a topographic high, though the scale of the current topography may not be as significant. There are numerous steep west-dipping reflections in the basement rock on the eastern side of the high which may be evidence for faults and fractures associated with a major structural boundary.

Peat cover at Hannukainen is limited to wetland areas in the north of the project area at the valley bottom, especially at Kuervitikko (Pöyry, 2008a).



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Modelled Quaternary Sediment Thickness Modified from Moreau and Koivisto (2012)	Figure 6.5

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Rautuvaara

Drilling by Northland during the hydrogeological and geotechnical programmes indicates that overburden thickness is variable at Rautuvaara, with thicknesses ranging from 3 m to 46 m recorded at the site:

- Generally overburden thickness is greater on the hillsides than in the bottom of the valley;
- The overburden is generally thickest on the hillsides to the southeast of the existing TMF (20 – 46 m);
- Overburden is less than 10 m thick in the region of the Kylmäoja Stream and the existing tailings pile, and 20 – 30 m thick in proximity to the Niesajoki River; and
- Overburden thickness in the hillside to the northwest of the Niesa Basin does not appear to be related to elevation. Thickness ranges from 8 – 33 m.

It should be noted that observations are limited to the extent of the drilling programme, which is focussed primarily around the edges of the proposed tailings facility. Drilling directly beneath the proposed facility was limited in the hydrogeological drilling programme because of the specification that the hydrogeological boreholes should form the basis of a monitoring network for the proposed facility. Drilling in the geotechnical study was generally shallow and did not always penetrate the full thickness of the overburden meaning that a thickness could not be derived.

Peat cover is recorded beneath the majority of the existing tailings facility with the exception of the northwest and northeast corners of the facility where overburden is deposited directly on top of the bedrock (GTK, 2010a). Peat is also recorded in the lake sediments of the North and South tailings ponds (Pöyry, pers. comm.).

Sediment thickness in the North Pond ranges from 0.2 – 6.2 m and is thickest in the northeast portion of the pond. The sediments are generally heterogeneous and comprise gravely / sandy moraine to silty moraine. Sediments are poorly graded in the northeast region of the pond, close to the existing water treatment plant. Water depth above these sediments is approximately 2 – 4 m. There is no information available regarding the hydraulic properties of the bed sediments (Pöyry, pers. comm.).

The characteristics of the overburden are currently being investigated in more detail by the University of Helsinki. The study has focused on the stratigraphy and thickness of the sediments.

The preliminary description of the Quaternary deposits generated by the University of Helsinki describes the sediment as sandy diamicton and gravelly sand through to silt with sandy interlayers. This is consistent with the geological logs collected during drilling which described the overburden as variable with layers of silt, sand, gravel and broken rock all recorded in the borehole logs. A full stratigraphic sequence has not yet been developed and the sequence has not been divided into glacial cycles (Salonen et al., 2012).

The University has collected approximately 53 km of GPR data in order to generate a map of overburden thickness at Rautuvaara. They note the presence of paleo channels, but processing of the GPR data has not yet been completed and so the location of these features is not yet defined. As yet there are no estimates of overburden thickness available from the study to supplement the Northland drilling programme (Salonen et al., 2012).

6.2.3 Structural Geology

The structural geology is important at Hannukainen because groundwater flow in the bedrock is likely to be controlled by flow through the open, connected fracture network.

Hannukainen

The Hannukainen deposit is hosted by the easternmost portion of the main structural lineaments of the PJKSZ – the KTZ or more locally the HTZ. The thrust zone has a north to north northeast oriented strike, and the dip is 15° to 30° to west or west southwest. The thrust zone intersects the northeast to southwest striking Äkäsjoki shear zone (ASZ) at the southern margin of the Hannukainen deposit. Regional scale structural interpretation has been undertaken by the Finnish Geological Survey and provided by NMOY in GIS format. This is shown in Figure 4-1.

Interrogation of the geotechnical database identified a number of discrete shattered, crushed and sheared zones occurring at various depths within the bedrock. Weathering of the upper bedrock is generally limited to the top 10 m. The average RQD values for both Hannukainen and Kuervitikko (90% and 74% respectively) indicate that the bedrock is more fractured at Kuervitikko (SRK, 2011).

It is uncertain why there is more fracturing at Kuervitikko than Hannukainen; however, the existence of a broad, approximately north-south trending valley to the west of Kuervitikko suggests the presence of a footwall structure which, it is conjectured, may have interacted with the main Hannukainen-Kuervitikko fault zone to produce a broader zone of deformation in the Kuervitikko area. In addition, at Kuervitikko the Hannukainen Thrust zone (HTZ) has been locally offset by two branch faults which may also be the cause of enhanced deformation (SRK, 2011).

Borehole scale structural analysis shows the presence of a strong sub horizontal foliation striking SE, dipping SW, across the whole of the site. A second sub vertical joint set striking NW-SE is prevalent in the hanging wall only, principally at the Hannukainen pit (SRK 2011).

Rautuvaara

The Rautuvaara Shear Zone (RSZ) is part of the larger Pajala-Kolari Shear System which is located between the Norbotten and Kalerian Cratons. The dominant direction of the main shear zone and syncline structures at Rautuvaara is NE-SW.

The RSZ comprises IOCG mineralisation within the overlying and underlying cratonic rocks. Rocks are strongly foliated and sheared within, and adjacent to, the mineralised zones. The mineralisation is associated with a SW opening syncline structure and is over 800 m long, up to 80 m thick and plunges approximately 80° SE (GTK, 2010b).

The regional and local structural geology is summarised in Figure 6-6 and Figure 6-1 respectively.

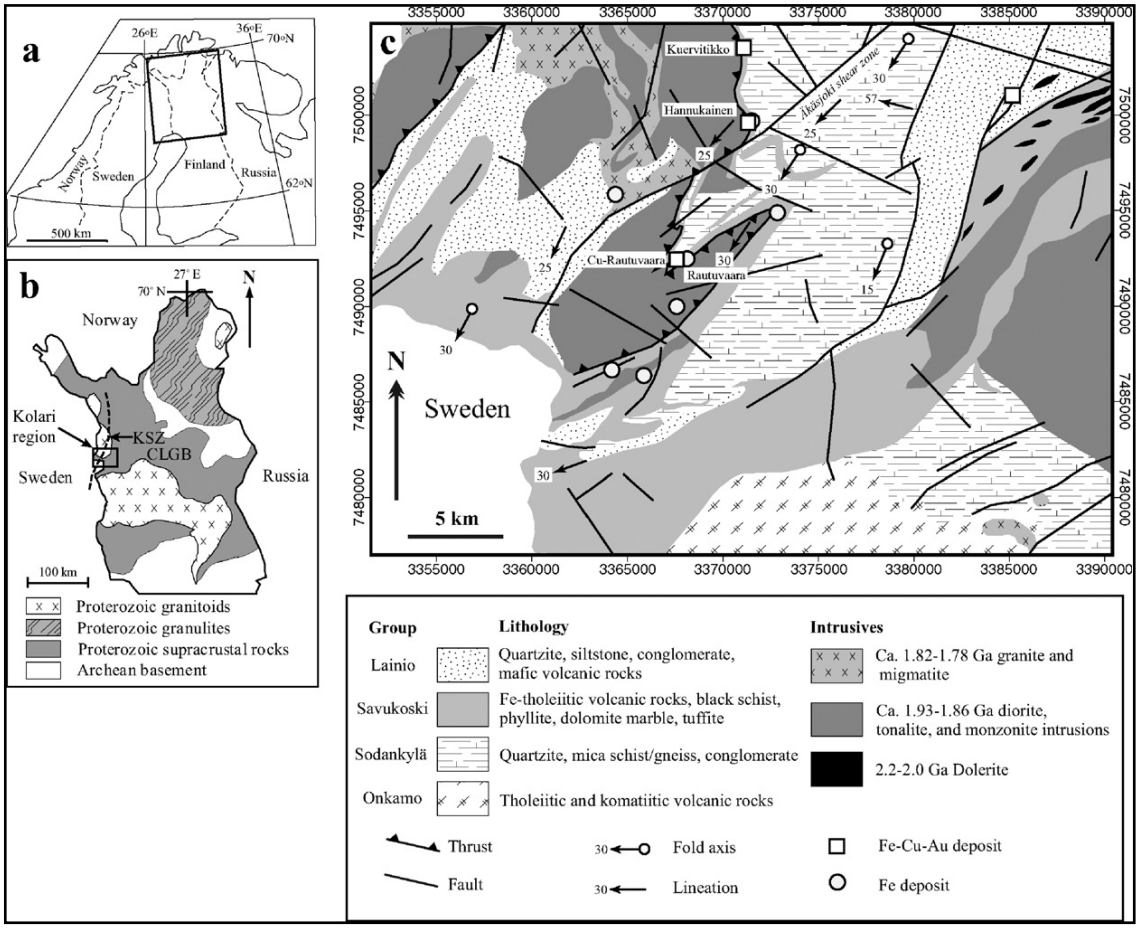


Figure 6-6: Pajala-Kolari Shear System in the Kolari region (taken from Niiranen et al. 2007)

6.3 Surface Water

The current conditions assessment for surface water focuses on an assessment of stream flow conditions and water quality in key watercourses potentially impacted by the Hannukainen Project (Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki, Kylmäoja and Muonionjoki Rivers) as well as existing flow pathways at the Niesa Basin. An overview of the methods and data sets used in the current conditions assessment is provided in Section 5.2.

A typical annual flow hydrograph for a catchment in Lapland is shown in Figure 6-7. Flow conditions vary through the year and the annual hydrograph can be divided into three general periods:

- ***Spring*** (May and June) characterised by high flows due to snowmelt. Generally, this is the period which contains the annual flow peak;
- ***Summer and Autumn*** (July through September/October) characterised by moderate to low lows with flow rates generally decreasing through this period as the remaining snow melts. However, there can be periods of higher flow in response to rainfall; and
- ***Winter*** (October through April) characterised by low flows as precipitation is held in the catchment as snow. All but the largest streams become ice-covered in the depths of winter. Some smaller streams freeze to the bed during winter with negligible to zero stream flows.

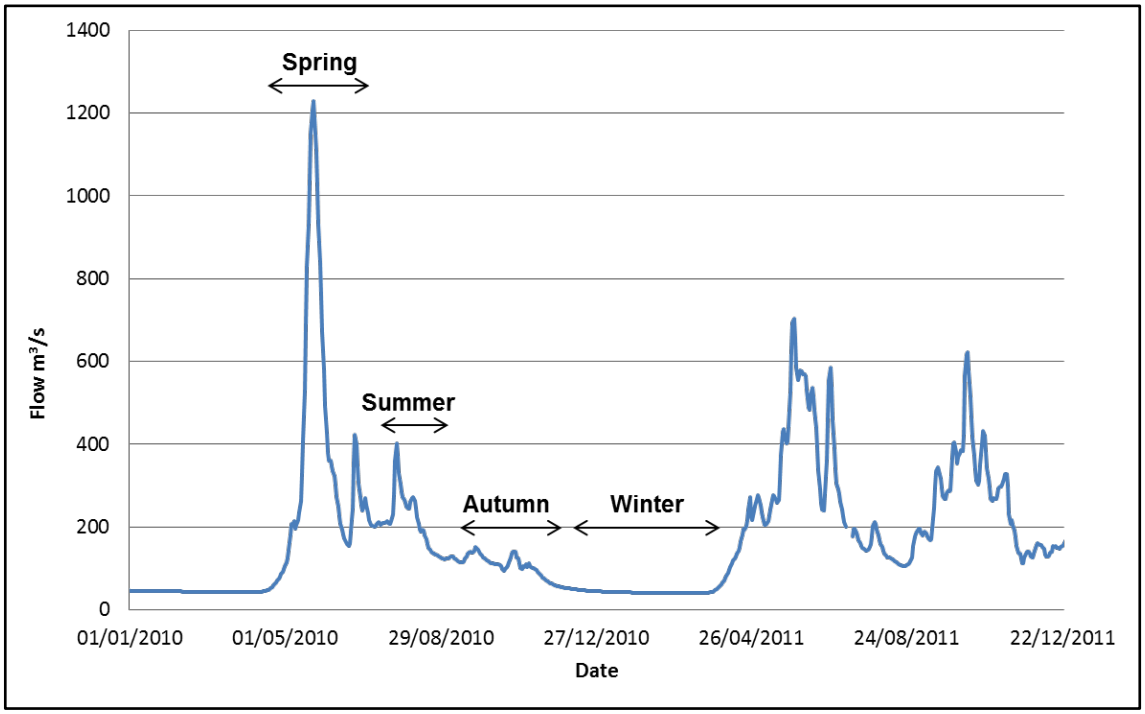


Figure 6-7: Typical annual flow hydrograph for rivers in Finnish Lapland (data for Muonionjoki at Kallio, gauge number 2395 from OIVA database)

6.3.1 Äkäsjoki River

Catchments and General Flow Pathways

The mine site and associated infrastructure is located within the catchment of the Äkäsjoki, Figure 5-4.

At the mine site the catchment area of the Äkäsjoki is around 520 km^2 and the Äkäsjoki is a broad, shallow river around 30 m wide, with coarse bed sediment, Photo 6-1.



Photo 6-1: Äkäsjoki close to proposed Hannukainen pit (SW014) (SRK 10/05/2011)

The river is sourced from Äkäsjärvi Lake located in its headwaters north of the site. The Kuerjoki is the major tributary of the Äkäsjoki and it joins the Äkäsjoki upstream of the mine site. The Äkäsjoki also receives flow from a small catchment that was diverted from the Niesajoki to the Äkäsjoki by way of a man-made ditch (named Kylmäoja Stream), see Figure 5-4.

The Äkäsjoki enters the Muonionjoki some 15 km downstream of the mine. The catchment area of the Äkäsjoki at its mouth is 650 km^2.

Surface Water Flows

The average annual runoff total for the Äkäsjoki catchment is 310 mm, based on regional analysis of gauged flow data.

Estimated monthly flows for the Äkäsjoki are shown in Table 6-4, where they are compared to monthly flow totals obtained from an application of the SYKE and NOPEX catchment models. There is a reasonably good comparison between the flow estimates produced by the three methods. The estimated monthly return period flows are summarised Table 6-5.

Low flow estimates for the Äkäsjoki are shown in Table 6-6.

One hydrological monitoring station was installed on the Äkäsjoki near to the mine site at the end of June 2012 (RAUSW005). Water levels recorded at the gauged site have been converted to flows using rating curves developed based on spot flow measurements obtained by Northland staff. Details of the spot flow measurements and rating curves are provided in Appendix B.

Average monthly flows for the period July to October were calculated and compared to monthly flows for an average year, calculated using the results of the regional hydrological analysis outlined in Appendix C. Results are presented in Table 6-7.

Table 6-4: Average monthly runoff and flow rates for the Äkäsjoki at the mine site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	8.3	6.2	6.1	12.7	101.2	46.7	23.9	22.6	23.4	27	20.3	12
Average flow (m^3/s)	1.7	1.3	1.2	2.6	20.4	9.4	4.8	4.6	4.7	5.4	4.1	2.4
SYKE model (m^3/s)	2.3	1.9	2.2	5.2	21.1	6.4	2.7	3.6	4.0	4.5	3.8	2.7
NOPEX model (m^3/s)	1.9	1.4	1.0	2.5	19.5	11.7	6.3	6.0	5.8	1.0	0.5	0.3

Table 6-5: Predicted return period average monthly flows for the Äkäsjoki adjacent to mine site

				Average Monthly Flow (m^3/s)								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.77	0.69	0.68	0.72	9.3	3.4	1.6	1.1	1.4	1.8	1.2	1.0
1 in 50 DRY	0.85	0.74	0.73	0.84	10.2	3.9	1.8	1.3	1.6	2.1	1.4	1.1
1 in 10 DRY	1.1	0.90	0.88	1.3	13.2	5.4	2.6	2.1	2.4	3.0	2.1	1.5
Average	1.7	1.3	1.2	2.6	20.4	9.4	4.8	4.6	4.7	5.5	4.1	2.4
1 in 10 WET	2.6	1.8	1.7	5.2	31.5	16.4	8.8	9.8	9.3	10.0	8.1	3.9
1 in 50 WET	3.3	2.1	2.1	7.9	40.8	22.9	12.7	15.6	14.0	14.4	12.3	5.2
1 in 100 WET	3.6	2.3	2.2	9.2	44.8	25.8	14.4	16.5	16.2	16.4	14.2	5.8

Table 6-6: 7-day low flow and 7-day Q_{10} estimates for the Äkäsjoki

	Äkäsjoki River at the site
7-day annual average low flow (m^3/s)	1.0
7-day Jul-Sep average low flow (m^3/s)	1.3
7-day annual average Q_{10} flow (m^3/s)	0.55
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.79

Table 6-7: Observed flows at hydrology station RAUSW005 on the Äkäsjoki River

Site	Parameter	July	August	September	October	Average (July to September)
RAUSW005	Observed flow (m^3/s)	8.5	4.7	6.5	9.7	7.2
	Estimated average flow (m^3/s)	4.8	4.6	4.7	5.5	4.9
	Percentage of average	180%	100%	140%	180%	150%

The observed flows are higher in three of the four months when data is available. However, observed flows in August are similar to estimated average flow conditions at the site. Overall the average observed flows are 150% of the estimated average flow conditions. This could suggest that the regional flow estimates for Äkäsjoki are under-predicted; however, the observed data needs to be viewed with caution as the rating curve is based on a limited number of spot flow measurements, resulting in a high degree of uncertainty associated with the estimation of flows based on the rating curve. In addition, it may be that 2012 was a particularly wet year, although regional flow data (Section 5.1.1) is contradictory as to whether 2012 was wet or dry. Based on return period monthly flow estimates the observed flow data at Äkäsjoki would suggest flows in July to October were consistent with 1 in 10 wet year conditions.

It should also be noted that the average flow estimates presented in Table 6-4 are based on analyses of many years of data and would tend to smooth out variability in monthly flow rates. In reality, as shown with the observed flow data for the Äkäsjoki, monthly flows in any one year can vary significantly from average conditions from one month to the next. Hence, the year with average monthly flows in each month would be unlikely to ever occur; however, these average flow rates are useful to assess the impact of development at a site.

Given the short period of the RAUSW005 flow record the effects assessment was undertaken using the flow estimates based on regional flow data. In addition, as the regional flow estimates are lower than the observed data, undertaking an effects assessment considering lower flows is considered to be more conservative, as less dilution with natural runoff will be considered in water quality calculations.

Water Quality

Median and maximum concentrations for 'Key' and 'Other' parameters at four baseline water quality monitoring stations on the Äkäsjoki River are shown in Table 6-8 and Table 6-9 respectively. The locations of the sampling stations are shown in Figure 5-3 and Figure 5-4.

FS11 is located upstream of the confluence of the Äkäsjoki with Kuerjoki, FS09 is adjacent to the mine site, FS10 downstream of the confluence with Valkeajoki and FS26 at the mouth of Äkäsjoki.

Median concentrations of a number of metals (chromium, mercury, manganese, lead and zinc) and nitrate and sulphate are higher at FS09 (close to the mine) than at the other sites. This may reflect an input from the existing mining operations at Hannukainen. WQOs were developed for sites FS09 and FS10 only and the baseline data are compared to TVs and AVs in the baseline water quality tables.

Maximum observed mercury concentrations at FS09 and FS10 are above the AV for this parameter. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80^{th} percentile of observed data).

Median concentrations of ammonium, nitrite, nitrate, arsenic, cadmium, cobalt, mercury, lead and antimony are affected by having 50% or more of the samples below detection limit.

In summary the baseline surface water quality in Äkäsjoki River is considered generally good when compared to site specific AVs.

Table 6-8: Water quality concentrations for key parameters at sampling sites on the Äkäsjoki (refer to Figure 5-3 and Figure 5-4)

Parameter	Unit	FS11		FS26		WQO FS10		FS10		WQO FS09		FS09	
		Median	Max	Median	Max	TV	AV	Median	Max	TV	AV	Median	Max
Suspended solids	mg/l	1.5	19	2.1	36	2.7	25	1.7	7.8	2.5	25	1.3	5.3
Ammonium	mg/l	0.0015[b]	0.034[b]	0.0030	0.11	0.0075	1.0	0.0033	0.015	0.0086	1.0	0.0030	0.015
Nitrite	mg/l	0.0010[b]	0.0040[b]	0.0010[b]	0.085[b]	0.0018	0.010	0.0010[b]	0.0040[b]	0.0019	0.010	0.0010[b]	0.0040[b]
Nitrate	mg/l	0.0040[b]	0.076[b]	0.0092	0.091	0.067	20	0.0089	0.076	0.073	20	0.012	0.10
Chloride	mg/l	0.74	8.1	0.80	6.3	0.90	150	0.70	1.1	0.992	150	0.00080	1.2
Sulphate	mg/l	2.8	4.4	3.0	7.1	4.0	65	3.1	4.9	4.4	65	3.2	5.0
Iron	mg/l	0.37	0.77	0.41	2.1	0.38	1.1	0.29	0.97	0.40	0.98	0.28	0.83
Aluminium	mg/l	0.017	0.066	0.022	0.071	0.051	0.10	0.022	0.065	0.050	0.10	0.021	0.066
Arsenic	mg/l	0.000067	0.016	0.000069[b]	0.00012	0.000091	0.0050	0.000062	0.00015	0.000098	0.0050	0.000065	0.00011
Cadmium	mg/l	0.0000027[b]	0.000025[b]	0.0000025[b]	0.000014	0.0000027	0.000080	0.0000025[b]	0.0000082	0.0000031	0.000080	0.0000025[b]	0.0000079
Cobalt	mg/l	0.000032	0.00035	0.000065[b]	0.00025[b]	0.00008	0.0040	0.000047[b]	0.00025[b]	0.000077	0.0040	0.000040	0.00018
Chromium	mg/l	0.00028	0.00038	0.00025	0.00041	0.00033	0.0010	0.00028	0.00035	0.00032	0.0010	0.00028	0.00035
Copper	mg/l	0.00031	0.0054	0.00039	0.011	0.00055	0.0050	0.00040	0.0012	0.00047	0.0050	0.00036	0.00071
Mercury	mg/l	0.0000013[b]	0.00020[b]	0.0000010[b]	0.0000053	0.0000021	0.000050	0.0000010[b]	0.000055	0.0000026	0.000050	0.0000016[b]	0.000093
Manganese	mg/l	0.0043	0.044	0.0070	0.050	0.021	0.70	0.011	0.040	0.018	0.70	0.010	0.043
Molybdenum	mg/l	0.00013	0.00023	0.00024	0.00037	0.00021	1.0	0.00020	0.00025	0.00019	1.0	0.00017	0.00023
Nickel	mg/l	0.00023	0.019	0.00025	0.00045	0.00031	0.020	0.00025	0.00047	0.00030	0.020	0.00021	0.00056
Lead	mg/l	0.000044	0.00012	0.000028[b]	0.000095[b]	0.000054	0.0072	0.000031	0.00012	0.000052	0.0072	0.000036	0.00011
Zinc	mg/l	0.00075	0.0065	0.00071	0.0023	0.0017	0.030	0.00090	0.0044	0.0016	0.030	0.00088	0.0021
Uranium	mg/l	0.000090	0.00010	0.000091	0.00026	0.00011	0.015	0.000099	0.00012	0.00011	0.015	0.000092	0.00012

a TVs (TV) and AVs (AV) for the Äkäsjoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit.

Table 6-9: Water quality concentrations for other parameters at sampling sites within Äkäsjoki (refer to Figure 5-3 and Figure 5-4)

Parameter	Unit	FS11		FS26		WQO FS10		FS10		WQO FS09		FS09	
		Median	Max	Median	Max	[a]TV	[a]AV	Median	Max	TV	AV	Median	Max
pH		6.9	7.3	6.7	7.7		<6 or >9	6.9	7.3		<6 or >9	7	7.5
Electrical Conductivity	mS/m	3.1	4.8	2.8	18	4.3	8.3	3.5	6.6	4.3	6.5	3.4	4.8
Phosphate	mg/l	0.0060	0.022	0.0070	0.020	0.0080	0.016	0.0067	0.013	0.0080	0.019	0.0060	0.015
TOC	mg/l	4.2	7.8	3.9	7.9	6.5	12	4.3	7.9	6.5	12	4.2	8.2
Calcium	mg/l	3.0	4.4	3.0	4.8	4.2	6.7	3.4	4.8	4.1	6.5	3.1	4.7
Potassium	mg/l	0.45	1.1	0.47	0.67	0.58	0.90	0.49	0.67	0.53	0.89	0.37	0.63
Magnesium	mg/l	0.89	1.8	0.96	1.3	1.1	1.8	0.90	1.3	1.2	1.8	0.91	1.3
Sodium	mg/l	1.4	2.1	1.7	2.0	1.9	2.9	1.6	2.1	1.8	2.8	1.5	2
Sulphur	mg/l	1.2	5.9	1.3	2.2	1.6	2.5	1.0	1.7	1.6	2.4	1.3	1.7
Silicon	mg/l	4.3	57	5.1	14	5.9	10	4.3	7.4	5.7	9.6	4.1	7
Barium	mg/l	0.0074	0.012	0.008	0.012	0.0089	0.018	0.0082	0.015	0.0092	0.018	0.008	0.015
Strontium	mg/l	0.014	0.021	0.017	0.021	0.020	0.031	0.017	0.022	0.020	0.030	0.017	0.021
Antimony	mg/l	0.0000050 [b]	0.000091 [b]	0.0000050 [b]	0.000055 [b]	0.000012	0.000027	0.0000050[b]	0.000018[b]	0.000014	0.000028	0.000011[b]	0.000019[b]

a TVs (TV) and AVs (AV) for Äkäsjoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit.

6.3.2 Kuerjoki River

Catchments and General Flow Pathways

The Kuerjoki is the largest tributary of the Äkäsjoki. At its mouth, where it joins the Äkäsjoki, the Kuerjoki has a catchment area of 162 km^2. At this location the Kuerjoki is a broad, shallow river around 15 m wide, Photo 6-2.



Photo 6-2: Mid-reach of Kuerjoki (SW025) (SRK 09/05/2011)

Surface Water Flows

Average annual runoff total for the Kuerjoki is 270 mm, based on regional analysis of gauged flow data.

Monthly average flow estimates for the Kuerjoki are provided in Table 6-10 where they are compared to monthly flow totals obtained from an application of the SYKE catchment model. There is generally a good correlation between the two methods. There is a disparity in the high flow predicted in the months of May to July. The estimated monthly return period flows are summarised in Table 6-11.

Low flow estimates for the Kuerjoki are shown in Table 6-12.

Due to high stream flow velocities and unstable river banks a continuous flow monitoring station was not constructed on Kuerjoki. However, Table 6-13 summarises the flow data collected by SRK in May 2011, at locations are shown on Figure 5-3. Table 6-13 also contains data for Valkeajoki and Äkäsjoki measured at the same time and which can be compared to the Kuerjoki data.

Table 6-10: Average monthly runoff and flow rates for the Kuerjoki at its mouth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	7.2	5.4	5.3	11.1	88.1	40.6	20.8	19.7	20.4	23.5	17.7	10.5
Average flow (m^3/s)	0.5	0.3	0.3	0.7	5.5	2.5	1.3	1.2	1.3	1.5	1.1	0.7
SYKE model (m^3/s)	0.5	0.5	0.5	1.0	9.0	1.3	0.6	1.0	1.1	1.3	1.0	0.6

Table 6-11: Predicted return period average monthly flows for the Kuerjoki at its mouth

				Average Monthly Flow (m^3/s)								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.21	0.19	0.18	0.19	2.5	0.93	0.43	0.31	0.37	0.49	0.32	0.28
1 in 50 DRY	0.23	0.20	0.20	0.23	2.8	1.0	0.49	0.36	0.43	0.56	0.37	0.31
1 in 10 DRY	0.30	0.24	0.24	0.34	3.6	1.5	0.71	0.57	0.65	0.80	0.56	0.41
Average	0.45	0.34	0.33	0.69	5.5	2.5	1.3	1.2	1.3	1.5	1.1	0.66
1 in 10 WET	0.69	0.47	0.46	1.4	8.5	4.4	2.4	2.7	2.5	2.7	2.2	1.1
1 in 50 WET	0.89	0.58	0.56	2.1	11.0	6.2	3.4	4.2	3.8	3.9	3.3	1.4
1 in 100 WET	0.98	0.62	0.60	2.5	12.1	7.0	3.9	4.5	4.4	4.4	3.8	1.6

Table 6-12: 7-day low flow and 7-day Q_{10} estimates for the Kuerjoki

	Kuerjoki River at the mouth
7-day annual average low flow (m^3/s)	0.27
7-day Jul-Sep average low flow (m^3/s)	0.26
7-day annual average Q_{10} flow (m^3/s)	0.15
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.15

Table 6-13: Baseline stream flow measurements for the Kuerjoki measured by SRK in May 2011

Station	Date	River/Stream	Latitude	Longitude	Q (m^3/s)
SW017	11 May 2011	Kuerjoki	2501897	7497900	2.22
SW019	10 May 2011	Kuerjoki	2501229	7499755	3.22
SW020	10 May 2011	Local Stream	2501265	7500064	0.002
SW021	Too deep to gauge				
SW022	10 May 2011	Hilajankanoja	2500862	7500930	0.02
SW023	10 May 2011	Kuerjoki	2500413	7500861	2.30
SW024	10 May 2011	Aavaoja	2500199	7500909	0.04
SW025	9 May 2011	Kuerjoki	2499136	7501094	2.03
SW027	9 May 2011	Kuerjoki	2499105	7501173	1.88
SW001	11 May 2011	Local Stream	2495801	7495561	0.12
SW002	11 May 2011	Valkeajoki	2495925	7496234	0.57
SW004	11 May 2011	Valkeajoki	2496072	7495209	0.78
SW006	9 May 2011	Valkeajoki	2496407	7494934	1.04
SW008	Too deep to gauge				
SW009	10 May 2011	Kylmäoja	2497858	7494094	0.75
SW012	10 May 2011	Äkäsjoki	2499130	7495517	9.94
SW013	Insufficient flow				
SW014	10 May 2011	Äkäsjoki	2499584	7495888	8.34
SW015	Insufficient flow				
SW016	Too fast to gauge				
SW018	11 May 2011	Äkäsjoki	2502261	7498094	5.58

Water Quality

Median and maximum concentrations at three baseline monitoring stations at sites FS40, FS41 and FS42 on the Kuerjoki River are shown in Table 6-14 and

Table 6-15 respectively. Site FS40 lies adjacent to the proposed mine site, with the other sites

lying upstream of the proposed mine.

Given the relatively limited number of samples for these baseline stations (between 10 and 14 measurements for each site) an assessment of spatial trends in water quality between the sites is difficult. However, by comparing median concentrations of Key parameters it is noted that sulphate and uranium concentrations are almost three times (for sulphate) and almost five times (for uranium) higher at FS40 near to the mine site, compared to the upstream stations. In contrast, median concentrations of cobalt, mercury and lead concentrations are around double the concentrations at FS40 compared to the upstream stations.

WQOs were developed for site FS40 only and the baseline data are compared to TVs and AVs in the baseline water quality tables.

No parameters are predicted to exceed AVs in the baseline data set. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80th percentile of observed data).

Median and maximum concentrations of nitrite, cadmium, cobalt, mercury and antinomy are affected by having 50% or more of the samples below detection limit.

In summary the baseline surface water quality in Kuerjoki River is considered as generally good when compared to site specific WQOs.

Table 6-14: Water quality concentrations for key parameters at FS41, FS42 and FS40 for the Kuerjoki (refer to Figure 5-3 and Figure 5-4)

Parameter	Unit	FS41		FS42		[a]WQO FS40		FS40	
		Median	Median	Max	Max	TV	AV	Median	Max
Suspended solids	mg/l	0.76	2.0	0.85	1.3	1.2	25	0.68	2.1
Ammonium	mg/l	0.0036	0.90	0.0037	0.012	0.0034	1.0	0.0022	0.0078
Nitrite	mg/l	0.0010[b]	0.0020[b]	0.0020[b]	0.002[b]	0.0020	0.010	0.0010[b]	0.0020[b]
Nitrate	mg/l	0.0028	0.022	0.0025	0.017	0.0068	20	0.0020	0.040
Chloride	mg/l	0.50	0.73	0.46	0.85	0.60	150	0.50	0.80
Sulphate	mg/l	0.74	2.0	0.79	2.7	2.3	65	2.0	2.8
Iron	mg/l	0.51	0.71	0.51	0.73	0.43	0.72	0.32	0.51
Aluminium	mg/l	0.040	0.066	0.037	0.065	0.0381	0.10	0.027	0.052
Arsenic	mg/l	0.00011	0.00017	0.00010	0.00017	0.000086	0.0050	0.000059	0.00010
Cadmium	mg/l	0.0000038	0.0000087	0.0000050	0.000013	0.0000035	0.000080	0.0000025[b]	0.0000050[b]
Cobalt	mg/l	0.000057	0.00011	0.000062	0.00011	0.000043	0.0040	0.000025[b]	0.000050[b]
Chromium	mg/l	0.00043	0.00052	0.00041	0.00053	0.00038	0.0010	0.00035	0.00041
Copper	mg/l	0.00021	0.0010	0.00013	0.00022	0.00033	0.0050	0.00020	0.00050
Mercury	mg/l	0.0000020[c]	0.0000020[c]	0.0000020[c]	0.0000020[c]	0.0000010	0.000050	0.0000010[c]	0.0000010[c]
Manganese	mg/l	0.0048	0.013	0.0027	0.010	0.0039	0.70	0.0029	0.0065
Molybdenum	mg/l	0.000094	0.00021	0.00012	0.00022	0.00022	1.0	0.00014	0.00024
Nickel	mg/l	0.00011	0.00024	0.00012	0.00023	0.00020	0.020	0.00012	0.00024
Lead	mg/l	0.00014	0.00022	0.00010	0.00017	0.000046	0.0072	0.000037	0.000052
Zinc	mg/l	0.0014	0.0083	0.0012	0.0031	0.0018	0.030	0.0010	0.0055
Uranium	mg/l	0.000024	0.000034	0.000028	0.000032	0.00011	0.015	0.00011	0.00012

Table 6-15: Water quality concentrations for other parameters at FS41, FS42 and FS40 for the Kuerjoki (refer to Figure 5-3 and Figure 5-4)

Parameter	Unit	FS41		FS42		[a]WQO FS40		FS40	
		Median	Max	Median	Max	TV	AV	Median	Max
pH		6.3	6.6	6.4	6.6		<6 or >9	6.8	7.5
Electrical Conductivity	mS/m	1.8	3.1	1.8	3.1	3.3	5.2	2.8	3.7
Phosphate	mg/l	0.017	0.024	0.014	0.018	0.011	0.017	0.0085	0.013
TOC	mg/l	11	16	10	16	7.7	14	5.0	8.7
Calcium	mg/l	1.6	2.5	1.5	2.4	3.1	4.8	2.7	3.2
Potassium	mg/l	0.30	0.60	0.38	0.63	0.49	0.82	0.39	0.56
Magnesium	mg/l	0.59	0.92	0.58	0.92	0.96	1.4	0.87	0.99
Sodium	mg/l	1.2	1.9	1.2	1.9	1.8	2.5	1.6	1.9
Sulphur	mg/l	0.22	0.39	0.23	0.40	0.81	1.3	0.63	0.90
Silicon	mg/l	4.1	7.5	4.2	7.5	6.1	10	4.8	7.0
Barium	mg/l	0.0046	0.011	0.0047	0.014	0.0052	0.010	0.0046	0.0079
Strontium	mg/l	0.011	0.018	0.010	0.017	0.020	0.030	0.017	0.020
Antimony	mg/l	0.000012[c]	0.000012[c]	0.000010[c]	0.000010[c]	0.00001	0.000014	0.000010[c]	0.000010[c]

a Site specific TVs (TV)based on the Kuerjoki FS40 water quality baseline data.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs
b 50% or more of the baseline data is below detection limit

6.3.3 Valkeajoki River

Catchments and General Flow Pathways

The Valkeajoki enters the Äkäsjoki to the south-west of the mine site (Photo 6-3). At its mouth where it joins the Äkäsjoki the Valkeajoki has a catchment area of 53 km^2. There is a fish pond located on the Valkeajoki adjacent to the mine site. In addition, the Saivojärvi wetland nature reserve is located at the mouth of the Valkeajoki, just downstream of the confluence with Äkäsjoki.



Photo 6-3: Valkeajoki upstream of the mine site (SW004) (SRK 11/05/2011)

Surface Water Flows

Average annual runoff total for the Valkeajoki is 250 mm, based on regional analysis of gauged flow data.

Monthly average flow estimates for the Valkeajoki are provided in Table 6-16 where they are compared to monthly flow totals obtained from an application of the SYKE catchment model. There is generally a good correlation between the two methods. The SYKE model predicts higher flow in May than the gauge flow estimate. The estimated monthly return period flows are summarised in Table 6-17.

Low flow estimates for the Valkeajoki are shown in Table 6-18.

One hydrological monitoring station was installed near the mouth of the Valkeajoki at the end of June 2012 (RAUSW006). Water levels recorded at the gauged site have been converted to flows using rating curves developed based on spot flow measurements obtained by Northland staff. Details of the spot flow measurements and rating curves are provided in Appendix B.

Average monthly flows for the period July to October were calculated and compared to monthly flows for an average year, calculated using the results of the regional hydrological analysis outlined in Appendix C. Results are presented in Table 6-19.

Table 6-16: **Average monthly runoff and flow rates for the Valkeajoki at its mouth**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	6.5	4.9	4.8	10.0	79.6	36.7	18.8	17.8	18.4	21.2	16.0	9.5
Average flow (m^3/s)	0.1	0.1	0.1	0.2	1.6	0.8	0.4	0.4	0.4	0.4	0.3	0.2
SYKE model (m^3/s)	0.2	0.2	0.2	0.4	2.5	0.6	0.2	0.3	0.4	0.4	0.4	0.2

Table 6-17: Predicted return period average monthly flows for the Valkeajoki at its mouth

	Average Monthly Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.06	0.06	0.05	0.06	0.75	0.28	0.13	0.09	0.11	0.15	0.09	0.08
1 in 50 DRY	0.07	0.06	0.06	0.07	0.82	0.31	0.15	0.11	0.13	0.17	0.11	0.09
1 in 10 DRY	0.09	0.07	0.07	0.10	1.06	0.43	0.21	0.17	0.19	0.24	0.17	0.12
Average	0.13	0.10	0.10	0.21	1.64	0.76	0.39	0.37	0.38	0.44	0.33	0.19
1 in 10 WET	0.21	0.14	0.14	0.42	2.52	1.31	0.71	0.79	0.75	0.80	0.65	0.31
1 in 50 WET	0.27	0.17	0.17	0.63	3.28	1.84	1.02	1.25	1.12	1.15	0.98	0.42
1 in 100 WET	0.29	0.18	0.18	0.73	3.59	2.07	1.16	1.32	1.30	1.31	1.14	0.46

Table 6-18: 7-day low flow and 7-day Q10 estimates for the Valkeajoki

	Valkeajoki River at mouth
7-day annual average low flow (m^3/s)	0.08
7-day Jul-Sep average low flow (m^3/s)	0.06
7-day annual average Q_{10} flow (m^3/s)	0.04
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.05

Table 6-19: Observed flows at hydrology station RAUSW006 on Valkeajoki

Site	Parameter	July	August	September	October	Average (July to September)
RAUSW006	Observed flow (m^3/s)	1.16	0.83	0.88	1.72	1.15
	Estimated average flow (m^3/s)	0.39	0.37	0.38	0.44	0.40
	Percentage of average	300%	220%	230%	390%	220%

The observed flows in Table 6-19 are significantly higher (around 200 to 300%) than the regional flow estimates. The observed flow data would appear to suggest that regional flow estimates for Valkeajoki stream are significantly under-estimated.

Hence, it would appear that flows in the Valkeajoki during the observed period were significantly higher than would be predicted using the regional hydrological approach developed in Appendix C. This pattern is seen at other gauging stations as outlined in other sections of this chapter. However, the observed data needs to be viewed with caution as the rating curve is based on a limited number of spot flow measurements, resulting in a high degree of uncertainty associated with the estimation of flows based on the rating curve. Regional flow data (Section 5.1.1) is contradictory as to whether 2012 was a wet or dry year. Based on return period monthly flow estimates the observed flow data at Valkeajoki would suggest flows in July and October were consistent with 1 in 200 wet year conditions, with flows in August and September equivalent to 1 in 10 wet year conditions.

Given the short period of the RAUSW006 flow record the effects assessment was undertaken using the flow estimates based on regional flow data. In addition, as the regional flow estimates are lower than the observed data, undertaking an effects assessment considering lower flows is considered to be more conservative, as less dilution with natural runoff will be considered in water quality calculations.

Water Quality

Median and maximum concentrations at four baseline monitoring stations at sites FS08, FS02, FS06 and FS07 on the Valkeajoki River are shown in Table 6-20 and Table 6-21.

There are no clear trends in water quality data within the Valkeajoki. Concentrations of many parameters are low and median estimates are affected by many samples having below detection limit concentrations. Median concentrations of ammonium, nitrite, nitrate, arsenic, cadmium, cobalt, mercury, nickel, lead, uranium and antimony are affected by having 50% or more of the samples below detection limit.

WQOs were developed for site FS08 only and the baseline data are compared to TVs and AVs in the baseline water quality tables.

The maximum nitrite concentration in the data set is predicted to exceed AVs. No other parameter exceeds AVs. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80^{th} percentile of observed data).

In summary the baseline surface water quality in Valkeajoki River is considered as generally good when compared to site specific AVs.

Table 6-20: Water quality concentrations for key parameters at water quality sampling sites for the Valkeajoki (refer to Figure 5-3)

Parameter	Unit	[a]WQO FS08		FS08		FS02		FS06		FS07	
		TV	AV	Median	Max	Median	Max	Median	Max	Median	Max
Suspended solids	mg/l	2.2	25	1.1	4.7	1.0	4.5	0.73	13	1.1	34
Ammonium	mg/l	0.0030	1.0	0.0030[b]	0.018[b]	0.0015[b]	0.0066[b]	0.0095	0.35	0.0020[b]	0.017[b]
Nitrite	mg/l	0.0030	0.010	0.0013[b]	0.027[b]	0.0010[b]	0.0050[b]	0.0010[b]	0.0030[b]	0.0010[b]	0.0030[b]
Nitrate	mg/l	0.0069	20	0.0010[b]	0.025[b]	0.0014[b]	0.022[b]	0.0027[b]	0.15[b]	0.0010[b]	0.023[b]
Chloride	mg/l	0.70	150	0.50	0.91	0.51	1.4	0.54	3.8	0.50	1.0
Sulphate	mg/l	2.7	65	2.2	3.2	1.62	2.6	1.5	14	2.3	3.2
Iron	mg/l	0.20	1.0	0.12	0.38	0.34	0.73	0.018	3.9	0.10	0.26
Aluminium	mg/l	0.036	0.10	0.017	0.086	0.034	0.061	0.0029	0.0090	0.016	0.074
Arsenic	mg/l	0.000080	0.0050	0.000025[b]	0.00011[b]	0.000083	0.00012	0.00010	0.00013	0.000025[b]	0.000089[b]
Cadmium	mg/l	0.0000027	0.000080	0.0000025[b]	0.0000068[b]	0.0000025[b]	0.0000078[b]	0.0000025[b]	0.0000075[b]	0.0000025[b]	0.0000250[b]
Cobalt	mg/l	0.000046	0.0040	0.000025[b]	0.00016[b]	0.000025[b]	0.000093[b]	0.000025[b]	0.000044[b]	0.000016	0.00013
Chromium	mg/l	0.000364	0.0010	0.00032	0.00044	0.00036	0.00044	0.00005	0.00011	0.00033	0.00041
Copper	mg/l	0.00049	0.0050	0.00033	0.0025	0.00020	0.00050	0.00039	0.0059	0.00039	0.00089
Mercury	mg/l	0.0000022	0.000050	0.0000010[b]	0.000045[b]	0.0000010[b]	0.0000027[b]	0.000093[b]	0.00010[b]	0.0000010[b]	0.00020[b]
Manganese	mg/l	0.0048	0.70	0.0023	0.015	0.0042	0.019	0.00255	0.22	0.0018	0.015
Molybdenum	mg/l	0.00033	1.0	0.00030	0.00041	0.00028	0.00050	0.000093	0.00013	0.00030	0.00040
Nickel	mg/l	0.00021	0.020	0.00013	0.00050	0.00016	0.0032	0.000086[b]	0.00026[b]	0.00012	0.00041
Lead	mg/l	0.000041	0.0072	0.000022[b]	0.00013[b]	0.000032	0.00010	0.000016[b]	0.00015[b]	0.000021	0.00018
Zinc	mg/l	0.0014	0.030	0.00071	0.0024	0.0011	0.0020	0.00087	0.00966	0.00083	0.0089
Uranium	mg/l	0.00012	0.015	0.000092	0.00013	0.00015	0.00028	0.0000050[c]	0.0000050[c]	0.00011	0.00055

a TVs and AVs for the Valkejoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the baseline data is below detection limit
c All samples below detection limit.

Table 6-21: Water quality concentrations for other parameters at water quality sampling sites for the Valkeajoki (refer to Figure 5-3)

Parameter	Unit	WQO FS08		FS08		FS02		FS06		FS07	
		[a]TV	[a]AV	Median	Max	Median	Max	Median	Max	Median	Max
pH			<6 or >9	7.0	7.4	6.8	7.2	6.7	7.5	6.9	7.4
Electrical Conductivity	mS/m	2.9	4.2	2.7	3.2	2.6	3.5	1.8	5.6	2.7	3.2
Calcium	mg/l	0.012	0.017	0.0094	0.013	0.0082	0.023	0.0010	0.019	0.011	0.015
Phosphate	mg/l	5.4	12	3.2	8.2	6.3	10	1.2[b]	2.1[b]	2.7	7.2
TOC	mg/l	2.7	19	2.5	16	2.3	3.5	1.2	2.2	2.5	2.9
Potassium	mg/l	0.45	0.93	0.39	0.71	0.35	0.56	0.35	0.49	0.41	0.61
Magnesium	mg/l	0.70	6.4	0.63	5.3	0.67	1.0	0.38	0.49	0.60	0.74
Sodium	mg/l	1.9	4.2	1.7	3.5	1.5	2.2	0.87	1.1	1.6	2.2
Sulphur	mg/l	0.97	1.4	0.88	1.0	0.67	0.86	0.50	0.64	0.93	1.1
Silicon	mg/l	6.1	9.7	5.2	7.2	5.1	7.9	0.20	0.49	5.3	7.1
Barium	mg/l	0.0044	0.0093	0.0035	0.0072	0.0041	0.011	0.0047	0.0056	0.0033	0.0073
Strontium	mg/l	0.019	0.028	0.018	0.0202	0.017	0.021	0.0062	0.0076	0.018	0.020
Antimony	mg/l	0.000012	0.000024	0.0000050[b]	0.000016[b]	0.000011[b]	0.00012[b]	0.000021	0.000026	0.0000050[b]	0.00027[b]

a TVs and AVs for the Valkeajoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

6.3.4 Niesajoki River

Catchments and General Flow Pathways

The Niesajoki is a tributary of the Muonionjoki, with a catchment area of around 70 km^2 at its confluence with the Muonionjoki, Photo 6-4 and Figure 5-4.

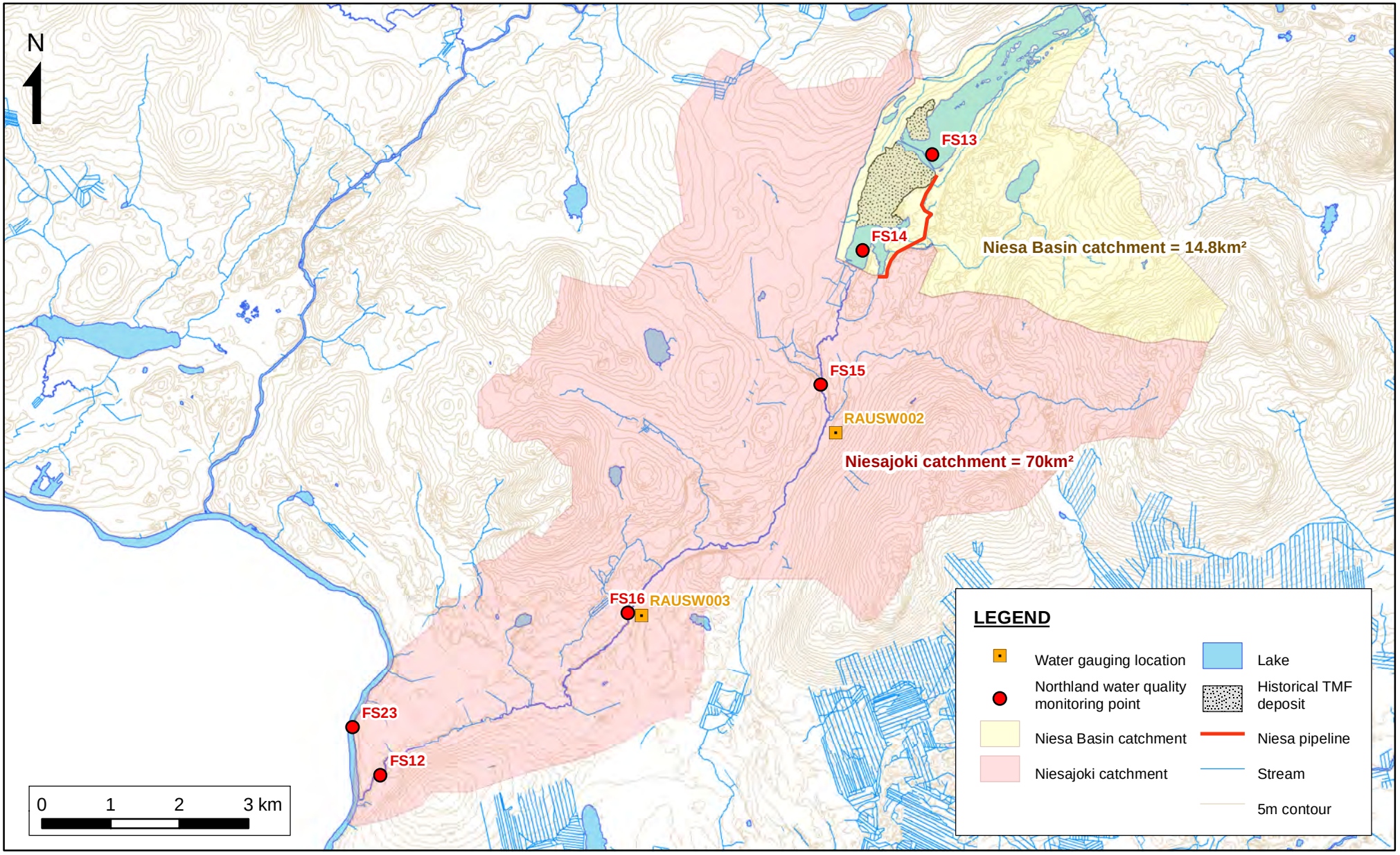


Photo 6-4: Niesajoki River near to borehole RAU12HYD12 (SRK 14/6/2012)

Flows and water quality within the Niesajoki have undergone anthropogenic alteration due to the presence of the existing TMF in the headwaters of the river. Northland proposes to expand the existing TMF and use it as the tailings storage facility for the Hannukainen Project. Post-development the footprint of the existing TMF will be increased with tailings covering a larger area. Details of the post-development layout are discussed in Section 6.4.4. This section focuses on the layout of the existing TMF and attempts to assess the impact that the current facility has on stream flows and water quality in the Niesajoki River.

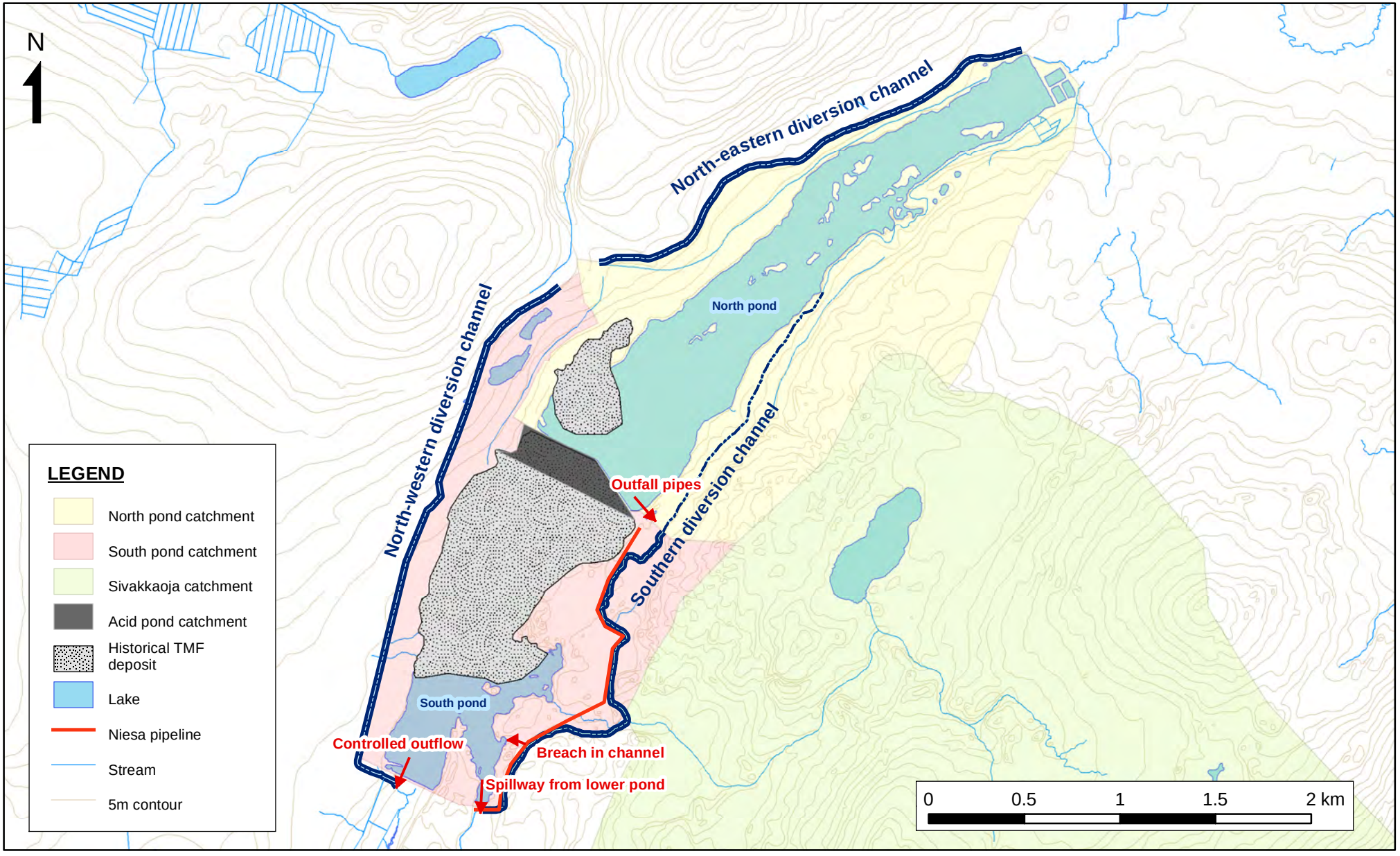
Existing infrastructure within the Niesa Basin catchment, which was utilised during historical mining between 1978 – 1996, includes a tailings clarification pond (called the North Pond) and a sedimentation pond (called the South Pond) (Figure 6-8). The North and South ponds are separated by a tailings dam. There is another small impoundment dam at the southern end of the North Pond that acts as a counter pressure dam to prevent acid runoff from the tailings dam mixing with relatively clean water in the North Pond. The pond contained behind the counter pressure dam is referred to in previous studies as the Acid Pond (GTK, 2012a)).

The hydrological catchments within which the existing TMF is located are shown in Figure 6-9.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Key Catchments Along Niesajoki River	Figure 6.8

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-5 Key_Catchments_along_Niesajoki_river_PH2_HIA.mxd



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Key Catchments Around Niesa Basin	Figure 6.9

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-6 Key_catchments_around_Niesa_Basin_PH2_HIA.mxd

The catchment flowing to the North Pond is estimated to be 3.8 km^2 in area, including the area of the pond which is approximately 1.4 km^2. There are two diversion channels to the north of North Pond, the 'north-eastern diversion channel' and the 'north-western diversion channel', that direct natural runoff from high ground north of the pond away from the North Pond towards the Kylmäoja Stream and Niesajoki River respectively (Figure 6-9). These diversion channels were viewed during a site visit in May 2012 and appear to be intact and operational. In addition, there is a diversion channel to the south of the North Pond, the 'southern diversion channel', (Figure 6-9). During the field visit in May 2012 this channel did not appear to convey water in the section parallel to the North Pond. As a result, this assessment assumes runoff from the south of the North Pond enters the South Pond, as shown in Figure 6-9 and Figure 6-10.

Water can flow south out of the North Pond by way of (Figure 6-10):

- Twin outfall pipes that discharge water from the pond into the southern diversion channel. These are auxiliary discharge channels and water is currently pumped to these pipes if required (K. Marja-Haanpaa (Pöyry), pers. comm.));
- A sub-surface 600 mm diameter pipeline identified by Northland staff that appears to flow approximately parallel to the southern diversion channel and discharges into a headwater stream of the Niesajoki, downstream of the South Pond; and
- Seepage from the pond through the tailings dam or into the local groundwater system, either reporting to the South Pond or to the Niesajoki.

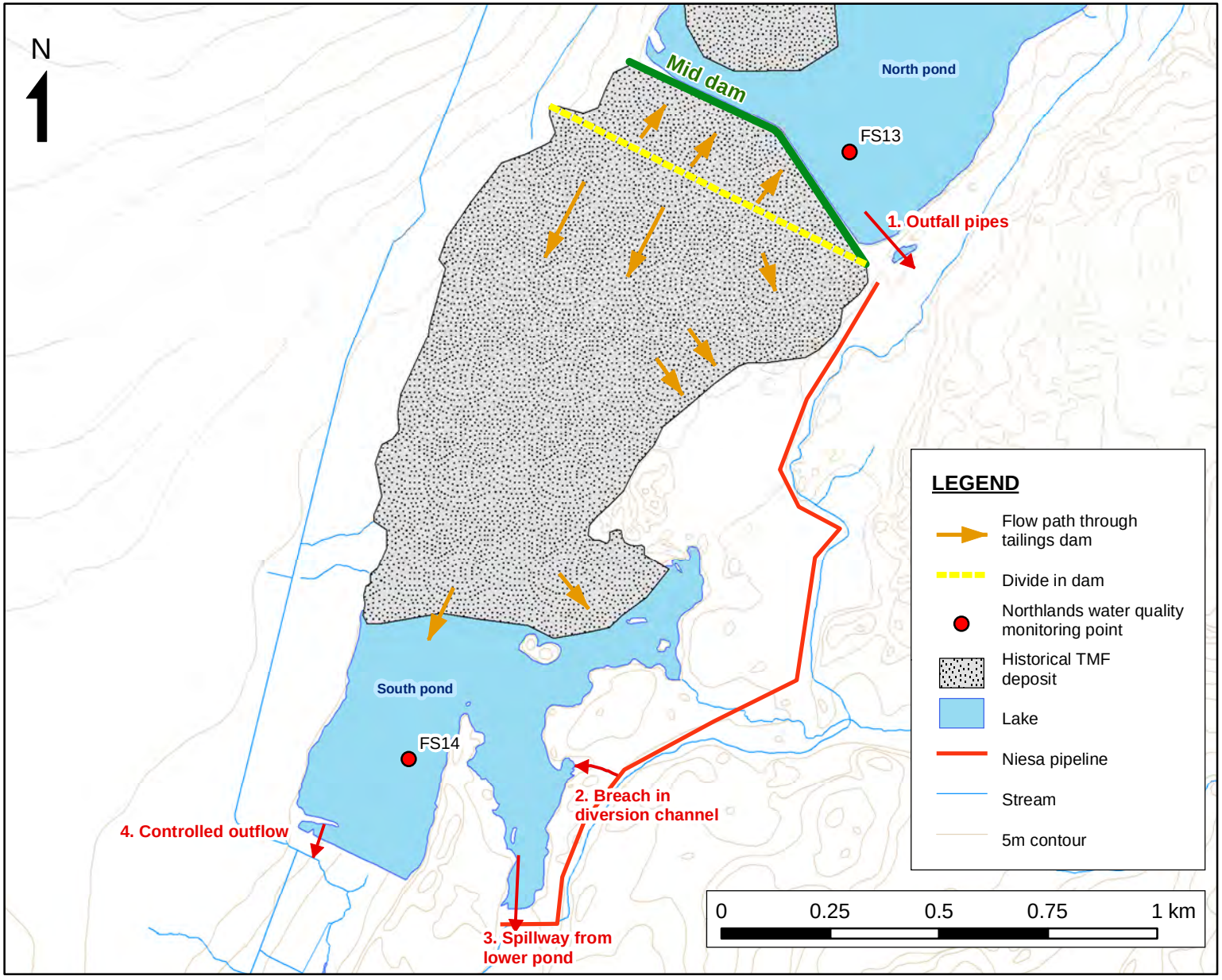
The catchment area of the Acid Pond is approximately 0.12 km^2, as shown in Figure 6-9 (dark grey area; refer to legend). The catchment includes runoff from the crest of the tailings dam.

The total catchment currently flowing to the South Pond is estimated to be 10.9 km^2. This includes the tailings dam (0.8 km^2), the South Pond (0.36 km^2), natural catchments surrounding the South Pond (0.74 km^2) and the Sivakkaoja catchment (8.5 km^2). The Sivakkaoja catchment and land to the east of the southern diversion channel drain to the southern diversion channel. Water in this channel should bypass the South Pond and discharge into a headwater stream of the Niesajoki downstream of the South Pond. However, the southern diversion channel is currently breached (and has been for a number of years) and water entering the channel flows directly into the South Pond (Figure 6-9). If the southern diversion channel were to be reinstated then the catchment area flowing to the South Pond would reduce from approximately 10.9 km^2 to 2.2 km^2. Key flow pathways at the southern end of the existing TMF are shown in Figure 6-10.

Water can flow south out of the South Pond by way of:

- A free spillway located to the south-east of the pond; and
- A controlled outflow pipe housed towards the western edge of the South Pond.

The total catchment of the Niesa Basin (North Pond, South Pond and Acid Pond) is approximately 14.8 km^2.





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JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Flow Pathways at Southern End of Niesa Basin	Figure 6-10

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-7 Flow_pathways_at_Southern_end_of_Niesa_Basin_PH2.mxd

There are no surface water flows from the North Pond of the Niesa Basin towards the Kylmäoja stream.

At present, the North Pond is utilised by the Ylläs wastewater treatment plant as a tertiary sedimentation pond. There is currently no active discharge of mine waters or tailings to the North Pond. The average depth of water in the North Pond is approximately 2 m (maximum approximately 4 m) (K. Haanpää, Pöyry, pers. comm. 24/01/2012). The water level in the North Pond is maintained between 190.0 – 190.5 masl.

It should be noted that during the development of the existing TMF in the Niesa Basin the natural headwaters of the region were diverted to the Äkäsjoki by way of a man-made ditch (Kylmäoja Stream). This ditch is still in operation and as a result there is no inflowing catchment to the Niesa Basin from the north-west. An assessment of current conditions in the Kylmäoja Steam is provided in Section 6.3.5.

Water Balance and Surface Water Flows for Niesa Basin and Niesajoki River

Pöyry are undertaking water balance estimates for the Niesa Basin and these results will be presented in their final water management report. However, simple water balance calculations were undertaken for the Niesa Basin and Niesajoki River, based on average precipitation and runoff conditions. The methods used are discussed in more detail in Section 5.2.2. Annual runoff totals and monthly flow distributions are based on results of the regional hydrological assessment outlined in Appendix C. Catchment areas have been calculated based on available topographical mapping.

Results of the water balance calculations, with predictions of average monthly flows at five key locations, are presented in Table 6-22. The key locations considered are:

- Outflow from North Pond;
- Outflow from South Pond (including contribution from North Pond and breached southern diversion channel);
- Niesajoki River downstream of the existing TMF near the mid-point of the catchment. This is at water quality sampling location FS15, shown on Figure 6-8;
- Niesajoki River near its mouth and at water quality sampling location FS16, shown on Figure 6-8; and
- Niesajoki River at its mouth and at water quality sampling location FS12, shown on Figure 6-8.

Return period average monthly flows at the mouth of Niesajoki River are provided in Table 6-23. As with the analysis in Table 6-22 the data in Table 6-23 are based on the results of the regional analysis outlined in Appendix C.

Low flow estimates for the Niesajoki River at key locations are shown in Table 6-24, calculated based on methods outlined in Appendix C.

Table 6-22: Average monthly flow calculations for Niesajoki River based on measured catchments and regional hydrological parameters

Key Hydrological Parameters		
Annual precipitation	529	mm
Annual evaporation	287	mm
Annual Runoff	275	mm
Runoff Coefficient	0.52	
North pond	**Area**	
Pond (excluding sewage ponds)	1.4	km^2
North catchment	0.8	km^2
South catchment max	1.6	km^2
South catchment min	0.1	km^2
Total	**3.8**	km^2
Acid Pond	**0.12**	km^2
South pond	**Area**	
Catchment	0.74	km^2
Dam	0.8	km^2
Pond	0.36	km^2
Local Catchment to Southern Diversion	0.5	km^2
Sivakkaoja catchment	8.5	km^2
Total	**10.90**	km^2
Total Basin	14.82	km^2
Niesa Mid-Point (FS 15)	37	km^2
Niesa near Mouth (FS16)	59	km^2
Niesa at Mouth (FS12)	69	km^2

Monthly percentage contribution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
% precipitation	6.5	5.1	5.4	5.9	6.4	9.8	14.0	13.4	9.6	8.9	8.6	6.3	100
% Effective Precipitation	0.0	0.0	0.0	0.0	44.2	9.8	14.0	13.4	9.6	8.9	0.0	0.0	100
% evaporation	0.0	0.0	0.0	0.3	11.0	23.7	27.6	22.9	10.4	3.8	0.4	0.0	100
% runoff	2.7	2.0	2.0	4.1	32.6	15.0	7.7	7.3	7.5	8.7	6.5	3.9	100
Flow Volumes (Mm^3)													
North Pond	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff Natural Catchment	0.02	0.01	0.01	0.03	0.22	0.10	0.05	0.05	0.05	0.06	0.04	0.03	0.66
Precipitation on Pond	0.00	0.00	0.00	0.00	0.33	0.07	0.10	0.10	0.07	0.07	0.00	0.00	0.74
Evaporation from Pond	0.00	0.00	0.00	0.00	0.04	0.10	0.11	0.09	0.04	0.02	0.00	0.00	0.40
TOTAL	*0.02*	*0.01*	*0.01*	*0.03*	*0.50*	*0.08*	*0.04*	*0.06*	*0.08*	*0.11*	*0.04*	*0.03*	*1.00*
South Pond	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff Natural Catchment (including dam)	0.01	0.01	0.01	0.02	0.14	0.06	0.03	0.03	0.03	0.04	0.03	0.02	0.42
From North Pond	0.02	0.01	0.01	0.03	0.50	0.08	0.04	0.06	0.08	0.11	0.04	0.03	1.00
Precipitation on Pond	0.00	0.00	0.00	0.00	0.08	0.02	0.03	0.03	0.02	0.02	0.00	0.00	0.19
Evaporation from Pond	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.01	0.00	0.00	0.00	0.10
Breached diversion	0.07	0.05	0.05	0.10	0.81	0.37	0.19	0.18	0.19	0.21	0.16	0.10	2.48
TOTAL	*0.10*	*0.07*	*0.07*	*0.14*	*1.52*	*0.51*	*0.26*	*0.27*	*0.31*	*0.37*	*0.23*	*0.14*	*3.98*
Niesa Mid-Point (FS 15)	0.27	0.20	0.20	0.42	3.32	1.53	0.78	0.74	0.77	0.88	0.66	0.39	10.18
Niesa near Mouth (FS16)	0.44	0.33	0.32	0.67	5.29	2.44	1.25	1.18	1.22	1.41	1.06	0.63	16.23
Niesa at Mouth (FS12)	0.51	0.38	0.37	0.78	6.19	2.85	1.46	1.39	1.43	1.65	1.24	0.73	18.98
Flows (L/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
North Pond	7	5	5	10	192	30	17	21	31	42	16	10	385
South Pond	37	28	27	56	585	196	102	104	118	144	89	53	1537
Niesa Mid-Point (FS 15)	105	79	77	161	1280	590	302	287	296	341	256	152	3926
Niesa near Mouth (FS16)	168	126	124	257	2040	941	482	457	472	543	408	242	6260
Niesa at Mouth (FS12)	196	147	144	300	2386	1101	563	534	552	636	477	283	7321

Table 6-23: Predicted return period average monthly flows for the Niesajoki at its mouth

				Average Monthly Flow (m^3/s)								
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1 in 100 DRY	0.09	0.08	0.08	0.08	1.09	0.40	0.19	0.13	0.16	0.21	0.14	0.12
1 in 50 DRY	0.10	0.09	0.08	0.10	1.19	0.45	0.21	0.16	0.19	0.24	0.16	0.13
1 in 10 DRY	0.13	0.11	0.10	0.15	1.55	0.63	0.31	0.25	0.28	0.35	0.24	0.18
Average	0.20	0.15	0.15	0.30	2.42	1.10	0.57	0.54	0.55	0.64	0.48	0.28
1 in 10 WET	0.30	0.21	0.20	0.61	3.68	1.92	1.03	1.15	1.09	1.17	0.95	0.46
1 in 50 WET	0.39	0.25	0.24	0.92	4.78	2.68	1.49	1.82	1.64	1.68	1.44	0.61
1 in 100 WET	0.42	0.27	0.26	1.07	5.24	3.01	1.69	1.93	1.89	1.91	1.66	0.68

Table 6-24: 7-day low flow and 7-day Q_{10} estimates for the Niesajoki

	Niesajoki River at mouth
7-day annual average low flow (m^3/s)	0.12
7-day Jul-Sep average low flow (m^3/s)	0.09
7-day annual average Q_{10} flow (m^3/s)	0.06
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.07

The flow estimates presented above are based on analysis of data from regional hydrological monitoring stations as outlined in Section 5.2.2 and Appendix C. Regional data was used as a surrogate for site-specific flow data, due to the lack of long-term site specific data. However, in late June 2012, three hydrological monitoring stations were constructed on the Niesajoki River (RAUSW001, RAUSW002 and RAUSW003). Water levels recorded at each gauged site have been converted to flows using rating curves developed based on spot flow measurements obtained by Northlands staff. Details of the spot flow measurements and rating curves are provided in Appendix B.

Observed average monthly flows for the period July to October are presented in Table 6-26 where they are compared to monthly flows for an average year predicted using the regional assessment methods. The observed flows are higher than the flow estimates using the regional methods, with the largest discrepancy at gauge RAUSW001, which is located downstream of the South Pond of the Rautuvaara TMF, with observed flows three times greater than would be predicted for an average year. Observed flows are around 50% higher than average conditions from regional flow estimates at RAUSW002 and RAUSW003, located further downstream of the Niesa Basin.

As there are only four months of data at the flow monitoring stations it is difficult to make any general conclusions related to the hydrology of the Niesajoki River based on the observed flow data; however, as has been seen previously the gauged flow data might suggest that flow estimates for the Niesajoki (and especially for outflows from the Niesa Basin) based on analysis of regional flow data may under-estimate the actual observed flows within the river.

As with previous stations the observed data needs to be viewed with caution since data is available for four complete months only. In addition, the rating curves at the site are based on a limited number of spot flow measurements and the rating curves are strongly influenced by a single higher flow measurement obtained at each site in October 2012. Hence, there is a high degree of uncertainty associated with the rating curves and further flow measurements are required to better constrain the flow records at these gauged sites.

Taking regional return period flow estimates at the mouth of the Niesajoki River (Table 6-23) and comparing them to the gauged data, it would appear that the gauged flows are equivalent to those expected in a 1 in 5 wet year.

Although the period of record at the gauged sites is too short to make estimates of long-term averages, the data can be used to assess the distribution of flows along the Niesajoki River. The regional methods used in the water balance calculations imply that river flows should scale with the upstream catchment area, i.e. flows should increase downstream. Using these methods, flows at RAUSW001 should be around 18% of the flows at RAUSW003, based on catchment area. Flows at RAUSW002 should be around 68% of the flows at RAUSW003 (Table 6-27).

Undertaking similar calculations with the gauged flow, data flows at RAUSW001 are observed to be 38% of the flows at RAUSW003, significantly higher than predicted (refer to Table 6-27). However, at RAUSW002 the gauged flows are 68% of the flows at RAUSW003; exactly the same as would be predicted by scaling flows by catchment area.

The results for RAUSW002 appear to confirm the catchment based approach used in the water balance calculations (Table 6-22). However, the results for RAUSW001 suggest that current estimates of flows leaving the existing Rautuvaara TMF might be under-predicted. One reason for this could be that the North and South Ponds provide attenuation for snowmelt runoff, with snowmelt to the ponds during early summer held in the ponds and then released later in the summer to the Niesajoki. This would tend to reduce spring runoff compared to catchment based methods, and increase runoff later in the summer.

However, without flow records for the spring snowmelt period and with no increase in flows observed at RAUSW002 compared to what would be expected, this hypothesis cannot be confirmed, although it would appear consistent with what might be expected downstream of a lake. This hypothesis will be further tested in 2013 once additional flow monitoring records have been collected at which time the runoff estimates for the Niesajoki can be adjusted.

Hence, given the limited period of record at the gauged sites and the reasonable comparison of gauged and calculated flows in the Niesajoki, the effects assessment for the new Rautuvaara TMF was undertaken using flows calculated using the results of the regional hydrological assessment. However, once additional flow data has been obtained at the gauged sites, it is recommended that the flow estimates are reviewed and updated if required.

Table 6-25: Comparison of flow distributions along the Niesajoki River

[a]Gauged average monthly flows (m^3/s)			
Month	RAUSW01	RAUSW02	RAUSW03
July	0.18	0.44	0.74
August	0.27	0.38	0.61
September	0.21	0.46	0.71
October	0.48	0.73	0.87
Flows as a percentage of observed flow at RAUSW03			
	RAUSW01	RAUSW02	RAUSW03
July	24%	59%	100%
August	45%	63%	100%
September	30%	65%	100%
October	55%	84%	100%
Average	***38%***	***68%***	***100%***
[b]Based on Catchment Area	***18%***	***68%***	***100%***

a Monthly averaged flows from flow monitoring stations
b Based on catchments areas of RAUSW001, 10.9 km^2; RAUSW002, 40 km^2; and RAUSW003, 59 km^2

Table 6-26: Observed flows at Northland hydrology stations on Niesajoki River compared to Regional Flow Estimates

Site	Parameter	July	August	September	October	Average (July to September)
RAUSW001	Observed flow (m^3/s)	0.18	0.27	0.21	0.48	0.22
	Estimated average flow (m^3/s)	0.1	0.1	0.12	0.10	0.09
	Percentage of average	203%	324%	244%	477%	318%
RAUSW002	Observed flow (m^3/s)	0.44	0.38	0.46	0.73	0.50
	Estimated average flow (m^3/s)	0.33	0.31	0.32	0.37	0.33
	Percentage of average	135%	123%	145%	198%	152%
RAUSW003	Observed flow (m^3/s)	0.74	0.61	0.71	0.87	0.69
	Estimated average flow (m^3/s)	0.48	0.46	0.47	0.54	0.49
	Percentage of average	153%	134%	151%	160%	150%

Water Quality

Median and maximum concentrations for 'Key' and 'Other' parameters (as defined in Section 3.2) at five sampling sites within the Niesajoki catchment are shown in Table 6-27 and Table 6-28 respectively. Site FS13 is located in the North Pond of the existing Rautuvaara TMF, FS14 in the South Pond and sites FS15, FS16 and FS12 are located downstream of the Niesa Basin as shown in Figure 5-3.

The following discussion focuses on key parameters only and uses median concentrations, as discussed in Section 5.2.2.

The water quality results show a clear trend in improving water quality from the headwaters of the Niesajoki River towards its mouth; with water quality improving with distance from the existing Rautuvaara TMF. In order to better visualise the spatial variation in parameter concentrations through the Niesajoki catchment, the observed data for each sampling station were fitted to a log-normal distribution, with distributions for each parameter together on a single graph, Figure 6-11. The results illustrate that most parameters show a general trend of dilution from the upper reaches of the Niesajoki to its mouth as would be expected, with sulphate, manganese, nickel and zinc concentrations showing clear trends of dilution.

WQOs were developed for two locations on the Niesajoki; at FS15, just downstream of the existing tailings facility and at FS12, near the mouth of the river. WQOs for these sites are presented in Table 6-27 and Table 6-28.

Median concentrations at both sites are shown to be below all Action and Trigger Values. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80^{th} percentile of observed data). Maximum phosphate, iron, copper and Total Suspended Solids concentrations at FS15 are predicted to exceed AVs. Maximum copper concentrations at FS12 are predicted to exceed AVs.

Table 6-27: Water quality concentrations at sampling sites in the Niesajoki; Key parameters

Parameter	Unit	FS13		FS14		WQO – FS15		FS15		FS16		WQO – FS12		FS12	
		Median	Max	Median	Max	[a]TV	[a]AV	Median	Max	Median	Max	[a]TV	[a]AV	Median	Max
Suspended solids	mg/l	2.8	6.2	1.3	17	3.1	25	2.0	42	1.4	16	2.2	25	1.1	20
Ammonium	mg/l	0.26	2.3	0.0090	0.87	0.1	1	0.019	0.65	0.0050	0.28	0.0090	1.0	0.0030	0.18
Nitrite	mg/l	0.0070	0.11	0.0020[b]	0.0082[b]	0.012	0.052	0.002[b]	0.036[b]	0.0041[b]	0.011[b]	0.0025[b]	0.010[b]	0.0010	0.0090
Nitrate	mg/l	0.24	0.80	0.015	0.069	0.28	20	0.16	0.56	0.067	0.30	0.15	20	0.053	0.22
Chloride	mg/l	4.6	31	1.1	8.9	3	150	2.2	5.3	1.2	2.1	2.0	150	1.2	3.1
Sulphate	mg/l	130	230	78	190	89	160	71	100	23	50	39	80	25	51
Iron	mg/l	0.39	2.3	0.66	3.3	0.92	4.1	0.66	4.4	0.51	2.5	0.81	1.9	0.63	1.9
Aluminium	mg/l	0.023	0.057	0.018	0.063	0.05	0.1	0.021	0.080	0.044	0.17	0.067	0.10	0.039	0.10
Arsenic	mg/l	0.000062	0.0030	0.0047	0.0099	0.0012	0.005	0.00050	0.0023	0.00050	0.0075	0.00045	0.0050	0.00028	0.00062
Cadmium	mg/l	0.0000062	0.000013	0.0000050	0.000014	0.0000064	0.00008	0.0000028[b]	0.000013[b]	0.0000073[b]	0.0000096[b]	0.0000028	0.000080	0.0000025	0.000011
Cobalt	mg/l	0.011	0.034	0.0011	0.068	0.0025	0.004	0.0020	0.0079	0.0015	0.0020	0.00042	0.0040	0.00020	0.00093
Chromium	mg/l	0.000076	0.00031	0.00026	0.0026	0.00033	0.001	0.00025	0.00087	0.00037	0.00052	0.00039	0.0010	0.00035	0.00049
Copper	mg/l	0.0055	0.010	0.0023	0.012	0.0048	0.005	0.0023	0.010	0.0015	0.0090	0.0021	0.0050	0.0014	0.0070
Mercury	mg/l	0.0000020[b]	0.000016[b]	0.0000020[b]	0.000029[b]	0.0000022	0.00005	0.000001[b]	0.000029[b]	0.00015[b]	0.00020[b]	0.0000022	0.000050	0.0000010	0.0000052
Manganese	mg/l	0.88	2.2	0.10	2.7	0.29	0.7	0.18	0.60	0.050	0.20	0.038	0.70	0.032	0.18
Molybdenum	mg/l	0.000050[b]	0.000066[b]	0.00045	0.00068	0.0002	1	0.00015	0.00022	0.00015	0.00020	0.00020	1.0	0.00015	0.00025
Nickel	mg/l	0.0099	0.017	0.011	0.024	0.0066	0.02	0.0048	0.0099	0.0017	0.0049	0.0024	0.020	0.0020	0.0030
Lead	mg/l	0.000053	0.00017	0.000057	0.00022	0.000078	0.0072	0.000043	0.00024	0.000040	0.00011	0.000061	0.0072	0.000030	0.000090
Uranium	mg/l	0.00015	0.00033	0.0011	0.0015	0.00041	0.015	0.00038	0.00049	0.00025	0.00029	0.00023	0.015	0.00019	0.00033
Zinc	mg/l	0.0065	0.028	0.0013	0.018	0.0024	0.03	0.0015	0.0037	0.0016	0.0084	0.0022	0.030	0.0013	0.0048

a TVs and AVs for Niesajoki River.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit.
c All samples below detection limit.

Table 6-28: Water quality concentrations at sampling sites within Niesajoki; Other parameters

Parameter	Unit	FS13		FS14		WQO – FS15		FS15		FS16		WQO – FS12		FS12	
		Median	Max	Median	Max	[a]TV	[a]AV	Median	Max	Median	Max	[a]TV	[a]AV	Median	Max
pH		6.9	7.8	7.2	7.7		<6 or >9	6.9	7.4	6.8	7.3		<6 or >9	6.9	7.5
Electrical Conductivity	mg/l	32	54	23	47	26	41	21	28	9.6	24	16	33	12	27
Phosphate	mg/l	0.0021	0.024	0.0040	0.019	0.007	0.036	0.0037	0.69	0.0040	0.018	0.007	0.027	0.004	0.027
TOC	mg/l	3.5	5.0	6.3	8.7	9.2	15	5.9	11	6.2	12	11	24	4.6	16
Calcium	mg/l	34	62	26	45	25	46	20	31	9.6	22	16	33	9.8	25
Potassium	mg/l	4.1	5.4	2.5	4.4	3	4.9	2.4	3.4	1.3	2.1	1.8	2.9	1.3	2
Magnesium	mg/l	14	37	11	17	9.8	17	9	11	4.7	6.1	5.3	9.1	3.1	5.6
Sodium	mg/l	6.6	8.8	3.8	7.2	5.3	9.1	4.1	6.5	2.8	4.1	3.4	5.8	2.4	4
Sulphur	mg/l	45	52	26	43	29	53	27	36	12	17	14	23	8.6	14
Silicon	mg/l	1.8	7.1	3.1	7.7	4.4	11	3.8	8.5	5.2	9.2	6.1	12	5.4	9.1
Barium	mg/l	0.015	0.022	0.014	0.024	0.01	0.014	0.0097	0.012	0.0072	0.0097	0.0077	0.013	0.0074	0.011
Strontium	mg/l	0.085	0.091	0.040	0.054	0.07	0.11	0.055	0.074	0.030	0.046	0.041	0.069	0.028	0.045
Antimony	mg/l	0.000011[b]	0.000034[b]	0.000039[b]	0.000082[b]	0.000022	0.000059	0.000017[b]	0.000039[b]	0.000017[b]	0.000020[b]	0.000014	0.000029	0.000005[b]	0.000018[b]

a TVs and AVs for Niesajoki River.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit.

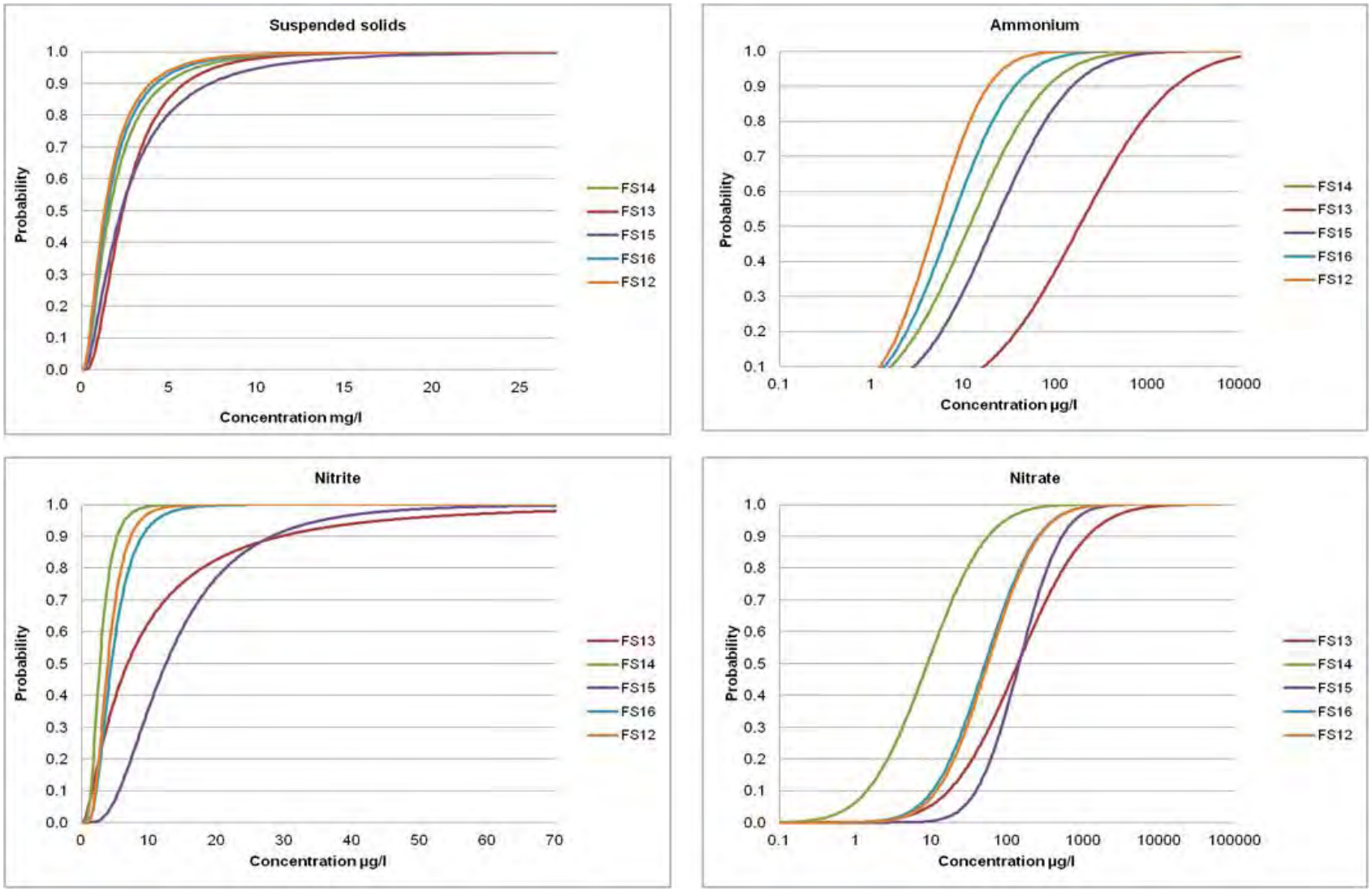


Figure 6-11: Baseline water quality data for Niesajoki River, fitted to log-normal distributions

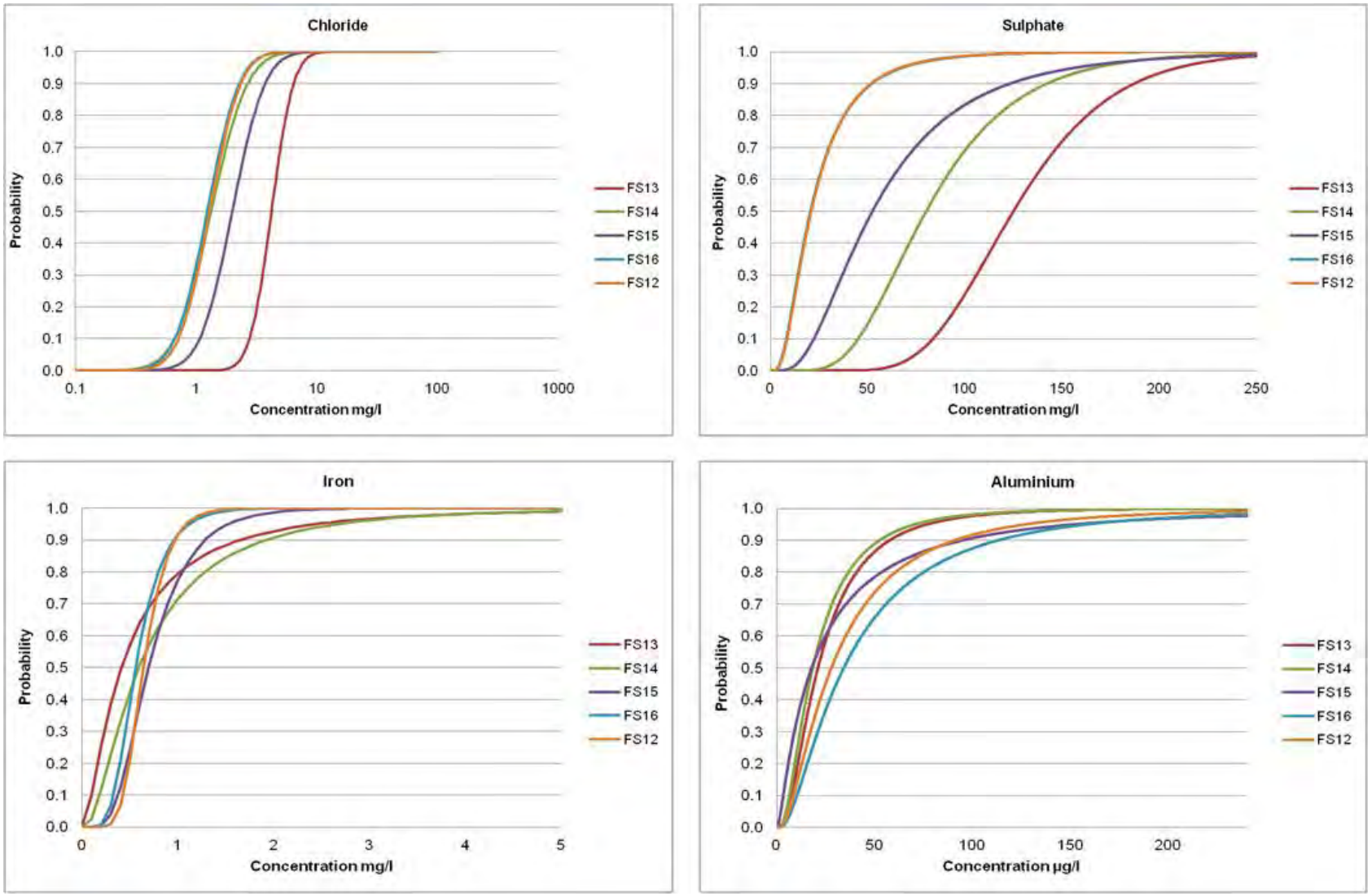


Figure 6-11 cont.: Baseline water quality data for Niesajoki River, fitted to log-normal distributions

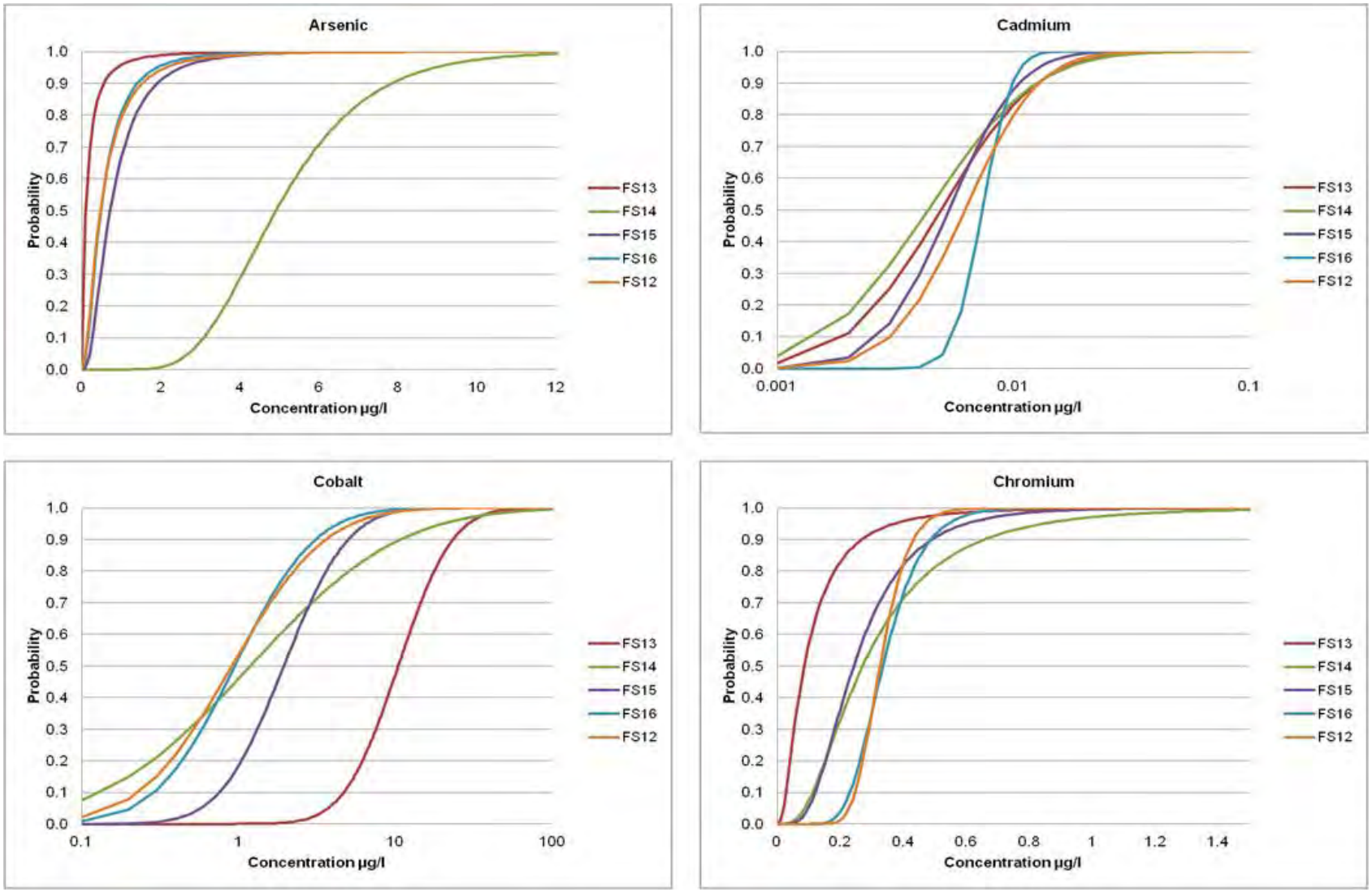


Figure 6-11 cont.: Baseline water quality data for the Niesajoki River, fitted to log-normal distributions

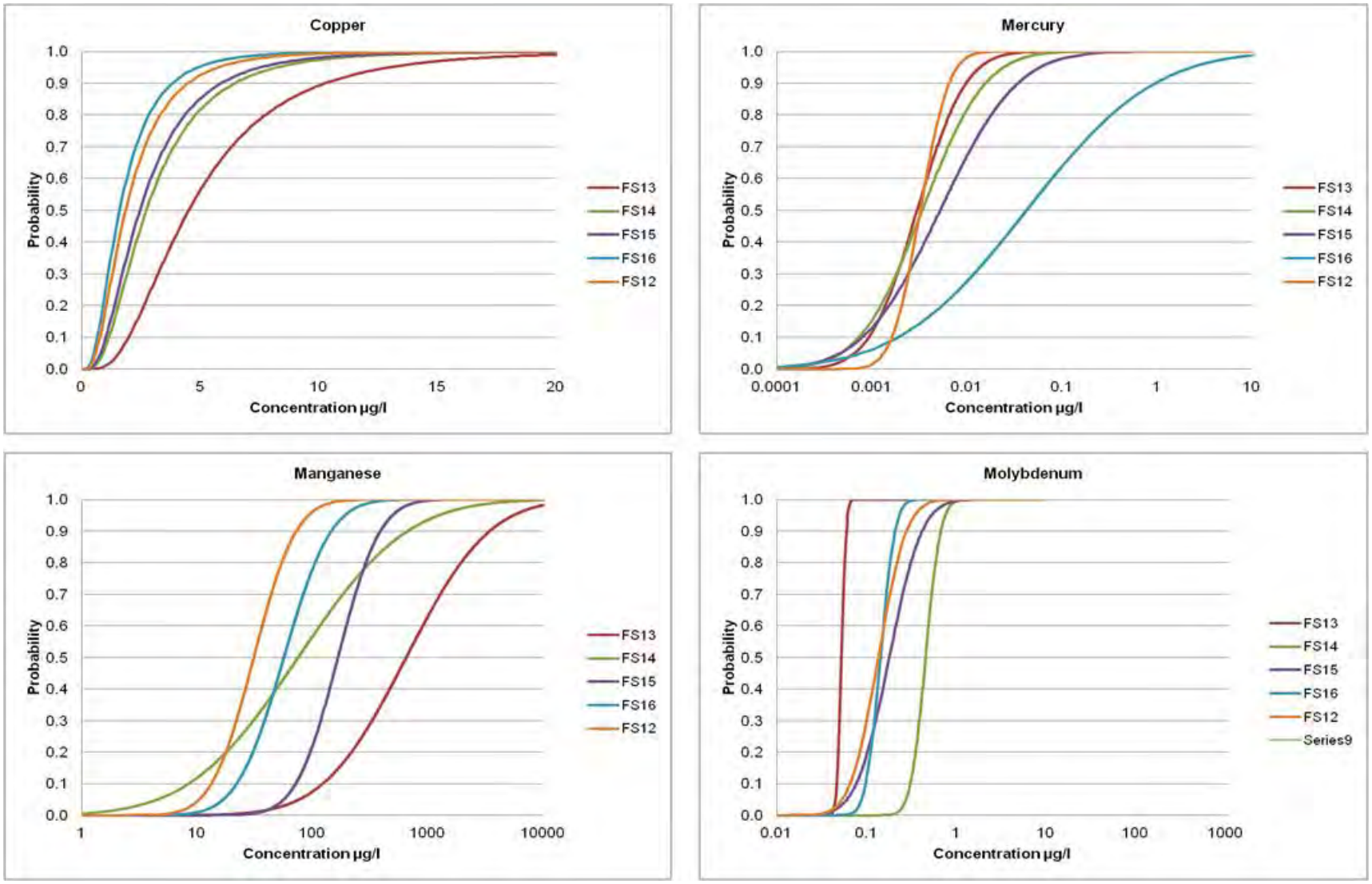
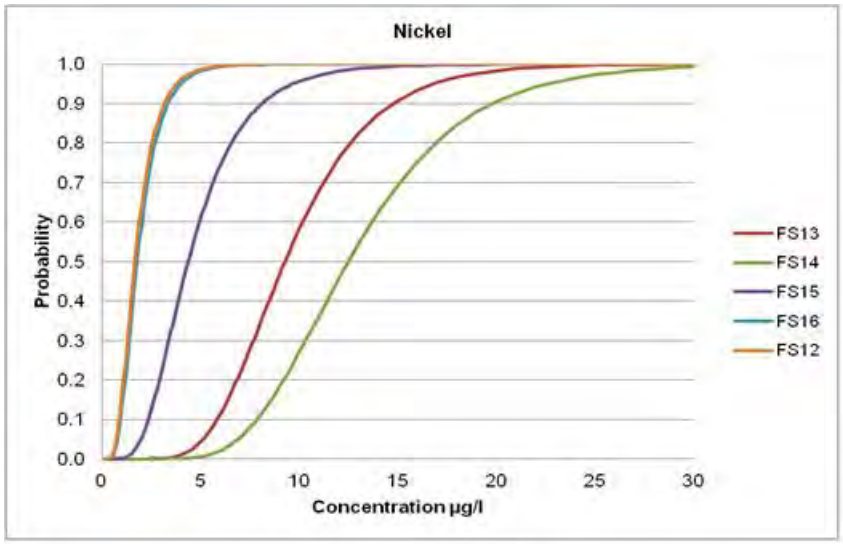
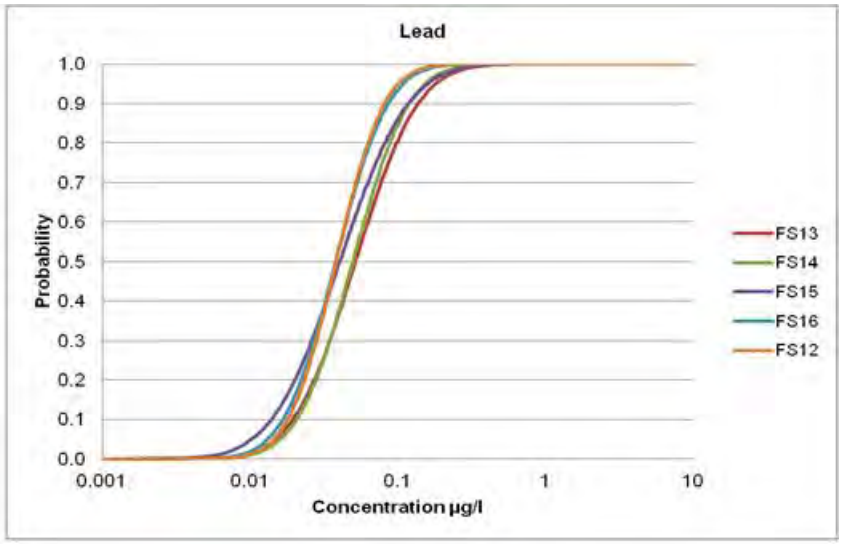
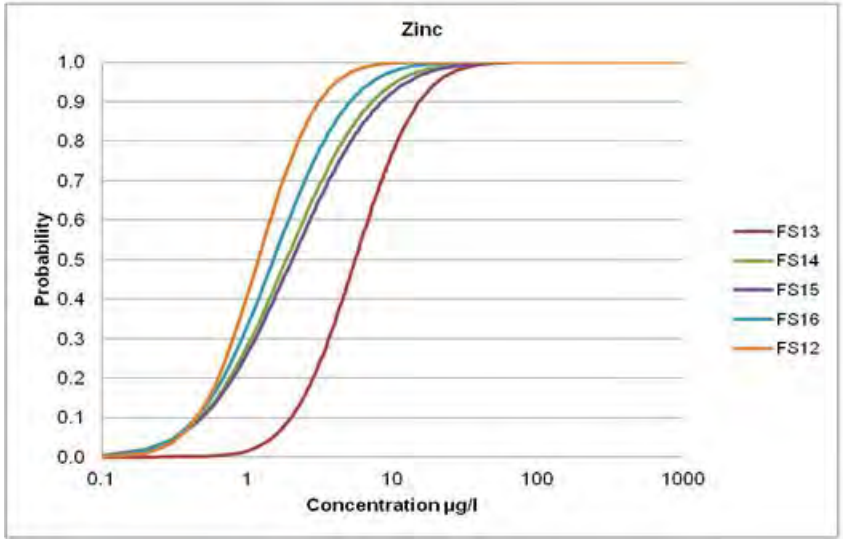


Figure 6-11 cont.: Baseline water quality data for the Niesajoki River, fitted to log-normal distributions







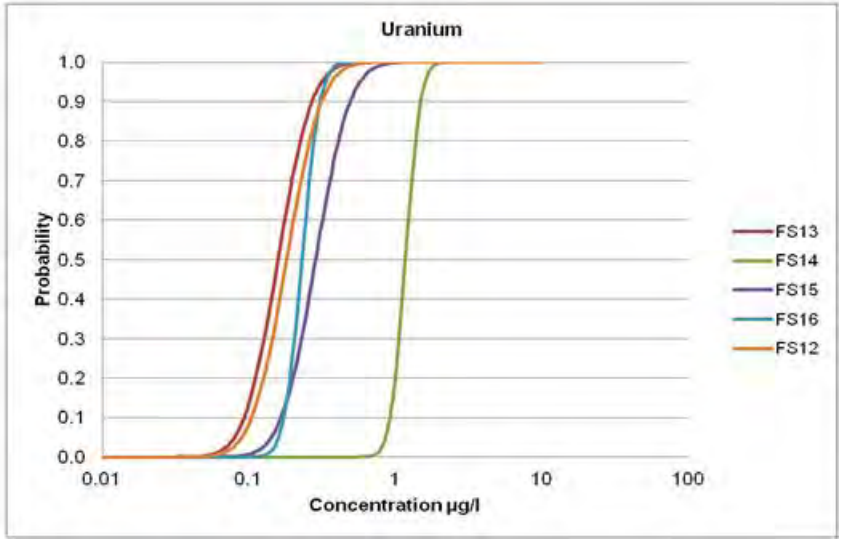


Figure 6-11 cont.: Baseline water quality data for the Niesajoki River, fitted to log-normal distributions

An important question to be addressed when considering the water quality of the Niesajoki River is what proportion of the total loadings at the mouth of the river are produced due to runoff and seepage from the existing Rautavaara TMF. An assessment of the loadings from this facility is important so that the impact of any changes to the facility on water quality in the Niesajoki can be assessed later in this report.

A simple load balance calculation was undertaken (Table 6-29), where the median concentrations at FS15 and FS12 were multiplied by the average annual flow at these water quality sampling locations (calculated based on flow estimation methods outlined in Section 5.2.2). These calculations give a crude approximation of the total annual load (kg) of each parameter at each sampling station. These loadings were then expressed as a percentage of the load at FS12 (mouth of Niesajoki). The percentage calculated for FS15, which is the most upstream sampling site and is located just downstream of the existing Rautuvaara TMF, provides an indication of the percentage loading from the TMF.

The catchment area at FS15 is 54% of the catchment at the mouth of the Niesajoki (FS12). Hence, if concentrations of a parameter were the same throughout the Niesajoki River catchment, the percentage loading at FS15 should also be 54% those observed at FS12, in proportion to the catchment area.

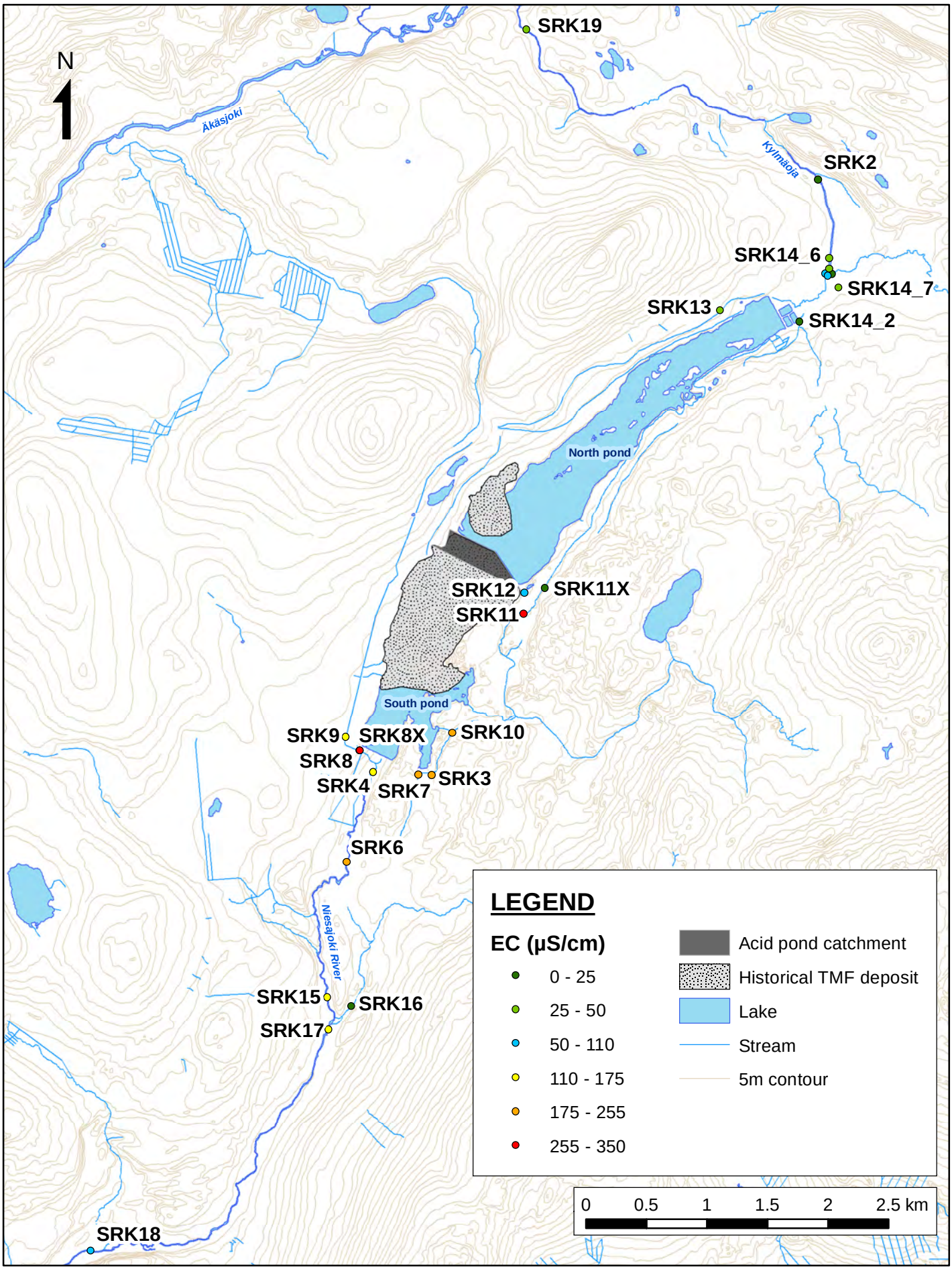
The calculations outlined in Table 6-29 have a high degree of uncertainty as loadings will vary over time in response to flow conditions and the relative loading from the TMF will also vary during the year. Hence, the actual numbers in Table 6-29 should not be taken as accurate (for some parameters the percentage values were >100% for example); however, they do separate the parameters into three main groupings:

- For ammonia, nitrite, nitrate, chloride, sulphate, manganese and nickel the results suggest that all of the loading at FS12 could be sourced from the existing TMF. In reality the TMF will not produce all of the loadings; however, the analysis suggests that concentrations of these parameters at FS12 are dominated by the effect of runoff and seepage from the TMF;
- For copper, uranium and zinc the results suggest that around 65 – 87% of the total loading at the mouth of the Niesajoki River is sourced from the existing TMF. For these parameters the calculations would suggest that the TMF is a major source of loading; and
- For other parameters, e.g. iron, aluminium, cadmium, cobalt, mercury, chromium, molybdenum and lead the percentage sourced from the existing TMF is consistent with what would be expected if concentrations were equal throughout the catchment (i.e., around 54%). This would suggest that, for these parameters, the TMF is not a key source of loadings at the mouth of the river. It is noted that these results are not consistent with analyses undertaken for the Kylmäoja Stream (Section 6.3.5), which identified elevated concentrations of cadmium, mercury and cobalt (amongst others) assumed to be sourced from seepage from the North Pond of the existing TMF. This discrepancy could reflect uncertainties and errors in the methodology used in this section; however, it may also reflect differences in concentrations in the North and South Pond, as shown in Table 6-27, where concentrations of these parameters are seen to be elevated in the North Pond (FS13) compared to the South Pond (FS14).

More detailed analyses of the water quality data could identify different trends; however, as there are limited water quality samples within any year (typically five) it is unlikely that there is sufficient data to develop a more complex conceptual model.

Further confirmation of the importance of loadings from the existing TMF is produced through analysis of data collected in October 2012. Northland staff (A.Haaparanta) undertook a spot survey of stream conductivity along the Niesajoki in October 2012. Conductivity is a surrogate for Total Dissolved Solids (TDS), which are expected to be elevated in the existing TMF (i.e., as shown by high sulphate concentrations at FS13 which is a major component of TDS). Sampling was undertaken in October as it is a period of low surface water runoff, such that flows in the stream are expected to be supported by groundwater (including seepage from the existing TMF), with limited dilution from surface water runoff. Conductivity measurements are summarised in Figure 6-12 and they indicate that the highest conductivity values are observed close to the existing TMF. It should be noted that it is difficult to compare conductivity measurements undertaken during October 2012 with values in the baseline water quality data set as values are dependent on the calibration of the conductivity probe used in any site survey.

Simple load balance calculations were undertaken based on flow surveys carried out by Northland staff at the time of the conductivity measurements, augmented by data from the stream flow monitoring stations. Results are presented in Table 6-30. The results are consistent with the more detailed load balance work in Table 6-29 that around 100% of the loadings at the mouth of the Niesajoki appear to be sourced from the existing TMF.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Results of Conductivity Survey Undertaken by Northland in October 2012	Figure 6.12

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Table 6-29: Simple load balance for Niesajoki River

Station	Annual average flow (L/s)	Median observed concentration (mg/L)									
		Ammonia	Nitrite	Nitrate	Chloride	Sulphate	Iron	Aluminium	Arsenic	Cadmium	Cobalt
FS15	327	18.5	12	177	2.3	71.1	0.671	18.6	0.5	0.0053	2
FS12	610	3.06	3.5	88.8	1.35	25.3	0.659	32.8	0.5	0.0068	2
Annual Loading (kg); Concentration x Annual average flow											
FS15	327	191,000	124,000	1,820,000	23,700	734,000	6,920	192,000	5,160	54.7	20,600
FS12	610	58,900	67,300	1,710,000	25,900	487,000	12,700	632,000	9,620	131	38,500
Loading as percentage of total at FS12 (mouth of Niesajoki)											
FS15	327	[a]>100%	[a]>100%	[a]>100%	[a]>100%	[a]>100%	55%	30%	54%	42%	54%
FS12	610	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

a Parameters where around 100% of the loadings appear to come from the existing TMF. Note some values >100% due to uncertainties in calculation method, see text for details. Catchment at FS15 is 54% of catchment at FS12

Station	Annual average flow (L/s)	Median observed concentration (mg/L)								
		Chromium	Copper	Mercury	Manganese	Molybdenum	Nickel	Lead	Zinc	Uranium
FS15	327	0.25	2.09	0.0023	166	0.161	4.6	0.0416	1.5	0.3
FS12	610	0.328	1.5	0.0037	33.5	0.16	1.5	0.0382	1.24	0.184
Annual Loading (kg); Concentration x Annual average flow										
FS15	327	2580	21500	23.7	1710000	1660	47500	429	15500	3090
FS12	610	6320	28900	71.2	644000	3080	28900	735	23800	3540
Loading as percentage of total at FS12 (mouth of Niesajoki)										
FS15	327	41%	75%	33%	[a]>100%	54%	[a]>100%	58%	65%	87%
FS12	610	100%	100%	100%	100%	100%	100%	100%	100%	100%

a Parameters where around 100% of the loadings appear to come from the existing TMF. Note some values >100% due to uncertainties in calculation method, see text for details. Catchment at FS15 is 54% of catchment at FS12

Table 6-30: Load balance based on Northland site survey in October 2012

Eastern side of Niesa Basin	Description	Conductivity (mS/m)	Flow (m^3/s)	[a]Surrogate for Loading (mSm^3/m)	Percentage of total load at SRK18 (%)
SRK11	Outflow North Pond	35.1	0.23	8.2	98.5
SRK10	Western bypass channel	25.6	0.27	6.9	83.4
SRK7	Outflow South Pond (spillway)	25.5	0.30	7.6	92.2
Western side of Niesa Basin					
SRK9	North-western bypass channel	17.5	0.02	0.3	3.8
SRK8	Downstream Niesa Basin	9.6	0.05	0.5	5.9
SRK8X	South Pond outflow	29.7	0.01	0.2	2.9
Downstream of Niesa Basin					
SRK6	Downstream of Niesa Basin, main channel Niesajoki	25.7	0.37	0.9	>100.0
SRK15	Main channel Niesajoki	16.7	0.44	7.4	88.8
SRK16	Tributary	2.2	0.12	0.3	3.2
SRK17	Main channel Niesajoki	13.4	0.56	7.5	90.4
SRK18	Main channel Niesajoki	11.0	0.75	8.3	100.0

a Calculated as Conductivity x Flow. This is a representation of a loading (i.e., kg), but units are mSm^3/m. Conductivity would need to be converted to kg/L to provide a true loading. But the value in this column is sufficient for requirements.
Row highlighted in orange is equivalent to sampling station FS15 in Table 6-13

6.3.5 Kylmäoja Stream

Catchments and General Flow Pathways

The Kylmäoja Stream is a tributary of the Äkäsjoki River, with a catchment area of 38.8 km^2 at its confluence with the Äkäsjoki. It is sometimes also referred to as the Kylmämaanoja Rivulet (Northland, 2011a), Photo 6-5.



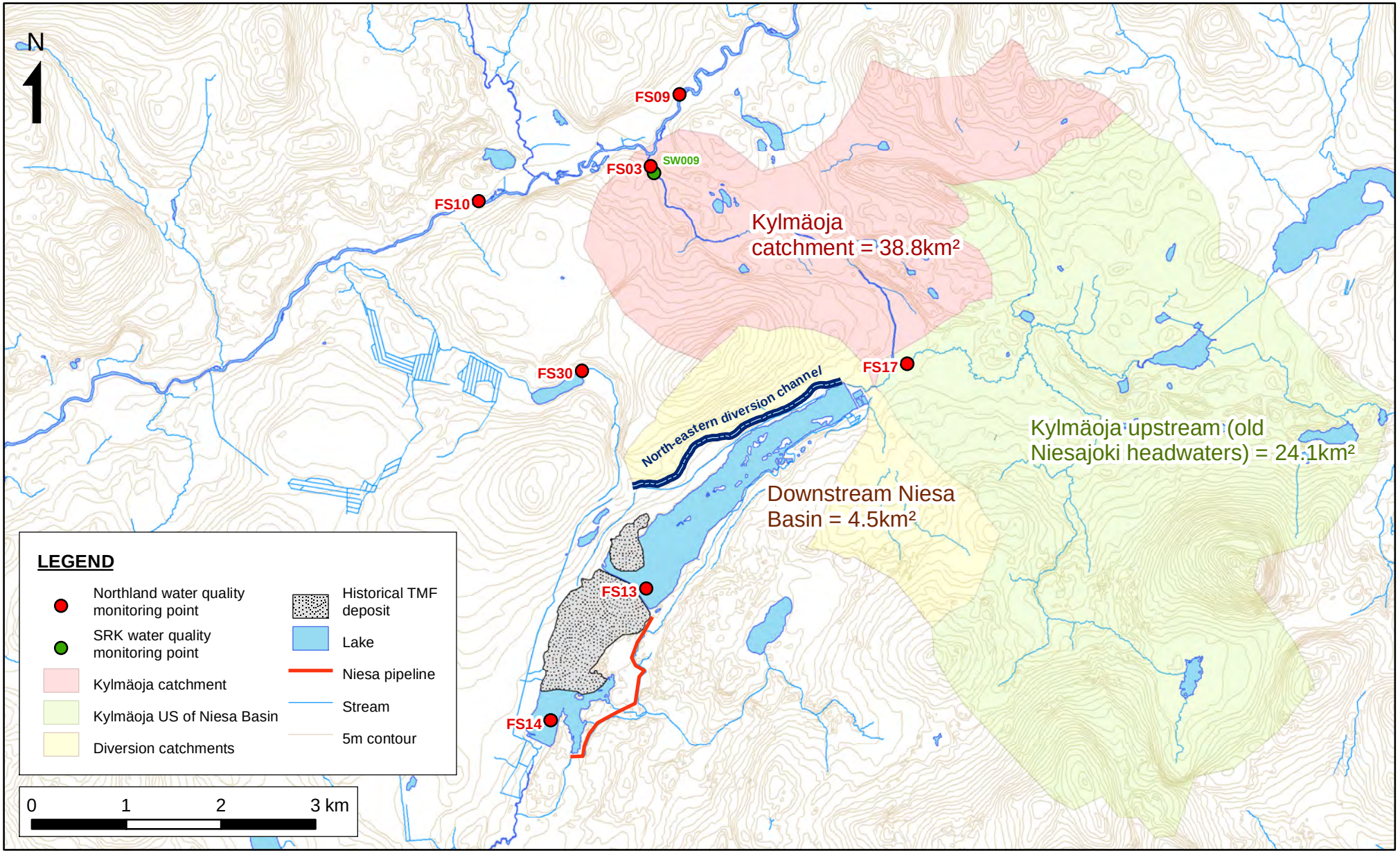
Photo 6-5: Kylmäoja Stream near to borehole RAU12HYD14 (SRK 10/06/2012)

The natural catchment of the Kylmäoja is significantly smaller than the present day catchment. The current headwaters of the Kylmäoja used to flow to the Niesa Basin and lie within the catchment of the Niesajoki River (

Figure 6-13). However, with the development of the Niesa Basin as a tailings storage facility the headwaters of the Niesajoki were diverted to the Kylmäoja through the construction of a cut-off ditch. This man-made channel now provides a flow path for runoff from the former headwaters of the Niesajoki River to flow to the Kylmäoja Stream and into the Äkäsjoki River.

At its confluence with the Kylmäoja the Äkäsjoki River has a catchment area of approximately 520 km^2, such that the Kylmäoja Stream is 7% of the size of the Äkäsjoki.

There are no surface water discharges from the Niesa Basin to the Kylmäoja Stream catchment, although there is seepage from the North Pond to the Kylmäoja Stream as outlined in Section 9.1.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Key Catchments Along Kylmäoja Stream	Figure 6.13

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Surface Water Flows

The average annual runoff total for the Kylmäoja is estimated to be approximately 250 mm, based on regional analysis of gauged flow data, Appendix C. Monthly average flow estimates for the Kylmäoja are provided in Table 6-31, with estimated monthly return period flows summarised in Table 6-32.

Low flow estimates for the Kylmäoja stream at its mouth are shown in Table 6-33.

One hydrological monitoring station was installed near the mouth of the Kylmäoja stream at the end of June 2012 (RAUSW004). Water levels recorded at the gauged site have been converted to flows using rating curves developed based on spot flow measurements obtained by Northland staff. Details of the spot flow measurements and rating curves are provided in Appendix B.

Average monthly flows for the period July to October were calculated and compared to monthly flows for an average year, calculated using the results of the regional hydrological analysis outlined in Appendix C. Results are presented in Table 6-34.

Table 6-31: Average monthly runoff and flow rates for the Kylmäoja

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	6.7	5.0	4.9	10.3	81.6	37.6	19.3	18.3	18.9	21.8	16.3	9.7
Average flow (m^3/s)	0.11	0.083	0.081	0.17	1.3	0.62	0.32	0.3	0.31	0.36	0.27	0.16

Table 6-32: Predicted return period average monthly flows for the Kylmäoja

				Average Monthly Flow (m^3/s)								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.046	0.041	0.040	0.043	0.56	0.21	0.096	0.068	0.082	0.11	0.071	0.061
1 in 50 DRY	0.051	0.044	0.043	0.050	0.61	0.23	0.11	0.080	0.095	0.12	0.082	0.068
1 in 10 DRY	0.066	0.054	0.053	0.076	0.79	0.32	0.16	0.13	0.14	0.18	0.12	0.09
Average	0.11	0.083	0.081	0.17	1.3	0.62	0.32	0.3	0.31	0.36	0.27	0.16
1 in 10 WET	0.15	0.10	0.10	0.31	1.88	0.98	0.53	0.59	0.56	0.60	0.49	0.23
1 in 50 WET	0.20	0.13	0.12	0.47	2.44	1.37	0.76	0.93	0.84	0.86	0.73	0.31
1 in 100 WET	0.22	0.14	0.13	0.55	2.68	1.54	0.86	0.99	0.97	0.98	0.85	0.35

Table 6-33: 7-day low flow and 7-day Q_{10} estimates for the Kylmäoja Stream

	Kylmäoja
7-day annual average low flow (L/s)	33
7-day Jul-Sep average low flow (L/s)	19
7-day annual average Q_{10} flow (L/s)	11
7-day Jul-Sep average Q_{10} flow (L/s)	14

Table 6-34: Observed flows at hydrology station RAUSW004 on Kylmäoja Stream

Site	Parameter	July	August	September	October	Average (July to September)
RAUSW004	Observed flow (m^3/s)	0.75	0.46	0.69	0.94	0.71
	Estimated average flow (m^3/s)	0.32	0.30	0.31	0.36	0.32
	Percentage of average	236%	153%	222%	261%	220%

The observed flows are significantly higher (around 200%) than the regional flow estimates. The observed flow data would appear to suggest that regional flow estimates for Kylmäoja stream are significantly under-estimated.

Hence, it would appear that flows in the Kylmäoja during the observed period were significantly higher than would be predicted using the regional hydrological approach developed in Appendix C. One reason for this might be the presence of large areas of wet ground adjacent to the man-made diversion channel constructed to divert the headwaters of the Niesajoki to the Kylmäoja during construction of the existing Rautuvaara TMF. The stream in this area upstream of the diversion and near the Rautuvaara TMF has a low gradient, as it did not originally slope to the north. As a result, there are large areas of low-lying ground, which was very waterlogged during a site visit to the area in June 2012.

It is possible that this area acts to retain and store snowmelt during early summer, releasing the water during the later summer months. This would tend to reduce spring runoff rates, but increase those later in the year. There is insufficient observed data to test this hypothesis (i.e., no early summer stream flows), but it will be able to be assessed in 2013 once a full years worth of flow data is available. Once additional data is obtained the average stream flow estimates for Kylmäoja will need to be re-assessed.

However, as outlined in Section 6.3.4, the observed data needs to be viewed with caution as the rating curve is based on a limited number of spot flow measurements, resulting in a high degree of uncertainty associated with the estimation of flows based on the rating curve. Regional flow data is contradictory as to whether 2012 was a wet or dry year (Section 5.1.1). Based on return period monthly flow estimates the observed flow data at Kylmäoja would suggest 2012 was a 1 in 50 wet year, which would suggest very wet conditions.

Given the short period of the RAUSW004 flow record the effects assessment was undertaken using the flow estimates based on regional flow data. In addition, as the regional flow estimates are lower than the observed data, undertaking an effects assessment considering lower flows is considered to be more conservative, as less dilution with natural runoff will be considered in water quality calculations.

Water Quality

Median and maximum concentrations for 'Key' and 'Other' parameters at two water quality monitoring stations on the Kylmäoja Stream (FS17 and FS03) are provided in Table 6-35 and Table 6-36 respectively. The locations of the sampling stations are shown in

Figure 6-13.

As outlined in the previous section the headwaters of the Kylmäoja Stream originally flowed to the Niesajoki River and were diverted to the Kylmäoja following construction of the existing Rautuvaara TMF. There are no surface water discharges from the existing TMF to the Kylmäoja; however, there may be seepage from the facility to the stream.

Sampling station FS17 lies within the headwaters of the stream, upstream of the existing Rautuvaara TMF, while FS03 is located at the mouth of the stream close to the confluence with the Äkäsjoki River. Äkäsjoki sampling station FS09 lies just upstream of the confluence with the Kylmäoja, and data for this site was provided in Table 6-8.

Baseline median and maximum concentrations are shown in Table 6-35 and Table 6-36. WQOs were developed for site FS03 only and the baseline data are compared to TVs and AVs in the baseline water quality tables.

The results illustrate that median concentrations at FS03 for many parameters are higher than concentrations at FS17 or FS09, which may suggest some influence of seepage from the Rautuvaara TMF. Median nitrate concentrations at FS03 are five times higher than median concentrations at FS17; sulphate concentrations are double; cobalt and manganese three times; and nickel double. Mercury and cadmium concentrations at FS03 are also significantly higher than values at FS17, although analysis of these parameters is impacted by the detection limits of water quality samples. Geo-chemical modelling (refer to Section 8.1.3), predicts that the elevated parameters are typical of runoff from the historical tailings. Furthermore, observed sulphate, cobalt and manganese concentrations are predicted to exceed AV concentrations in the North Pond of the existing TMF (Table 6-27). Copper also exceeds AVs in the North Pond; and maximum concentrations at FS03 are also significantly elevated, although median concentrations are only 40% above median values at FS17.

Northland staff (A.Haaparanta) undertook a spot survey of stream conductivity along the Kylmäoja Stream in October 2012. Conductivity is a surrogate for TDS, which is expected to elevated in the existing TMF (i.e., as shown by high sulphate concentrations which is a major component of TDS). Sampling was undertaken in October as it is a period of low surface water runoff, such that flows in the stream are expected to be supported by groundwater (including seepage from the existing TMF), with limited dilution from surface water runoff.

Conductivity measurements are summarised in Figure 6-12 and they indicate that the highest conductivity values are observed close to the existing TMF. Conductivity at site SRK-06 (highlighted in yellow in Figure 6-12) was measured as 86 µS/cm, compared to values of 28.6 and 12.8 µS/cm for sites SRK13 and SRK14 which measure runoff from catchments upslope and unaffected by the existing TMF. These data appear to confirm the presence of seepage from the TMF impacting water quality in the Kylmäoja Stream. It should be noted that it is difficult to compare conductivity measurements undertaken during October 2012 with values in the baseline water quality data set as values are dependent on the calibration of the conductivity probe used in any site survey.

Comparing the observed water quality within the Kylmäoja Stream at FS03 to WQOs indicates that no parameters are predicted to exceed AVs in the baseline data set. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80th percentile of observed data).

Table 6-35: Water quality concentrations for key parameters at sampling sites within Kylmäoja

Parameter	Unit	WQO – FS03		FS03		FS17	
		TV	AV	Median	Max	Median	Max
Suspended solids	mg/l	4.4	25	1.4	20	1.1	17
Ammonium	mg/l	0.017	1	0.0035	0.057	0.0031	0.034
Nitrite	mg/l	0.004	0.01	0.0010[b]	0.0050[b]	0.0020[b]	0.0050[b]
Nitrate	mg/l	0.077	20	0.013	0.14	0.0065	0.058
Chloride	mg/l	1	150	0.79	1.4	0.65	9.0
Sulphate	mg/l	6.8	65	4.4	8.6	2.3	5.1
Iron	mg/l	0.59	2.6	0.44	2.1	0.53	1.9
Aluminium	mg/l	0.049	0.1	0.022	0.086	0.026	0.060
Arsenic	mg/l	0.0001	0.005	0.000061	0.00013	0.000072	0.011
Cadmium	mg/l	3E-06	0.00008	0.0000025[b]	0.0000069[b]	0.0000031[b]	0.0010[b]
Cobalt	mg/l	0.00031	0.004	0.00019	0.00076	0.000058	0.0040
Chromium (III)	mg/l	0.00034	0.001	0.00027	0.00039	0.00028	0.0030
Copper	mg/l	0.00052	0.005	0.00042	0.0008	0.00034	0.010
Mercury	mg/l	1.4E-06	0.00005	0.000001[b]	0.0000039[b]	0.0000020	0.000098
Manganese	mg/l	0.032	0.7	0.024	0.15	0.0089	0.031
Molybdenum	mg/l	0.00024	1	0.00019	0.00028	0.00019	0.00076
Nickel	mg/l	0.00069	0.02	0.00048	0.0031	0.00021	0.0092
Lead	mg/l	5.7E-05	0.0072	0.000039	0.00013	0.000052	0.0040
Uranium	mg/l	9.1E-05	0.015	0.000065	0.00013	0.000071	0.000078
Zinc	mg/l	0.0016	0.03	0.00034	0.0027	0.00072	0.040

a TVs and AVs for Äkäsjoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit

Table 6-36: Water quality concentrations for other parameters at sampling sites within Kylmäoja

Parameter	Unit	WQO – FS03		FS03		FS17	
		[a]TV	[a]AV	Median	Max	Median	Max
pH			<6 or >9	6.7	7.0	6.7	7.0
Electrical Conductivity	mS/m	5.6	10	4.2	6.7	3.0	5.2
Phosphate	mg/l	0.01	0.026	0.008	0.021	0.0065	0.019
TOC	mg/l	8.1	16	4.7	10	5.8	9.0
Calcium	mg/l	5.8	17	4.4	13	2.9	5.4
Potassium	mg/l	0.88	2.1	0.64	1.6	0.40	0.73
Magnesium	mg/l	1.5	4.3	1.2	3.3	0.75	1.3
Sodium	mg/l	2.3	8.1	2	6.8	1.7	2.3
Sulphur	mg/l	2.7	4.8	1.7	3.1	0.84	1.8
Silicon	mg/l	6.6	12	5	8.1	4.2	8.6
Barium	mg/l	0.014	0.022	0.012	0.016	0.0081	0.011
Strontium	mg/l	0.02	0.035	0.017	0.023	0.014	0.019
Antimony	mg/l	1.4E-05	2.4E-05	0.000011	0.000015	0.000016	0.0050

a TVs and AVs for Äkäsjoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

6.3.6 Muonionjoki River

Catchments and General Flow Pathways

The headwaters of the Muonionjoki are in the highlands of the Enontekiö region of Lapland from where it flows south along the Finnish-Swedish boarder towards Kolari. The river joins the Tornionjoki approximately 20 km south of Kolari and continues as Tornionjoki along the border towards the Gulf of Bothnia.

The Äkäsjoki and Niesajoki rivers join the Muonionjoki some 15 km to the west of the mine site. At the confluence with the Niesajoki the Muonionjoki has a catchment area of around 14,500 km^2, Photo 6-6.



Photo 6-6: Muonionjoki River near to Kolari (SRK 10/05/2011)

Surface Water Flows

The Muonionjoki is gauged at Kallio, which has a long period of record (see Section 5.2.1). Data from the gauge were analysed (refer to Appendix C) to produce estimates of key hydrological parameters for the Muonionjoki close to the study area.

Average annual runoff total for the Muonionjoki is 360 mm, based on observed flow data at Kallio gauging station. Monthly average flow estimates for the Muonionjoki are provided in Table 6-37 and estimated monthly return period flows are summarised in Table 6-38.

Low flow estimates for the Muonionjoki are shown in Table 6-39.

Table 6-37: Average monthly runoff and flow rates for the Muonionjoki

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	7.8	6.9	6.5	9.9	86.4	89.3	41.9	31.9	31.3	25.7	14.2	9.6
Average flow (m^3/s)	42.1	37.5	34.9	53.6	467	483	226	172	169	139	77	52

Table 6-38: Predicted return period average monthly flows for the Muonionjoki at Kallio gauge

				Average Monthly Flow (m^3/s)								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	4.3	4.1	3.8	2.6	33.7	33.4	16.0	9.8	10.1	9.1	5.2	4.6
1 in 50 DRY	4.6	4.4	4.1	3.0	37.3	37.1	17.8	11.1	11.4	10.2	5.8	5.0
1 in 10 DRY	5.6	5.1	4.8	4.4	50.0	50.2	23.9	15.9	16.1	14.0	7.8	6.2
Average	7.6	6.8	6.3	8.5	80.9	83.0	38.9	28.6	28.3	23.7	13.0	9.2
1 in 10 WET	10.3	9.0	8.3	16.3	131.2	137.1	63.5	51.4	49.8	40.1	21.7	13.5
1 in 50 WET	12.3	10.6	9.8	24.2	175.4	185.5	85.3	73.3	70.1	55.0	29.5	17.0
1 in 100 WET	13.2	11.2	10.4	27.8	194.4	206.4	94.6	83.1	79.1	61.6	32.9	18.4

Table 6-39: 7-day low flow and 7-day Q_{10} estimates for the Muonionjoki

	Muonionjoki River
7-day annual average low flow (m^3/s)	32.6
7-day Jul-Sep average low flow (m^3/s)	45.9
7-day annual average Q_{10} flow (m^3/s)	24.3
7-day Jul-Sep average Q_{10} flow (m^3/s)	30.6

Water Quality

Median and maximum concentrations at two baseline water quality monitoring stations (FS23 and FS24) on the Muonionjoki River are shown in Table 6-40 and Table 6-41 respectively. Concentrations at FS23 are compared to WQOs developed for the Muonionjoki River at this site. Water quality sampling station FS23 is located upstream of the confluence of Niesajoki with Muonionjoki, while station FS24 is located downstream of the confluence.

No parameters are predicted to exceed AVs in the baseline data set. All maximum concentrations are predicted to exceed TVs as would be expected (as TVs are defined as 80th percentile of observed data).

There is no clear trend showing median concentrations in Muonionjoki increasing from FS23 to FS24 due to loadings from Niesajoki River, i.e., due to impact of loadings from existing TMF impacting water quality in Muonionjoki. This likely reflects the size of the Muonionjoki River compared to the Niesajoki, with the Muonionjoki draining a catchment of around 14,500 km^2, compared to 70 km^2 for the Niesajoki.

Overall the quality of water in the Muonionjoki is very good and as would be expected for a large river flowing through predominantly undeveloped wilderness.

Table 6-40: Water quality concentrations for key parameters at sampling sites within Muonionjoki

Parameter	Unit	WQO – FS23		FS23		FS24	
		[a]TV	[a]AV	Median	Max	Median	Max
Suspended solids	mg/l	3.9	25	1.6	10	1.8	12
Ammonium	mg/l	0.0093	1	0.0036	0.046	0.0075	0.025
Nitrite	mg/l	0.0019	0.01	0.001[b]	0.005[b]	0.0050[b]	0.0050[b]
Nitrate	mg/l	0.07	20	0.0051	0.085	0.032	0.24
Chloride	mg/l	0.91	150	0.79	2.3	0.80	1.5
Sulphate	mg/l	3.8	65	2.6	4.6	2.6	7.9
Iron	mg/l	0.55	1.9	0.40	1.6	0.47	1.7
Aluminium	mg/l	0.057	0.1	0.021	0.083	0.023	0.083
Arsenic	mg/l	0.000073	0.005	0.000058[b]	0.000090[b]	0.000061[b]	0.00013[b]
Cadmium	mg/l	0.0000066	0.00008	0.0000025[b]	0.000020[b]	0.0000063[b]	0.0000066[b]
Cobalt	mg/l	0.000097	0.004	0.000031	0.00024	0.000054[b]	0.00027[b]
Chromium III	mg/l	0.00033	0.001	0.00024	0.00055	0.00021	0.00039
Copper	mg/l	0.00046	0.005	0.00037	0.00082	0.00033	0.00080
Mercury	mg/l	0.0000039	0.00005	0.0000012[b]	0.000098[b]	0.000016	0.00029
Manganese	mg/l	0.018	0.7	0.0067	0.045	0.0088[b]	0.080[b]
Molybdenum	mg/l	0.00025	1	0.00024	0.00033	0.00023	0.00031
Nickel	mg/l	0.00032	0.02	0.00025	0.00072	0.00022	0.0014
Lead	mg/l	0.00006	0.0072	0.000040	0.00031	0.000030	0.00011
Uranium	mg/l	0.00009	0.015	0.000085	0.000093	0.000079	0.000091
Zinc	mg/l	0.0017	0.03	0.00096	0.0022	0.00094	0.0068

a TVs and AVs for Muonionjoki River
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit

Table 6-41: Water quality concentrations for other parameters at sampling sites within Muonionjoki

Parameter	Unit	WQO		FS23		FS24	
		[a]TV	[a]AV	Median	Max	Median	Max
pH			<6 or >9	6.9	7.5	6.9	7.3
Electrical Conductivity	mS/m	4.6	8.4	3.2	5.9	3.1	10
Phosphate	mg/l	0.0051	0.017	0.0030	0.012	0.0040	0.013
TOC	mg/l	6.9	13	5.1	9.0	4.8	8.7
Calcium	mg/l	4.7	8.9	3.5	6.3	3.4	6.7
Potassium	mg/l	0.81	1.9	0.63	1.6	0.62	1.0
Magnesium	mg/l	1.3	2.4	0.90	1.7	0.96	1.9
Sodium	mg/l	1.9	3.4	1.4	2.5	1.3	2.6
Sulphur	mg/l	1.6	2.7	1.1	1.8	0.85	1.7
Silicon	mg/l	5.4	10	3.2	7.3	2.9	7.1
Barium	mg/l	0.0096	0.015	0.0069	0.011	0.0066	0.012
Strontium	mg/l	0.022	0.043	0.016	0.029	0.016	0.033
Antimony	mg/l	0.000012	0.00015	0.000005[b]	0.00015[b]	0.000011[b]	0.000011[b]

a TVs and AVs for Muonionjoki River

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the data for the parameter are below detection limit

6.3.7 Other Streams and Ditches

Catchments and General Flow Pathways

It is recognised that the mine development will substantially alter a number of small streams lying within the footprint of the mine site, i.e. Kivivuopionoja Ditch. Sections of stream will be removed following development of the open pits, covered by waste rock and diverted around mining infrastructure. Impacts on these small streams are not quantified in this report as it is clear that mine development will significantly alter or remove flows in these streams. Within the mine site there are also old pit lakes (Laurinoja and Kuervaara) that will be emptied of water prior to mining.

Table 6-42 summarises the flow data collected by SRK in May 2011. Locations are shown on Figure 5-3 and an example is provided in Photo 6-7.



Photo 6-7: Kivivuopionoja Ditch (SRK 09/05/2011)

Table 6-42: Baseline stream flow measurements for ditches and streams measured by SRK in May 2011

Station	Date	River/Stream	Latitude	Longitude	Q (m^3/s)
SW003	11 May 2011	Lamunjänkä	2496506	7496255	0.089
SW005	9 May 2011	Kivivuopionoja	2496370	7495266	0.082
SW010	10 May 2011	Laurinoja	2498923	7495597	0.144
SW026	9 May 2011	Laulukarhakanoja	2499097	7501142	0.177
SW028	9 May 2011	Local Stream	2499014	7501168	0.009
SW029	9 May 2011	Laulukarhakanoja	2496704	7501625	0.104
SW030	9 May 2011	Laulukarhakanoja	2497629	7501384	0.101

6.3.8 Wetlands and Springs

Wetlands

The Saivojärvi wetland nature reserve is located adjacent to the Valkeajoki and Äkäsjoki rivers, but downstream of the confluence between the two rivers (Figure 6-14). The wetland will not be impacted by direct runoff from the mine development as the mine site is located on the opposite bank of the Valkeajoki to the wetland. However, there are likely to be hydrological connections between the Valkeajoki and Äkäsjoki and the Saivojärvi wetland. In the absence of information on the hydrological connections between the rivers and wetlands, the impact of the development on Saivojärvi will be assessed based on predicted changes to

water levels in adjacent streams, assuming an influence of river levels on water levels in the wetlands.

Surface mapping has identified wetland areas covering approximately 16% of the land area between the Valkeajoki, Kuerjoki, Äkäsjoki and the northern extent of the mine facilities, approximately 24% of the Niesajoki catchment and approximately 43% of the Kylmäoja Stream catchment.

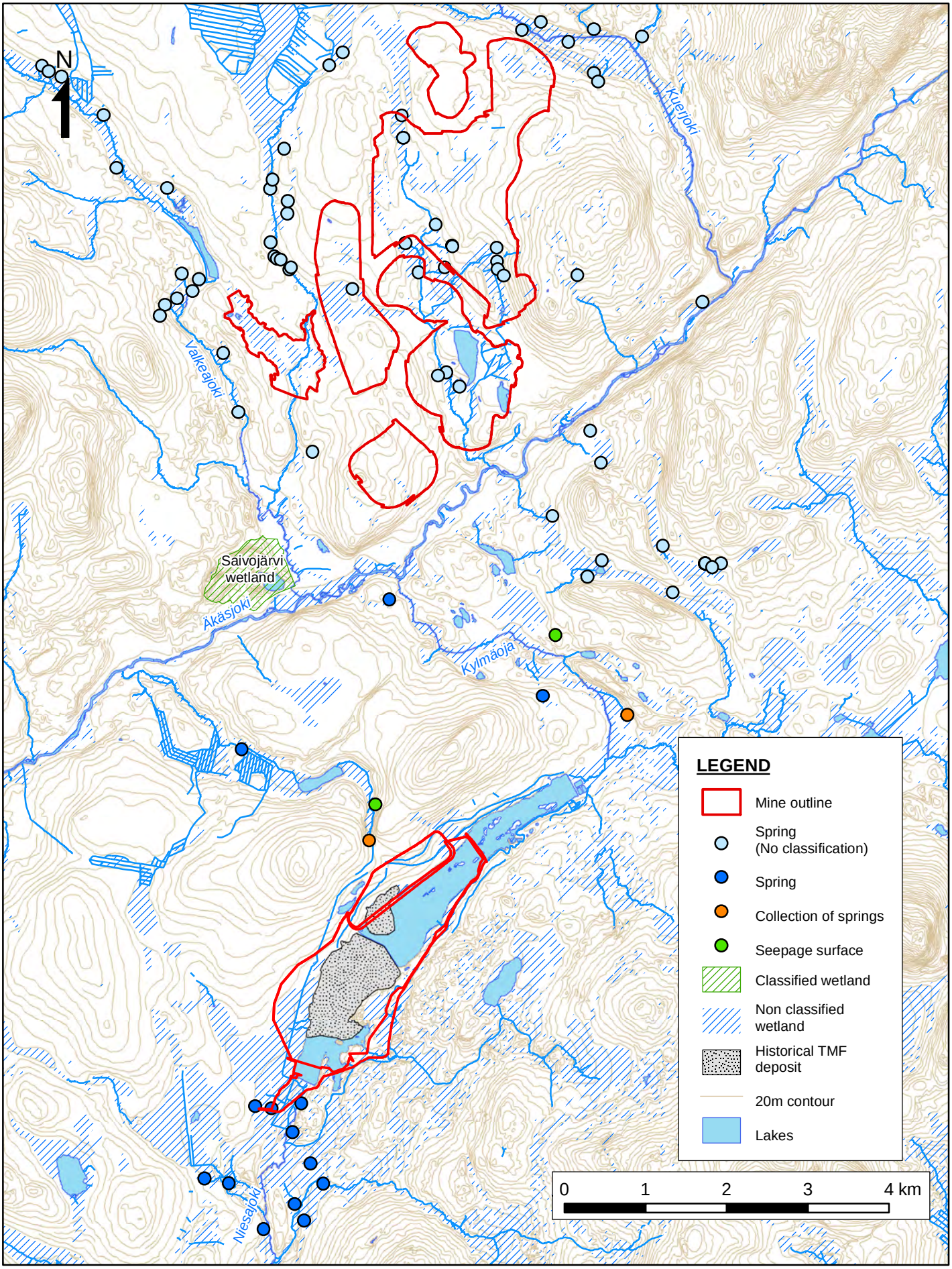
Springs

Surface water mapping also identified 96 groundwater springs in the Project area; 63 in the Hannukainen area, north of the Äkäsjoki River, 12 in the Niesajoki catchment and 11 in the Kylmäoja Stream catchments (LVT, 2008). The study distinguished the features as:

- 'Spring' (Lähde) – Single point of emergence from where groundwater emanates;
- 'Collection of springs' (Lähteikkö) – Several emergence points in close proximity to one another from where groundwater emanates;
- 'Seepage surface' (Tihkupinta) – Often treeless piece of ground covered with shallow peat from where groundwater emanates across a diffuse area; and
- 'No classification' – No classification provided.

The majority of features recorded at Rautuvaara are springs, with two collections of springs and one seepage surface identified. The features at Hannukainen are not classified. Further information, e.g. seasonal flow data and water chemistry, was not available.

Figure 6-14 shows the position of the Saivojärvi wetland nature reserve, wetland areas and springs across the site.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Springs and Wetlands Throughout the Project Site	Figure 6.14

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-11 Springs and Wetlands_PH2_HIA.mxd

6.3.9 Existing Pit Lakes

Hannukainen Historic Mining

Two pit lakes have formed in the voids left from historic mining (shown previously in Figure 1-2); Laurinoja, the larger pit lake to the north, has a maximum depth of 80 m whilst Kuervaara, the smaller pit lake to the south has a maximum depth of 27 m. Depth sampling in both lakes, undertaken approximately annually between 2005 and 2008 and subsequently in 2011, shows vertical stratification with the seasonally thermally active layer extending to a depth of 40m in Laurinoja and over the complete depth of Kuervaara. However, despite the thermally active layer both lakes may potentially be permanently stratified (meromictic) and therefore may not experience turnover throughout the year. This is evident from a clear chemocline[7] existing in both lakes marked by an increase in electrical conductivity and major ion loading with depth.

Both pit lakes experience oxygen depletion below a certain depth (30 m in the case of Laurinoja and 15 m in the case of Kuervaara). The upper 15 m of the Kuervaara pit lake is moderately acidic in nature with a pH of 3.5 but is shown to be circum-neutral at depth. This characteristic is not seen in Laurinoja where circum-neutral pH conditions are observed at all depths.

The increasing pH with depth in Kuervaara is associated with depletion of dissolved oxygen and elevated dissolved iron. The elevated concentration of iron at depth is likely due to iron redox cycling in the Kuervaara lake with iron (III)-oxides precipitating in the oxic surface waters sinking to the anoxic zone where they subsequently undergo reductive dissolution as iron (III) is reduced to iron (II). Although organic carbon concentrations have not been measured within the pit lakes, data from similar pit lakes (i.e. Udden pit lake, Northern Sweden; Ramstedt et al, 2003) in which organic carbon has been determined support this theory.

Median, maximum and minimum concentrations for key water quality parameters for deep and shallow waters in the Laurinoja and Kuervaara pit lakes are shown in Table 6-43. Water quality within the lakes has been assessed against WQOs developed for FS09. In the Kuervaara pit lake, concentrations of sulphate, iron, copper, manganese, nickel and zinc are found to be elevated showing distinct exceedences at all depths. Concentrations of iron and manganese are generally most elevated in the deeper portion of the pit lake as they are more mobile under reducing conditions. Copper, cobalt and nickel were generally found to be enriched in the acidic surface waters whilst the opposite was found with uranium and sulphate.

Concentrations of metals within the Laurinoja pit lake were generally much lower than in Kuervaara but still showed exceedences for copper in both deep and shallow water as well as sulphate, uranium, zinc and cobalt in the deeper portion only.

[7] *Chemocline is a layer witinh a water body caused by a strong chemical gradient resulting in clear stratification*

Table 6-43: Median and range in con concentrations of key water quality parameters in the Kuervaara and Laurinoja pit lakes

Parameter	Units	*Drinking Water Guidelines STM 401/2001*	WQO – FS09		Kuervaara						Laurinoja					
			TV	AV	Shallow (<15m)			Deep (>15m)			Shallow (<25m)			Deep (>25m)		
					Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum
pH		6.5 - 9.5	-	-	3.5	3.3	3.0	6.5	6.0	5.7	7.5	7.1	6.3	7.3	7.0	6.0
Dissolved oxygen	mg/L		-	-	12.0	9.8	9.7	0.20	0.10	0.001	11.6	10.4	7.8	4.3	1.5	0.2
Conductivity	mS/m		4.3	6.5	122	110	100	190	155	110	23.0	20.0	17.2	35.4	32.0	28.0
Bicarbonate	mg/L		-	-	0.6	0.6	0.6	143	77.2	0.6	45.8	35.4	32.9	92.1	68.6	49.8
Total Nitrogen	mg/L	0.50	-	-	0.54	0.515	0.45	3.1	2.3	1.2	0.1504	0.073	0.05	0.33	0.24	0.11
Sulphate	mg/l		4.4	65	570	533	498	1300	859	550	70.0	56.5	41.7	120	95.0	70.0
Iron	mg/l		0.4	0.98	7.9	2.6	1.5	380	302	160.0	0.09	0.04	0.01	4.90	0.98	0.04
Cobalt	mg/l		0.000077	0.004	0.11	0.091	0.09	0.051	0.0173	0.007	0.004	0.003	0.0013	0.0075	0.0046	0.0012
Copper	mg/l		0.00047	0.005	0.13	0.0873	0.077	0.04	0.01	0.0001	0.019	0.011	0.0075	0.012	0.0057	0.0003
Manganese	mg/l		0.018	0.7	0.692	0.621	0.608	2.503	2.479	2.455	0.0503	0.0334	0.0317	0.634	0.538	0.416
Nickel	mg/l		0.0003	0.02	0.22	0.153	0.148	0.095	0.032	0.0034	0.022	0.008	0.006	0.011	0.0052	0.0014
Zinc	mg/l		0.0016	0.03	0.0516	0.0423	0.04	0.04	0.01	0.0023	0.04	0.01	0.0063	0.04	0.04	0.0011
Uranium	mg/l		0.00011	0.015	0.0009	0.0009	0.0008	0.0002	0.0001	0.0	0.0105	0.0084	0.0083	0.0181	0.0167	0.0166

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Rautuvaara Historic Pit Lakes

Two pit lakes have formed in the voids left from historic mining of the Rautuvaara ore body located northwest of the historical WRD at Rautuvaara. The location of the pit lakes is shown in Figure 1-3. The maximum depth of the larger pit lake, located to the southwest is approximately 76 m, and the maximum depth of the smaller pit lake, located to the northeast, is approximately 45 m (observed during field sampling).

The current steady state water level in both of these pit lake is approximately 197.5 masl.

Table 6-44 and Table 6-45 show the water quality results for the Rautuvaara pit lakes compared to the WQO for FS15. Sulphate is elevated in both pit lakes relative to an AV WQO of 159 mg/L with a maximum value of 316 mg/L reported for the large pit lake and 336 mg/L for the small pit lake. The similarity of sulphate concentrations between the pit lakes and borehole RAU12HYD02 further supports the likelihood that RAU12HYD02 is influenced by the lakes.

Concentrations within the larger pit lake exceed WQO AVs for the Niesajoki for sulphate, cobalt, copper, manganese, zinc, calcium, potassium, magnesium, sodium, silicon and strontium. Concentrations within the smaller pit lake exceed WQO AVs for sulphate, cobalt, manganese, nickel, calcium, potassium, magnesium, sodium, sulphur, barium and strontium. Besides sulphate, other notable exceedances are:

- Cobalt, a maximum concentration of 0.015 mg/L is reported within the smaller pit lake relative to an AV WQO of 0.004 mg/L;
- Copper, a maximum concentration of 0.013 mg/L is reported within the larger pit lake relative to an AV WQO of 0.005 mg/L; and
- Manganese, a maximum concentration of 1.4 mg/L is reported within the smaller pit lake relative to an AV WQO of 0.7 mg/L.

Table 6-44: Water quality concentrations for key parameters in the Rautuvaara pit lakes, compared to FS15 WQOs

				Pit Lakes			
Parameter	Unit	WQO – FS15		FS 46 (large pit lake)		FS47 (small pit lake)	
		*TV	*AV	Mean	Max	Mean	Max
		Number of Samples		*9*	*9*	*7*	*7*
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.6	6.7	6.6	6.8
Suspended solids	mg/L	3	25	1.8	7.0	1.2	3.8
Ammonium	mg/L	0.101	1	0.068	0.13	0.031	0.18
Nitrite as N	mg/L	0.012	0.05218	<0.002	<0.002	<0.002	<0.002
Nitrate as N	mg/L	0.279	20	0.03	0.03	0.02	0.04
Chloride	mg/L	3.0	150	2.8	2.9	3.0	3.1
Sulphate	mg/L	89	159	290	320	320	340
Iron	mg/L	0.92	4.07	0.099	0.859	0.38	2.4
Aluminium	mg/L	0.050	0.1	0.006	0.01	0.002	0.002
Arsenic	mg/L	0.0012	0.0050	0.0001	0.0001	0.0001	0.0001
Cadmium	mg/L	0.00001	0.00008	0.00003	0.00004	0.00001	0.00002
Cobalt	mg/L	0.002	0.004	0.01	0.01	0.004	0.02
Chromium	mg/L	0.0003	0.001	0.0004	0.0007	<0.0001	<0.0001
Copper	mg/L	0.0048	0.005	0.007	0.01	0.001	0.002
Manganese	mg/L	0.294	0.70	1.0	1.2	0.34	1.4
Molybdenum	mg/L	0.0002	1	0.0006	0.0007	0.0002	0.0004
Nickel	mg/L	0.007	0.02	0.024	0.029	0.012	0.022
Lead	mg/L	0.0001	0.0072	0.00003	0.00005	0.00002	0.00003
Zinc	mg/L	0.002	0.03	0.038	0.045	0.012	0.024
Uranium	mg/L	0.0004	0.015	0.0049	0.0049	0.0025	0.0025

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
Samples shown as mean are an average of all sample depths.

Table 6-45: Water quality concentrations for other parameters in the Rautuvaara pit lakes, compared to FS15 WQOs

				Pit Lakes			
Parameter	Unit	WQO		FS 46 (large pit lake)		FS47 (small pit lake)	
		*TV	*AV	Mean	Max	Mean	Max
		Number of Samples		*9*	*9*	*7*	*7*
Electrical Conductivity	mS/m	26	41	72	77	77	79
Calcium	mg/L	25	46	110	120	110	110
Potassium	mg/L	3.0	4.9	13	15	13	13
Magnesium	mg/L	10	17	20	20	22	23
Sodium	mg/L	5.3	9.1	4.2	4.6	5.6	5.7
Sulfur	mg/L	29	53	100	110	120	120
Silicon	mg/L	4	11	7.9	8.2	6.0	8.0
Barium	mg/L	0.010	0.014	0.013	0.013	0.036	0.040
Strontium	mg/L	0.070	0.112	0.18	0.19	0.22	0.22

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
Samples shown as mean are an average of all sample depths

Figure 6-15 to Figure 6-20 below illustrate how various parameters vary with depth within the Rautuvaara pit lakes and also, where relevant, show comparisons with TV and AV WQOs calculated for FS15.

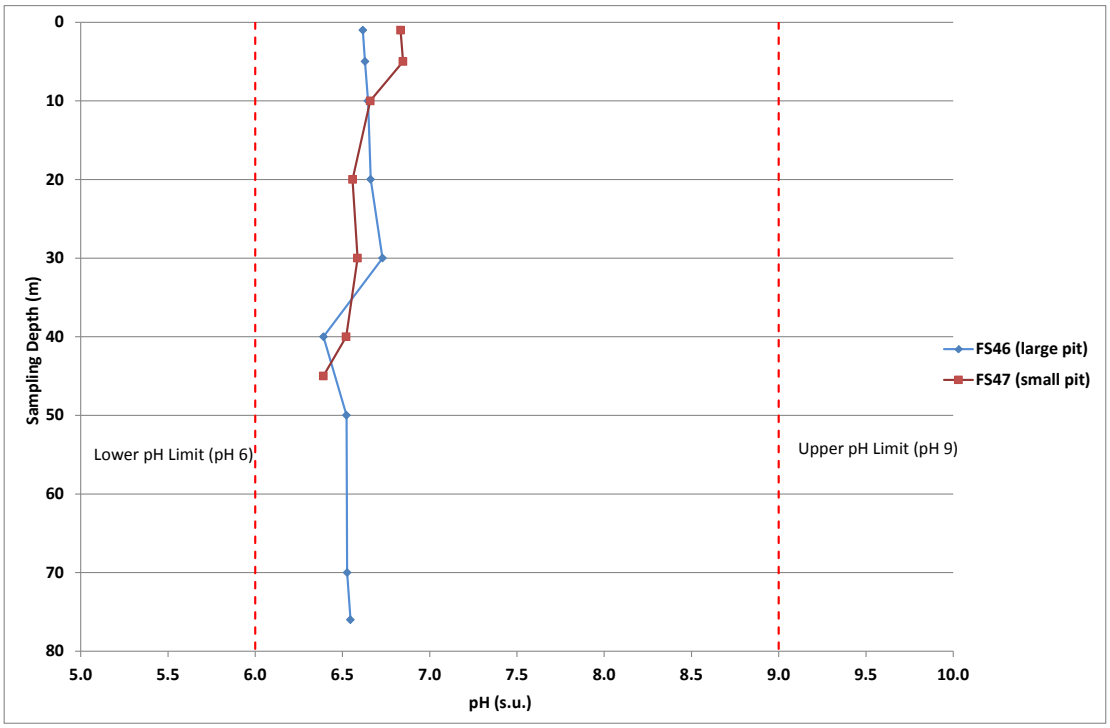


Figure 6-15: Rautuvaara pit lake pH concentrations relative to depth

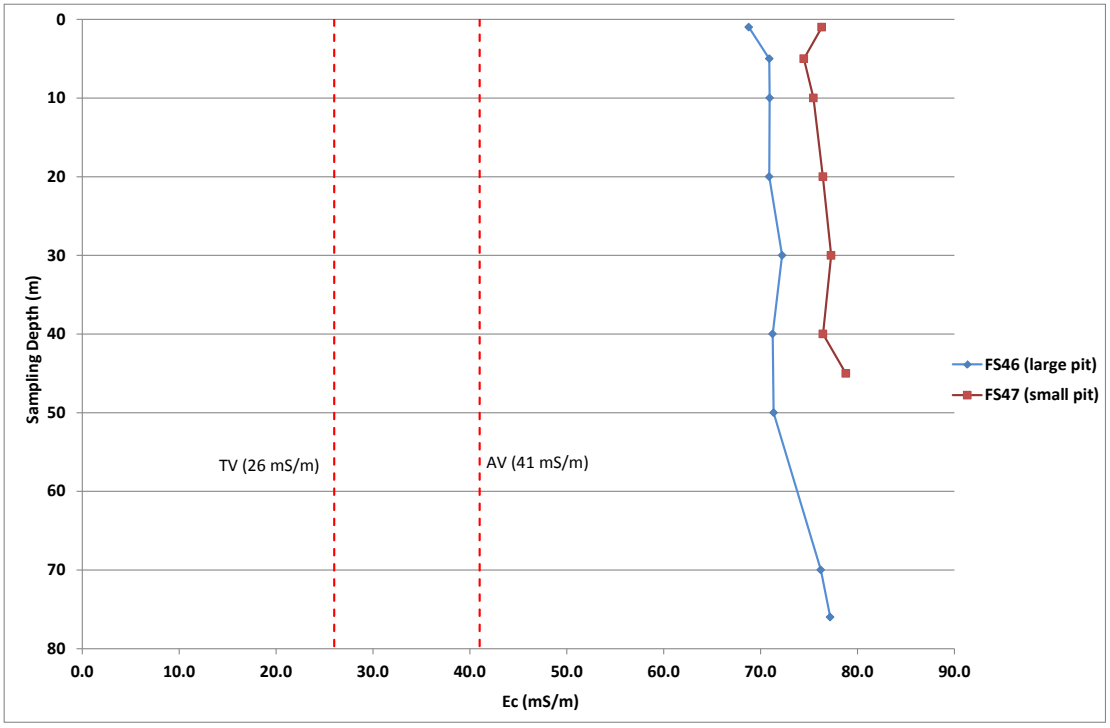


Figure 6-16: Rautuvaara pit lake conductivity relative to depth

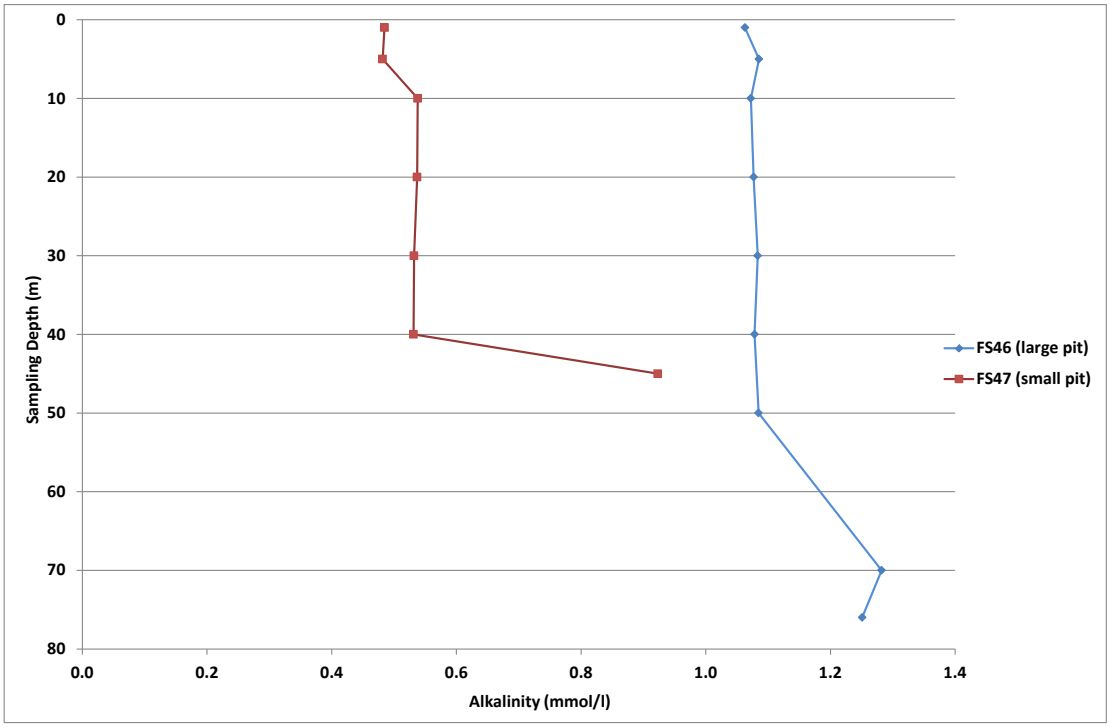


Figure 6-17: Rautuvaara pit lake alkalinity concentrations relative to depth

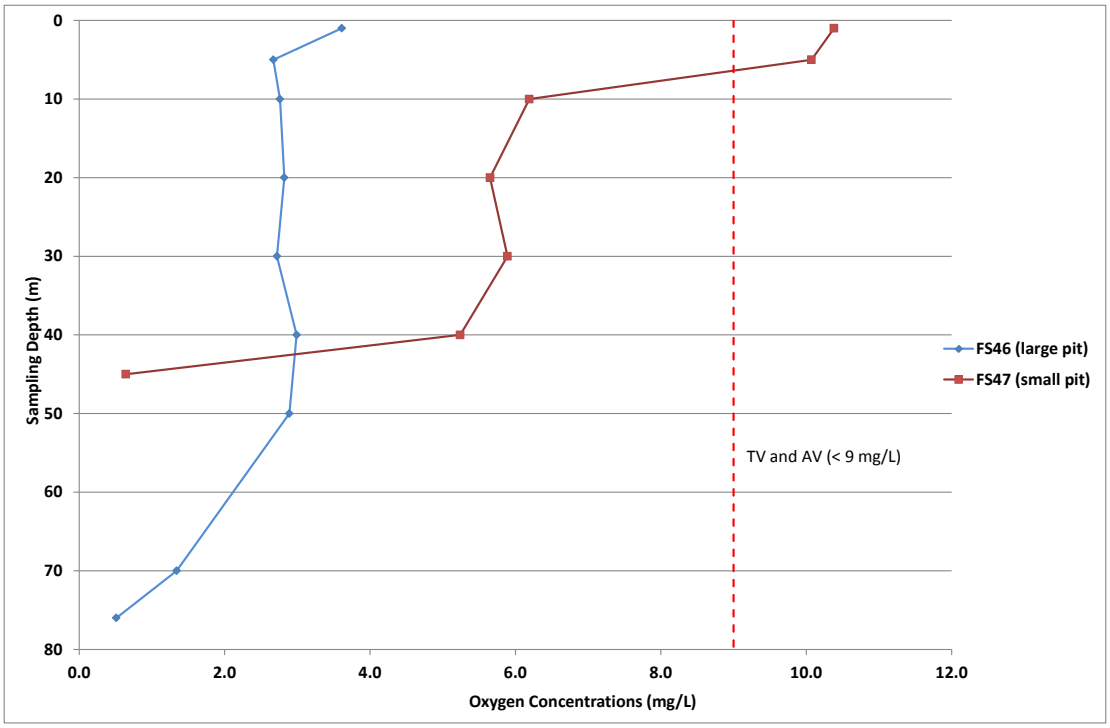


Figure 6-18: Rautuvaara pit lake oxygen concentrations relative to depth

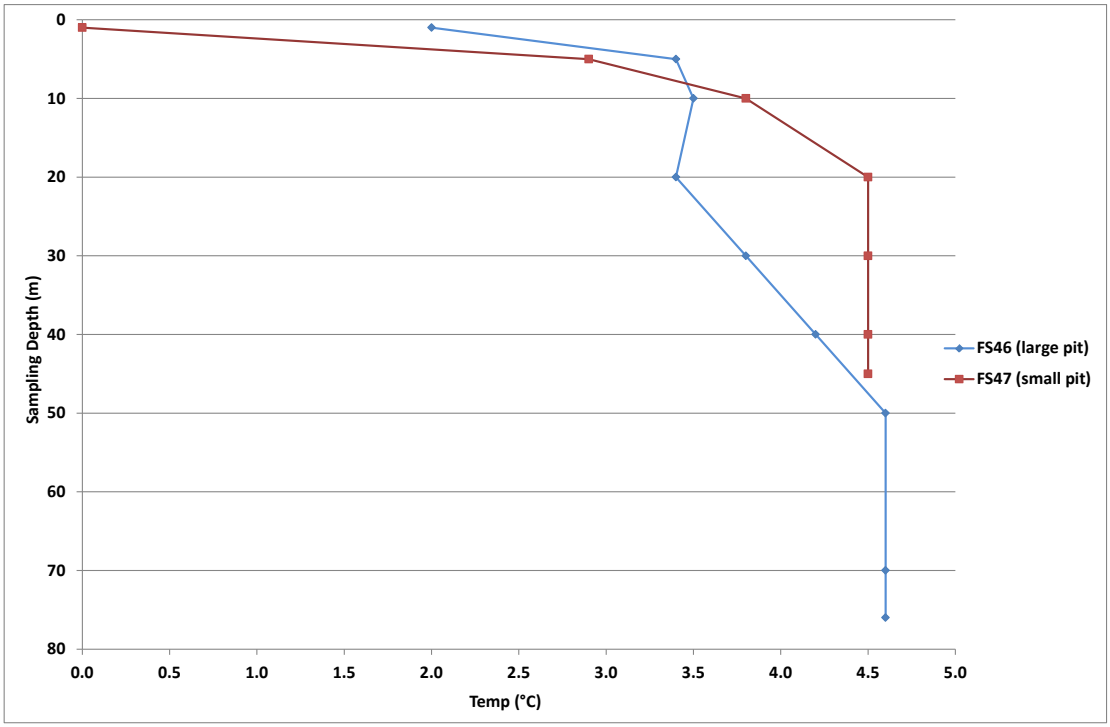


Figure 6-19: Rautuvaara pit lake temperatures relative to depth

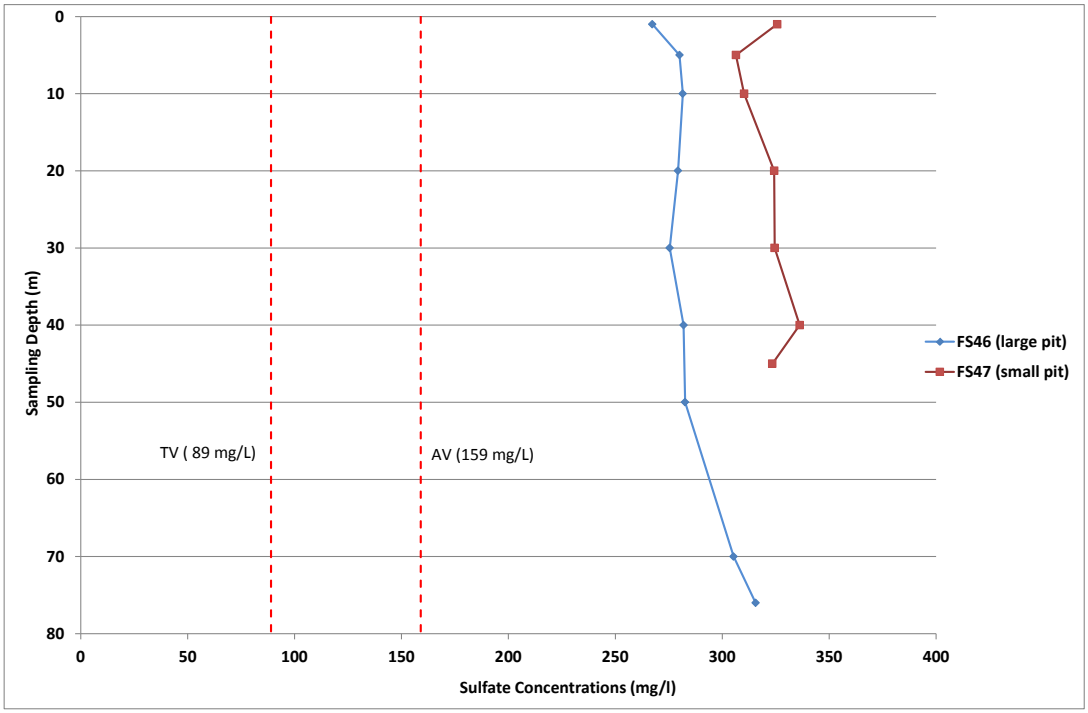


Figure 6-20: Rautuvaara pit lake sulphate concentrations relative to depth

6.3.10 Surface Water Users

Within the vicinity of the proposed mine and TMF there is limited human use of surface water as a resource or for navigation (Northland, 2011a). However, baseline studies (Northland, 2011a) have shown that the Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki and Muonionjoki rivers are breeding rivers for the Sea Trout (*Salmo truter*), an endangered species.

In addition, many of the rivers are used for recreational purposes, e.g. fishing is popular in the Muonionjoki (Pöyry, 2010). There are no towns or villages close to the mine site or proposed TMF, however, local maps indicate a number of holiday cottages adjacent to the Äkäsjoki River. Pöyry (2010) notes there are 15 households and 45 holiday homes close to the development, with the nearest houses roughly 100 m and holiday houses 500 m from the old mine facilities.

As discussed above, the North Pond is currently utilised by the Ylläs wastewater treatment plant as a tertiary sedimentation pond.

6.4 Groundwater

All of the main geological strata intersected at Hannukainen during hydrogeological and geotechnical drilling at Hannukainen (SRK, 2012a) and Rautuvaara were found to be water bearing to some extent, i.e. groundwater occurs in both the overburden and the bedrock.

Groundwater is generally unconfined in the overburden unit, though occasional artesian wells indicate that confined groundwater conditions may occur locally. Groundwater flow in the bedrock occurs through open, connected fractures and is therefore controlled principally by the fracture network (SRK, 2011).

Groundwater bodies within the overburden and within the weathered bedrock are referred to as the shallow and deep aquifers respectively throughout the ensuing text.

6.4.1 Hannukainen

Groundwater Levels

Water levels recorded by Northland throughout the Hannukainen site since October 2011 are shown in Figure 6-21. It can be seen that at 27 of the 45 monitoring locations there are only two water level records. It is not possible to interpret seasonal trends at these locations. There are only 8 locations with more than 6 water level records within a 1 year period.

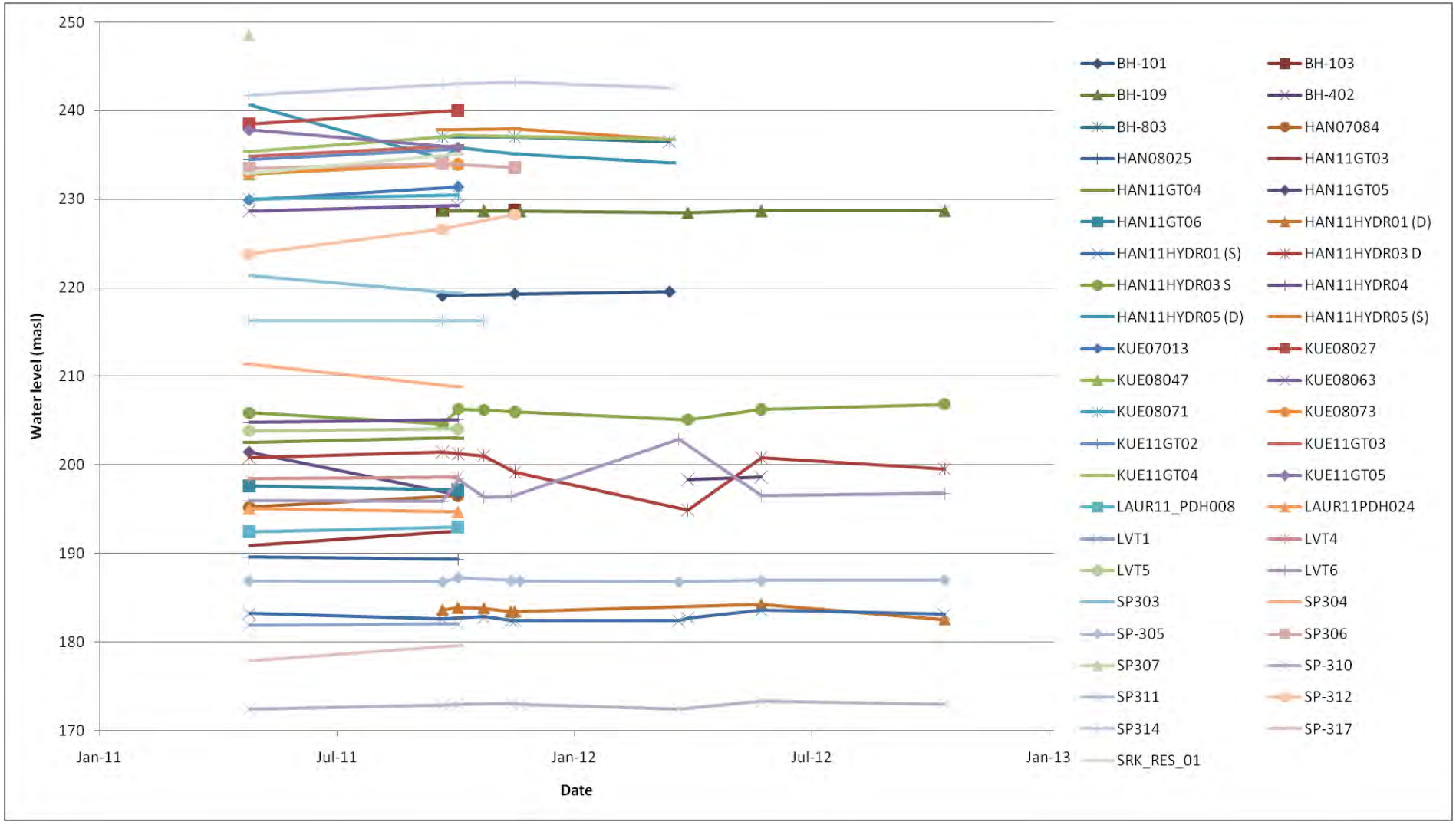


Figure 6-21: Groundwater hydrographs at Hannukainen and Kuervitikko

Figure 6-21 demonstrates that:

- Groundwater levels are generally lower in spring (April monitoring round) than during the winter months (October – December monitoring rounds). This may be due to reduced recharge during the winter months followed by increased recharge during the spring and autumn and consequently a recovery of the groundwater level;
- Groundwater levels generally vary less than 2 m (42% of all wells shown Figure 6-21 vary less than 1 m, a further 33% vary less than 2 m). Groundwater level variation greater than 3 m is observed at 6 locations (13% of the boreholes). These wells are located in both the bedrock and the overburden; and
- Across the Hannukainen site, measured depth to groundwater ranges from -0.02 (i.e. artesian) to 27 mbgs, with an average depth of 5.3 mbgs.

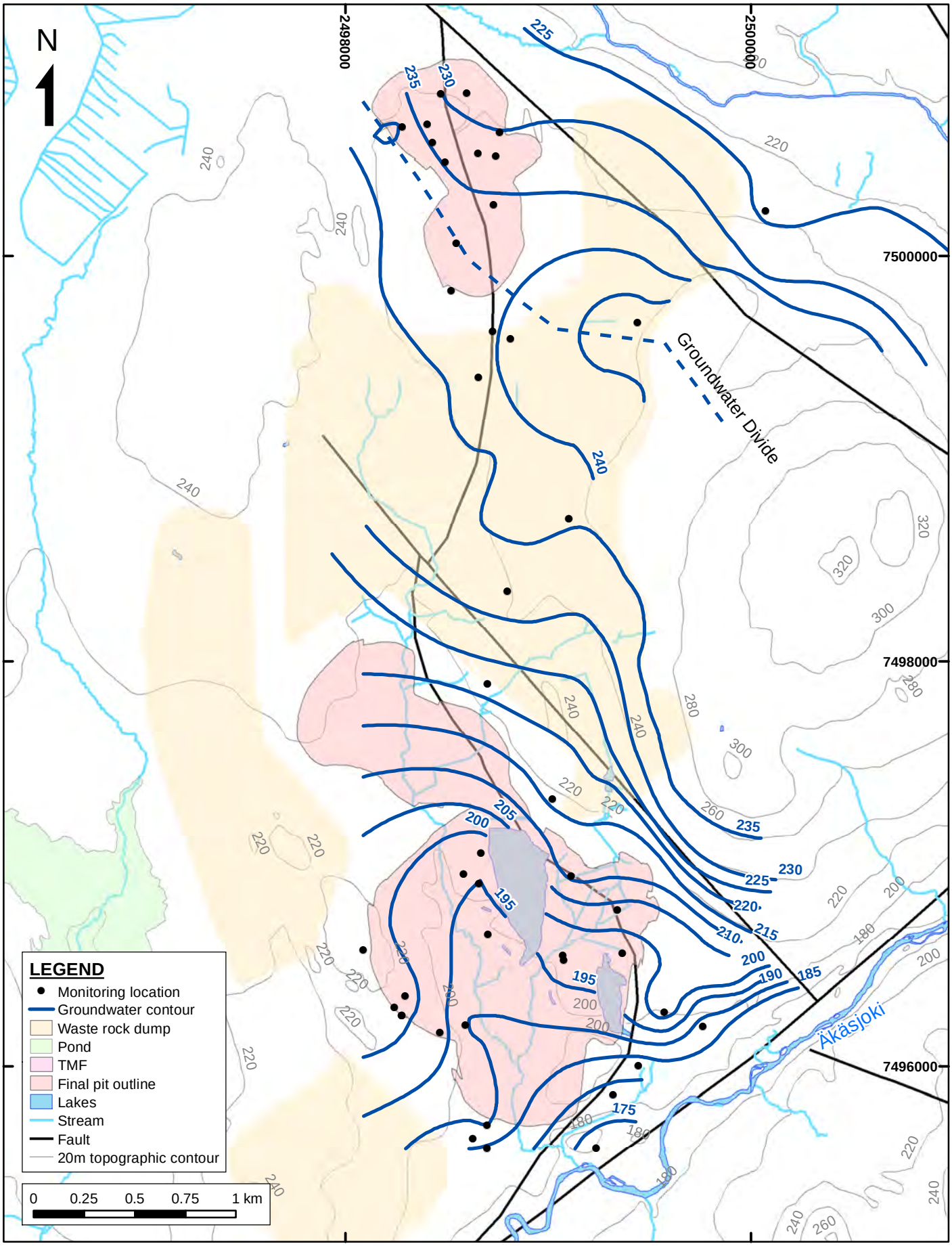
The available data indicates that at Hannukainen depths to groundwater are typically between 5 and 10 mbgs meaning that the upper sections of overburden deposits are largely unsaturated. The overburden comprises unconsolidated glacial material and therefore where saturated, flow is likely to be intergranular.

Groundwater Contours

Figure 6-22 shows interpolated contours for groundwater levels measured across the mine licence area by SRK in May 2011. Groundwater contours show that flow generally follows topography with the majority of flow draining to the Äkäsjoki River to the south. However a groundwater divide trending northwest-southeast is present across Kuervitikko resulting in some flow to the north towards the Kuerjoki River.

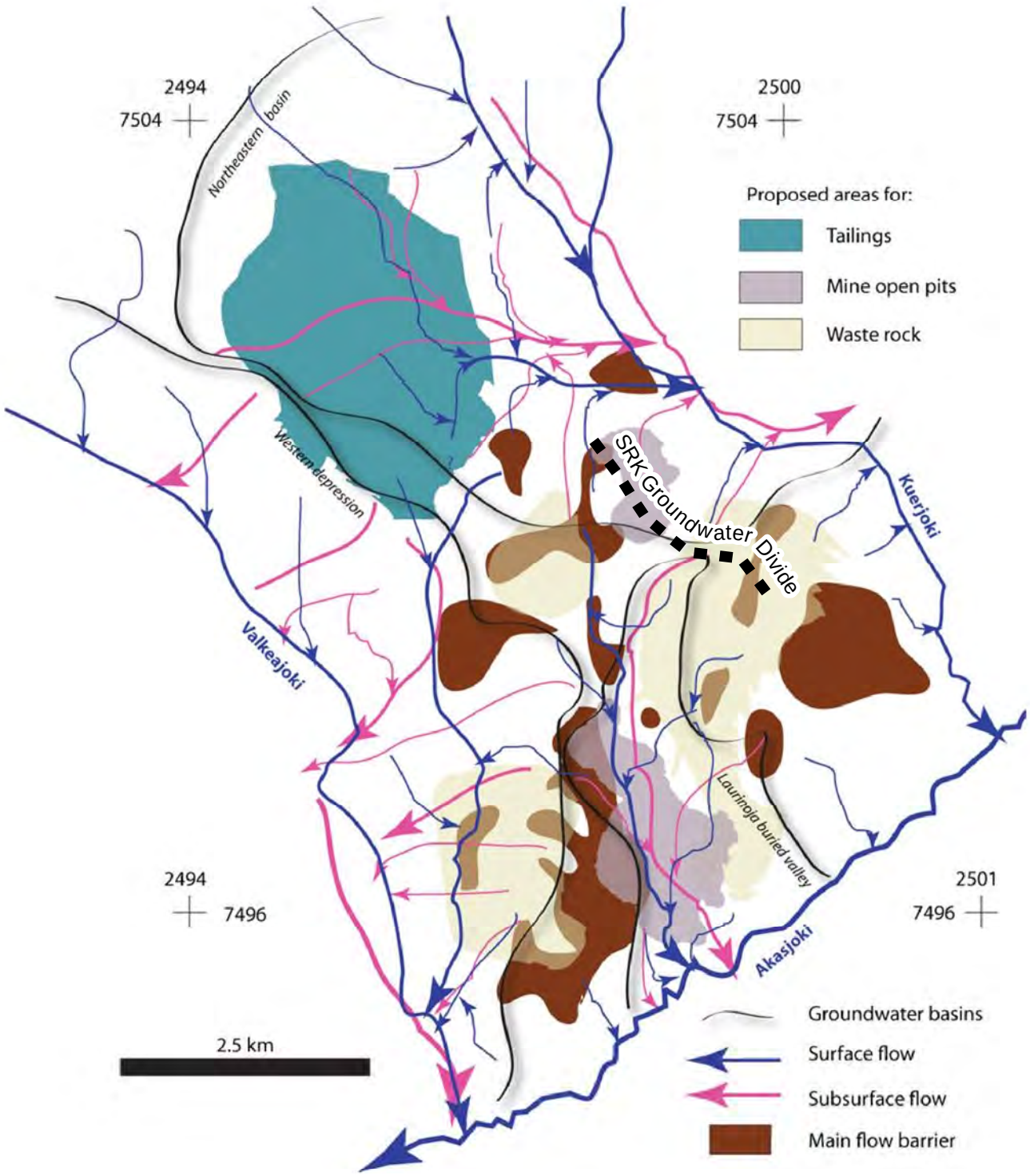
The University of Helsinki has combined GPR data (Moreau and Koivisto, 2012) and hydrological field observations (Nurminen and Korkka-Niemi, 2011) to investigate the hydrogeological regime of the Quaternary overburden sediments. Figure 6-23 presents the University's hydraulic conceptual model, and also shows the position of the groundwater divide identified by the SRK monitoring.

There is a good correlation between the location of the groundwater divide predicted by the University of Helsinki study and the groundwater contours interpolated by SRK.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting	Groundwater Levels at Hannukainen and Kuervitikko in May 2011		Figure 6.22

P:\U4342 Hannukainen DFS\Project\Data\GIS\Hydro Phase 4 Figures\Groundwater contoursV4_PH2_HIA.mxd



From Moreau and Keskinen (2012)

JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Hydraulic system at Hannukainen (from Moreau and Keskinen (2012))	Figure 6.23

P:\U4518 Hannukainen HIA\Project\CAD\Uni of Hels concep model_PH2_HIA.mxd

Surface Water – Groundwater Interaction

As part of their study the University installed temporary piezometers in the river bed of the Äkäsjoki. The piezometers were isolated in the river bed sediment and show a piezometric head which is above the level of the river bed (Table 6-46). This indicates that there is flow from the groundwater in the river sediments to the river, i.e. the Äkäsjoki is a gaining river with a baseflow component derived from groundwater.

Ground Penetrating Radar (GPR) data, also collected by the University, shows that there is no overburden in the location of the temporary piezometers; the alluvial river bed sediments are deposited directly on to the underlying bedrock. The alluvial sediments comprise sand and gravel (SRK field observation), and therefore are likely have a sufficiently high hydraulic conductivity to support a hydraulic connection between the underlying bedrock and the river.

Table 6-46: Temporary piezometers installations in the Äkäsjoki river (from Nurminen and Korkka-Niemi (2011))

Monitoring location	Piezometer depth (m below river bed)	River stage (m above river bed)	Groundwater level (m above river bed)
MP1	0.50	0.18	0.22
MP2	0.24	0.47	0.51
MP3	0.36	0.45	0.47

The University took water samples from observation wells (OWs) located in the Quaternary sediments, pits lakes, ponds and local rivers and analysed oxygen (δ18O) and hydrogen (deuterium, δ2H) isotopes in the water. The results are presented in Figure 6-24 which shows the relationship between δ2H and δ18O at Hannukainen. The global meteoric water line is shown for comparison.

The mean value of δ18O Vienna Standard Mean Ocean Water (VSMOW) in the Kolari area is -15 to -14.5 according to Kortelainen and Karhu (2004). The δ18O isotope values at Hannukainen range from -15 to -12 (VSMOW). Results in Figure 6-24 show mixing between groundwater and surface water in the Äkäsjoki and Valkeajoki river waters. In addition, two boreholes close to the existing Laurinoja pit show some evidence of surface water influence in the borehole samples. The results indicate that the pit lake water samples are dominated by surface water; there is no evidence of a groundwater signal. However, it has been shown previously (Section 6.3.9) that both pits display a clear chemocline and may be permanently stratified (meromictic). There is no information available regarding the sampling depth of the pit lakes isotope samples however, it is considered likely that these samples have been collected from the surface of the pit lake where the geochemical composition is dominated by surface water inputs (rainfall and ice melt).

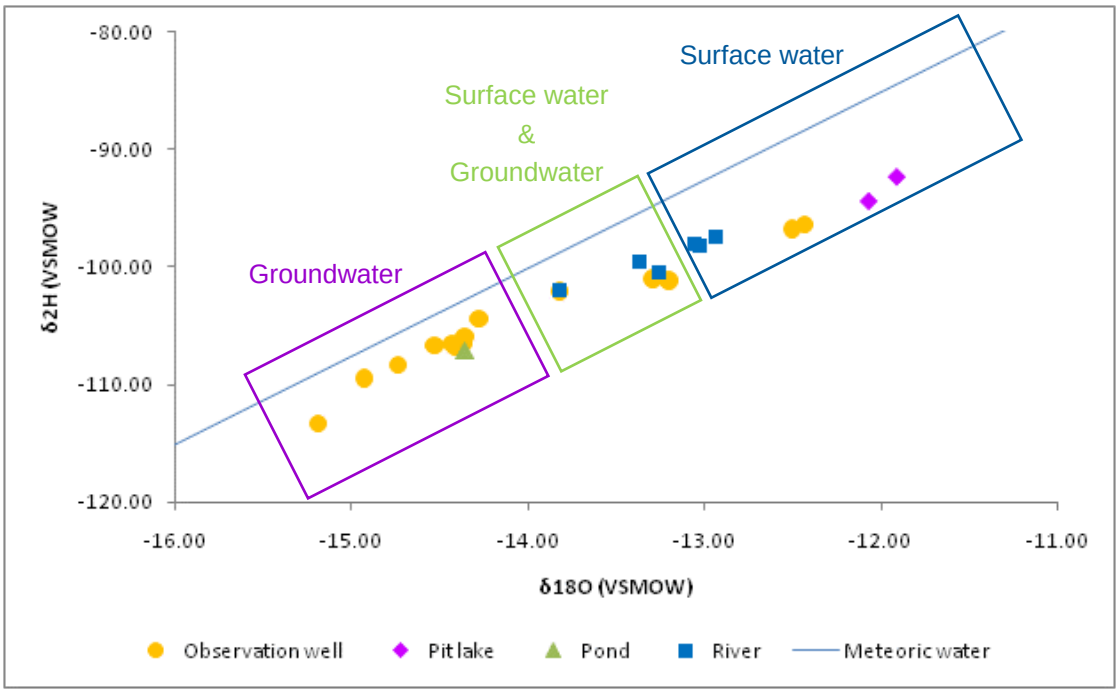


Figure 6-24: University of Helsinki isotope analysis

Aquifer Properties

A detailed analysis of aquifer properties for the various groundwater units present in the project area is presented in the DFS report (SRK 2011). A summary of the hydraulic properties is provided in Table 6-47.

Table 6-47: Summary of Hydraulic Properties

Location	Geol. Unit	Mean K (m/d)	n	S_s	S_y	Data source
Hannukainen	Overburden	0.18	0.27	N/A	N/A	PSD analysis
	Bedrock (HW)	0.01	N/A	1E-06	N/A	Pumping Tests and Spinner Testing
	Bedrock (FW)					
Kuervitikko	Overburden	0.18	0.27	N/A	N/A	PSD analysis
	Bedrock (HW)	0.10	N/A	1E-07	1E-06	Pumping Tests
	Bedrock (FW)					

The University of Helsinki have also derived hydraulic conductivity for the overburden sediments. The University undertook in-situ ring infiltration tests and also estimated hydraulic conductivity from laboratory testing of sediment samples ((Nurminen and Korkka-Niemi, 2011). In-situ tests estimated a vertical hydraulic conductivity of 0.7–15.0 m/d, however this test only investigates a very small area immediately below the infiltration ring and therefore does not give a good indication of bulk hydraulic properties. Hydraulic conductivity derived from the sediment samples ranged from 0.01 m/d to 373 m/d and was highly dependent on the nature of the sediment as shown in Table 6-48. There is not a strong correlation between hydraulic conductivity and depth, with the highest hydraulic conductivity recorded in the middle glacial sequence (C).

Table 6-48: Summary of overburden properties from laboratory testing

Type	Number of samples	K (m/d)
Gravel	1	373.25
Sandy gravel	2	142.56
Gravely sand	6	34.83
Sand	12	26.94
Silty sand	2	1.08
Sandy diamicton	6	0.59
Sandy silt	2	0.15
Silt	3	0.05

The bulk hydraulic conductivity value for overburden materials of 0.18 m/d, derived from PSD analysis, (Table 6-47) is consistent with sandy silt material. The values derived by the University are generally higher than the value derived from the PSD analysis used in SRK (2012a). However, the PSD analysis is consistent with falling head tests conducted in the field and is therefore considered more representative.

The hydraulic conductivity of the bedrock is approximately one to two orders of magnitude lower than the overburden material (0.10 – 0.01 m/d). Storage properties have been derived from pumping tests and are estimated to be 1E-07 to 1E-06. Given the geology of the bedrock, it is anticipated that aquifer storage and groundwater flow will be dominated by the fracture network.

Water Quality

A summary of the water type and average pH for each sample location is provided in Table 6-49. The table broadly groups the boreholes in to two areas, Hannukainen and Kuervitikko, which refer to the proposed open pits at the project site. Borehole locations and the proposed pit footprints are shown on Figure 5-5.

Average pH for each different locality ranges across the site from 5.15 at SP311 to 8.71 at HAN11HYDR05(D). There is no apparent correlation between lithology or borehole location and pH.

The water types are shown graphically in the form of a Piper plot in Figure 6-25 and Schoeller plots in Figure 6-26 and Figure 6-27.

Table 6-49: Summary of water type and pH for groundwater samples taken at Hannukainen

Sample Location	Area	Water Type	Mean pH
BH 101	Kuervitikko	Ca-Mg-Na-HCO3	6.4
BH 103	Kuervitikko	Ca-Na-HCO3	5.9
BH 109	Hannukainen	Ca-Na-Mg-HCO3	6.8
BH 803	Kuervitikko	Ca-Na-Mg-HCO3	7.0
HAN OW 02D	Hannukainen	Ca-Na_HCO3-SO4	7.2
HAN OW 02S	Hannukainen	Ca-Mg-Na-HCO3	6.5
HAN OW 08D	Hannukainen	Ca-Na-SO$-HCO3	7.2
HAN OW 08S	Hannukainen	Ca-Mg-SO4-HCO3	6.7
KUE_OW_01D	Kuervitikko	Na-Ca-HCO3	8.7
KUE_OW_01S	Kuervitikko	Ca-Na-Mg-HCO3	8.6
KUE11GT04	Kuervitikko	Na-Ca-Mg-HCO3	7.4
LVT 6	Hannukainen	Ca-Mg-SO4	5.9
LVT2-OW2s	Hannukainen	Ca-Na-Mg	6.8
LVT3 30.6	Hannukainen	Ca-Mg	6.3
SP 303	Hannukainen	Na-K-HCO3	6.0
SP 304	Hannukainen	K-Na-HCO3-SO4	5.4
SP 305	Hannukainen	Ca-Mg-SO4	5.7
SP 306	Hannukainen	Na-Ca-HCO3	6.6
SP 307	Kuervitikko	Na-HCO3-Cl	5.3
SP 308	Kuervitikko	Na-K-HCO3	5.6
SP 310	Hannukainen	Ca-Mg-SO4	6.2
SP 311	Hannukainen	Na-Ca-Mg-HCO3-SO4	5.1
SP 312	Kuervitikko	Na-Ca-HCO3	6.7
SP 314	Kuervitikko	Na-Ca-HCO3	6.4
SP 316	Kuervitikko	Mg-Ca-JHCO3	5.7
SP 317	Hannukainen	Cl-SO4	5.5
Pulkka-törmäntie 7	Hannukainen	Ca-SO4_HCO3	6.2
Ylläksen-tie 168	Hannukainen	Ca-HCO3	6.0
Ylläksen-tie 180	Hannukainen	Ca-Mg-SO4	6.3

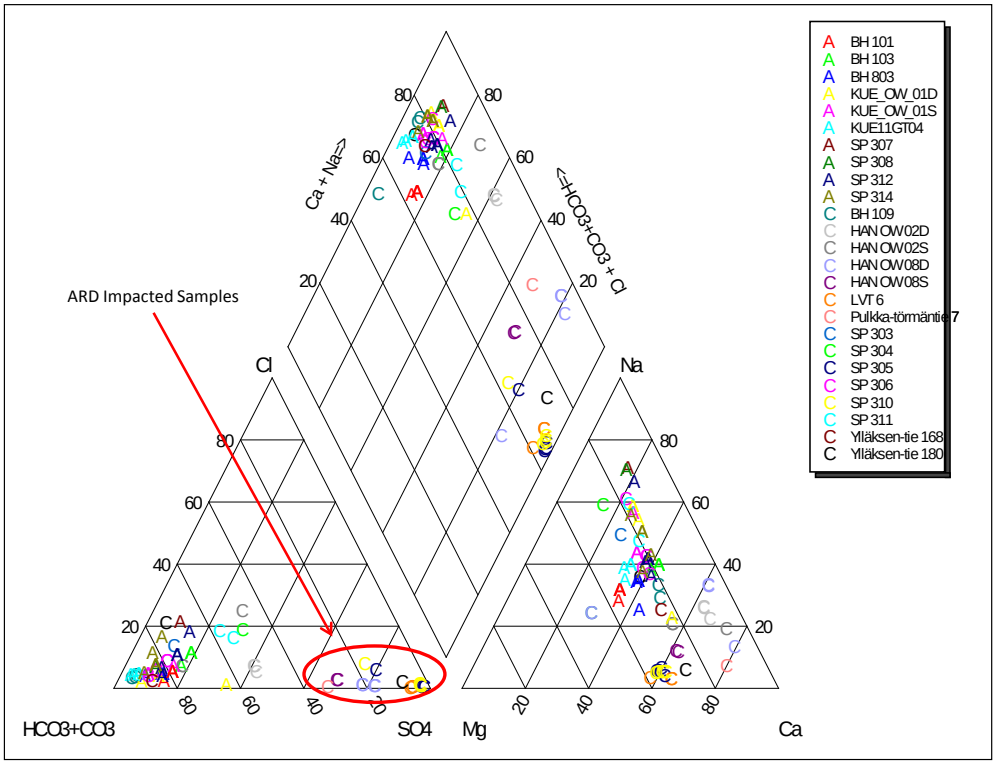


Figure 6-25: Piper plot of groundwater samples taken at Hannukainen and Kuervitikko using dissolved major ion concentrations

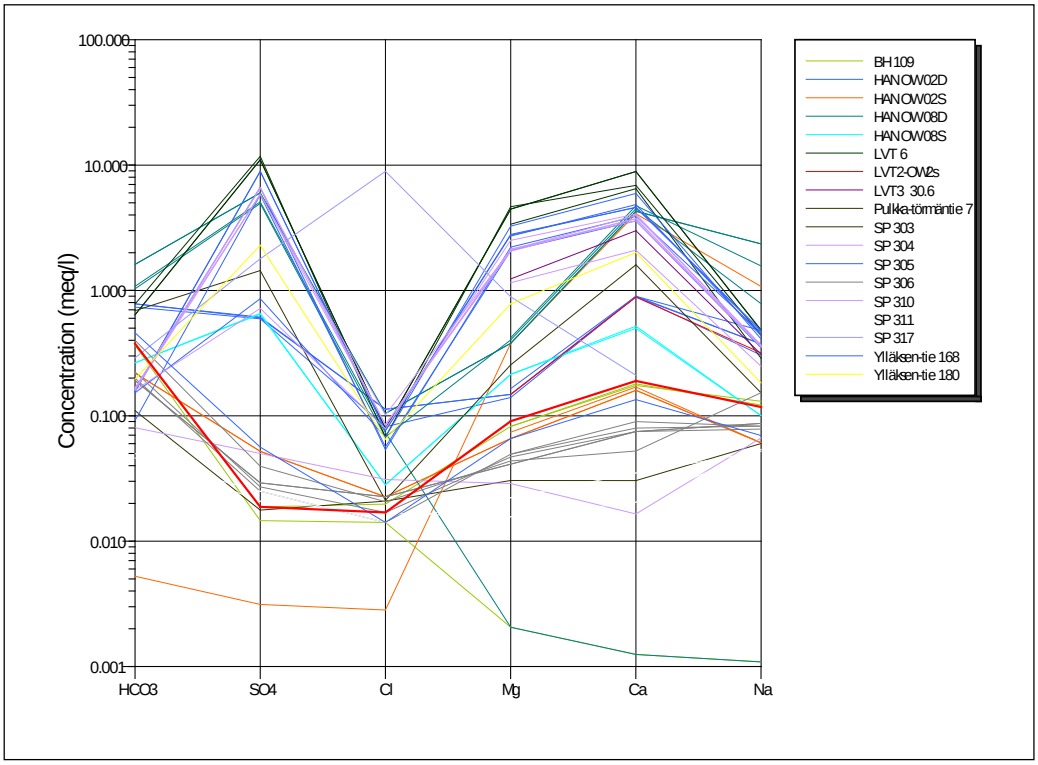


Figure 6-26: Schoeller plot of groundwater samples taken at Hannukainen using dissolved major ion concentrations

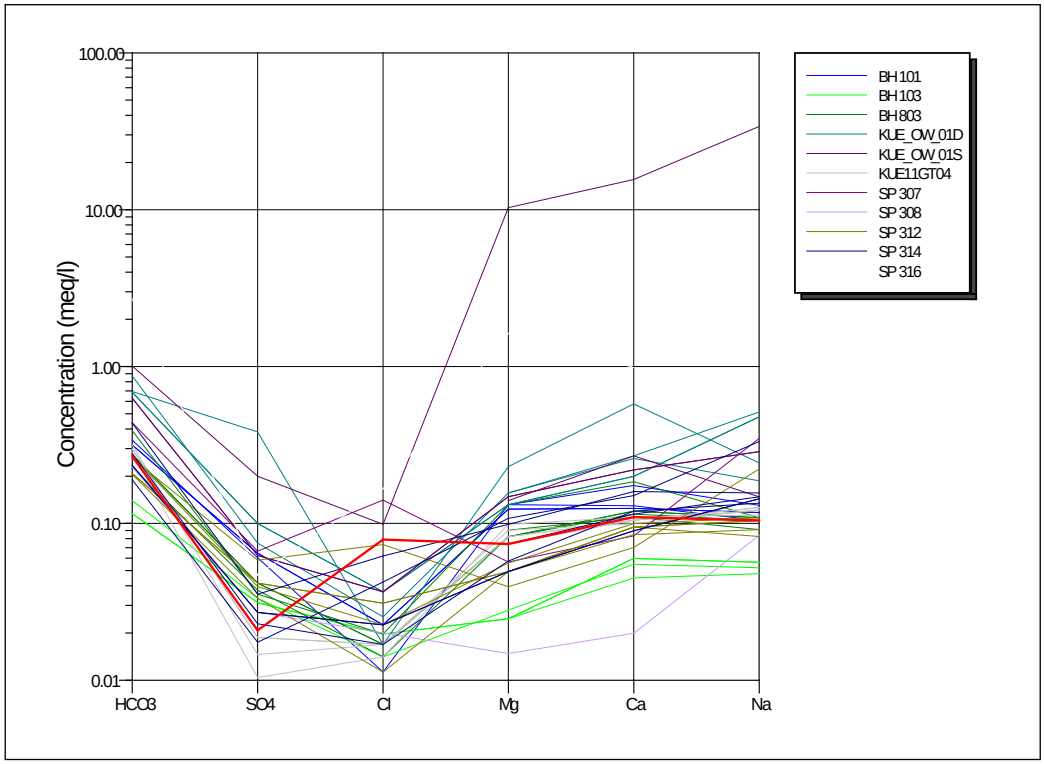


Figure 6-27: Schoeller plot of groundwater samples taken at Kuervitikko using dissolved major ion concentrations

Figure 6-25 plots the major ion chemistry of samples collected at both Hannukainen and Kuervitikko. It shows that samples generally cluster together, with no distinction between samples taken at Kuervitikko or Hannukainen. However, there are a number of Hannukainen samples that have a distinctly different major ion chemistry to those elsewhere across the site. These samples, circled in red on Figure 6-25, are referred to as 'ARD impacted samples' and are described in more detail below.

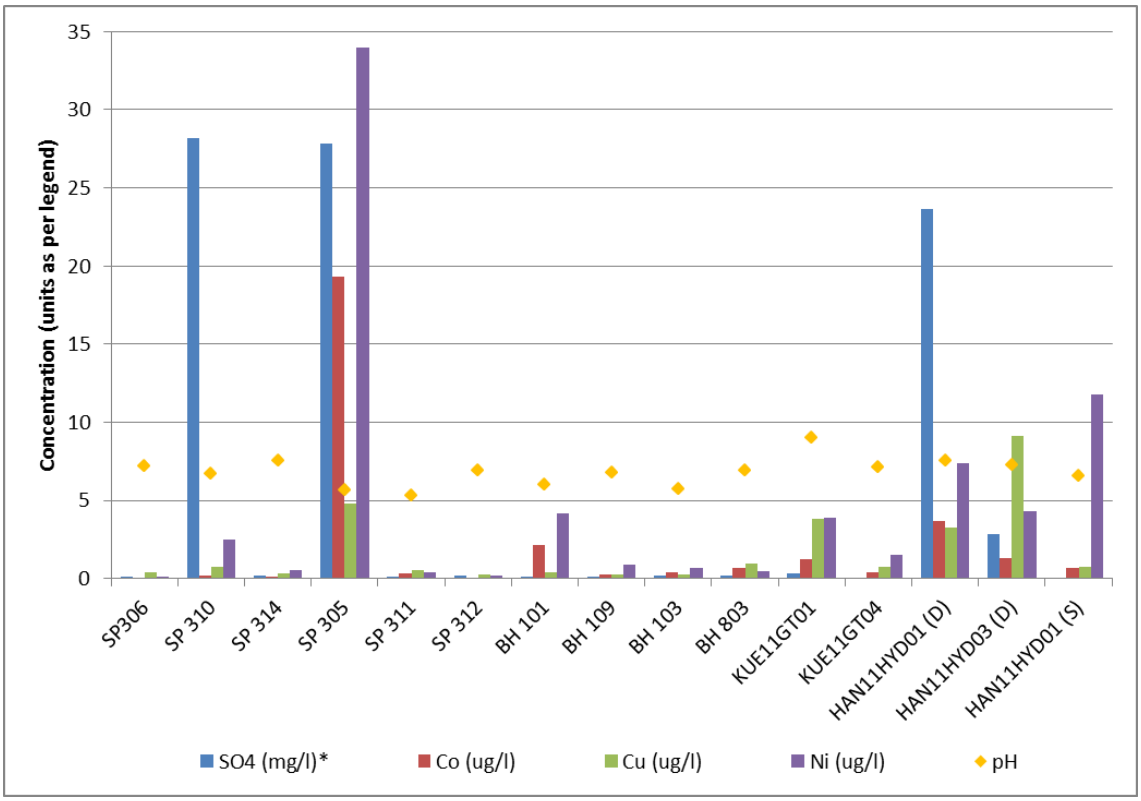
ARD Impacted Samples

The ARD impacted samples are all located within the Hannukainen area, specifically:

- Boreholes SP310, SP305 and LVT6 are located immediately down-gradient of the existing WRD and pit lakes (Figure 1-2 and Figure 5-5);
- Pulkka-törmäntie 7 and Ylläksen-tie 180 are also down-gradient of historical mining infrastructure though are not as nearby; and
- HAN11HYD01(D) (labelled HAN OW 08D in the charts) is not located immediately down-gradient of any existing infrastructure.

Samples SP305 and SP310 show low bicarbonate and elevated sulphate, magnesium and calcium. The elevated magnesium is indicative of silicate weathering. Samples collected at HAN11HYD01(D), HAN11HYD01(S) and HAN11HYD03(D) also show elevated sulphate and to some extent calcium. The HYD- series holes are not located immediately down-gradient of any existing infrastructure and it is possible that the increased sulphate is a consequence of sulphide weathering in the basement rocks at these locations. Sulphide weathering could also be the cause of elevated sulphate in the SP305 and SP310 samples however, the trends at the shallow wells may also indicate impact on the groundwater quality due to seepage from the existing WRDs which are located up-gradient of the boreholes.

Figure 6-28 shows the relationship between nickel (Ni), cobalt (Co), copper (Cu) and sulphate (SO_4) at Hannukainen. Generally, elevated SO_4 is accompanied by elevated Ni, Co and Cu. The positive correlation is strongest with Ni and weakest with Cu. Co and Ni are relatively mobile at neutral pH and elevated concentrations of these metals indicate sulphide weathering. Thus the concentrations of Co and Ni support the suggestion that elevated SO_4 observed at Hannukainen is a consequence of sulphide weathering.



**Note that concentrations of SO4 have been multiplied by 0.1 in order to plot them on the same scale as the other parameters*

Figure 6-28: Trace metal concentrations at Hannukainen

Currently at the Hannukainen site, sulfide-bearing rock is stored in the existing WRD and is also present in the walls of the existing pits. Within the Kuervaara pit, iron staining is observed on the eastern wall indicating that sulfide oxidation is taking place resulting in a pit lake that is acidic with a relatively high concentration of iron and sulphate. Sulphate in the pit lake may originate from leaching of the wall rock but also seepage from the WRD through fractures which are visible in the pit wall. There is no visible seepage from the dump and the magnitude of seepage from the WRD to the pit has not been quantified.

Water Quality at Hannukainen

Figure 6-29 to Figure 6-40 show Box and Whisker plots for pH, nickel, cobalt, copper, sulphate and uranium at the Hannukainen and Kuervitikko localities. Gaps in the Box & Whisker plots represent a lack of data.

The samples for Hannukainen have been compared with the drinking water standards as set out in government regulation STM 401/2001 where available. Cobalt and uranium have been compared with the Äkäsjoki FS09 Action Value (AV) guidelines since drinking water standards are not available for these parameters. Key findings are as follows:

- pH is reported as below the lower drinking water limit of pH 6.5 in several of the site localities (Figure 6-29). pH values are at a minimum at SP305 and SP311 where values were reported as pH 5.1 and pH 5 respectively indicating that they are moderately acidic;
- Figure 6-30 confirms that sulphate concentrations are elevated relative to the drinking water guidelines in HAN11HYD01D, LVT6, SP305 and SP310 which are all classified as ARD impacted samples on Figure 6-25. A maximum sulphate concentration of 564 mg/L was reported for sample LVT6 compared to the drinking water guideline of 250 mg/L;
- Figure 6-31 shows that all samples are within the Äkäsjoki FS09 Action Value (AV) guideline for cobalt (4 µg/L) with the exception of sample LVT6 where a maximum cobalt concentration of 24.86 µg/L was reported. Sample SP305 also showed a cobalt concentration which exceeded the AV reported as 19.32 µg/L for the Jun 2011 sample period, but this was an exceptional result as average concentrations for other SP305 sampling dates fall below the AV;
- All samples show copper concentrations that are within the drinking water guideline of 2000 ug/L (Figure 6-32); concentrations were greatest at Ylläksen-tie 168 where a maximum concentration of 35 ug/L was reported. It should be noted however that the drinking water guideline is significantly higher than the Äkäsjoki FS09 Action Value (AV) of 5 ug/L;
- Figure 6-33 shows that the majority of samples are within the nickel drinking water guideline of 20 µg/L with the exception of the August 2012 sampling round at LVT6 where a maximum concentration of 97 µg/L was reported and the June 2011 sampling round at SP305 where a maximum concentration of 34 µg/L was reported. There is a possibility that these results may reflect a testwork error since average concentrations for the other sampling dates were 14.8 µg/L at LVT6 and 4.3 µg/L at SP305; and
- Figure 6-34 shows that all samples have uranium concentrations below the Äkäsjoki FS09 Action Value (AV) of 15 µg/L with the exception of HAN11HYD01(D) where a maximum concentration of 27.5 µg/L was observed.

Water Quality at Kuervitikko

The samples for Kuervitikko have also been compared against the drinking water standards as set out in government regulation STM 401/2001 with the exception of cobalt and uranium which have been compared with the Kuerjoki FS40 Action Value (AV) guidelines since drinking water standards are not available for these parameters. Key findings are as follows:

- Samples collected from BH101, BH103, SP307, SP308 SP312, SP314 and SP316 have pH values reported as below minimum drinking water guideline of pH 6.5 (Figure 6-35). A minimum pH of 5.3 was reported for sample SP307 which can be classified as moderately acidic;
- Figure 6-36 shows that all samples have sulphate concentrations well below the drinking water guideline of 250 mg/L. Average concentrations are highest in samples HAN11HYD05(D) and HAN11HYD05(S) reported as 7.9 mg/L and 2.0 mg/L respectively;
- None of the water quality samples exceeded the Kuerjoki FS40 Action Value (AV) guideline for cobalt (4 µg/L) (Figure 6-37). A maximum concentration of 2.11 µg/L was reported in sample BH101. Figure 6-38 shows that none of the samples exceeded the copper drinking water guideline of 2000 µg/L. The guideline is significantly higher than the Kuerjoki FS40 Action Value (AV) guideline for copper 5 µg/L although all of the samples are also within this limit; a maximum concentration of 3.8 µg/L was reported in sample HAN11HYD05(D);
- All samples are within the nickel drinking water guideline of 20 µg/L (Figure 6-39); and
- Figure 6-40 shows that all samples are also within the Kuerjoki FS40 Action Value (AV) guideline for uranium (4 µg/L.). A maximum uranium concentrations of 0.92 µg/L was reported at HAN11HYD05(D).

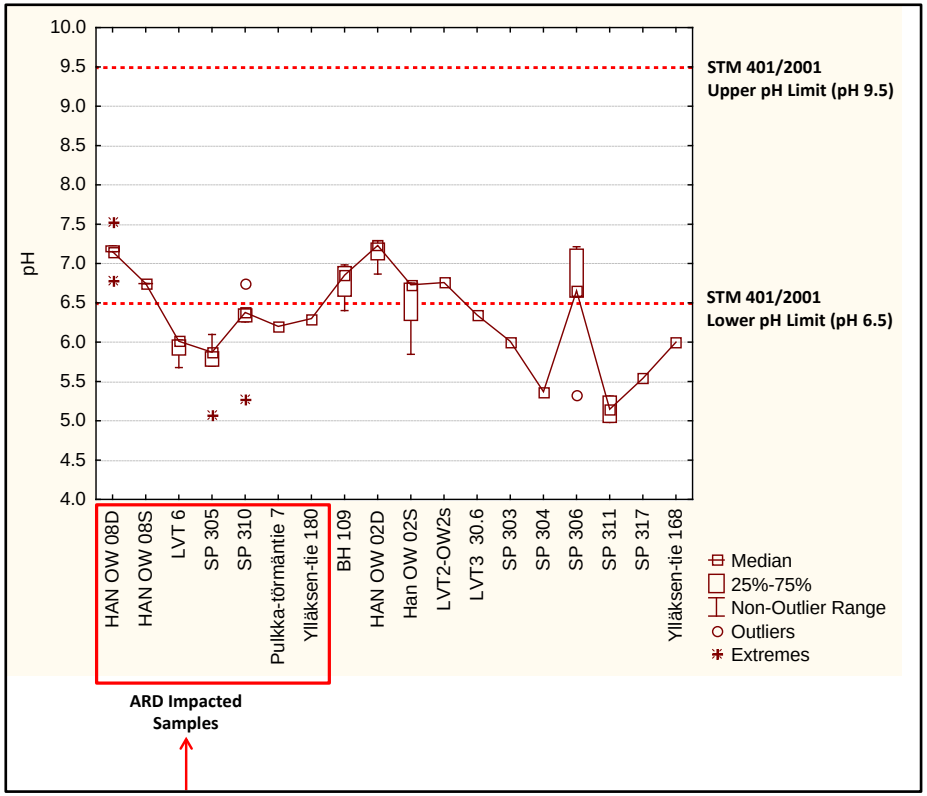


Figure 6-29: Box & Whisker plot showing pH values in Hannukainen samples

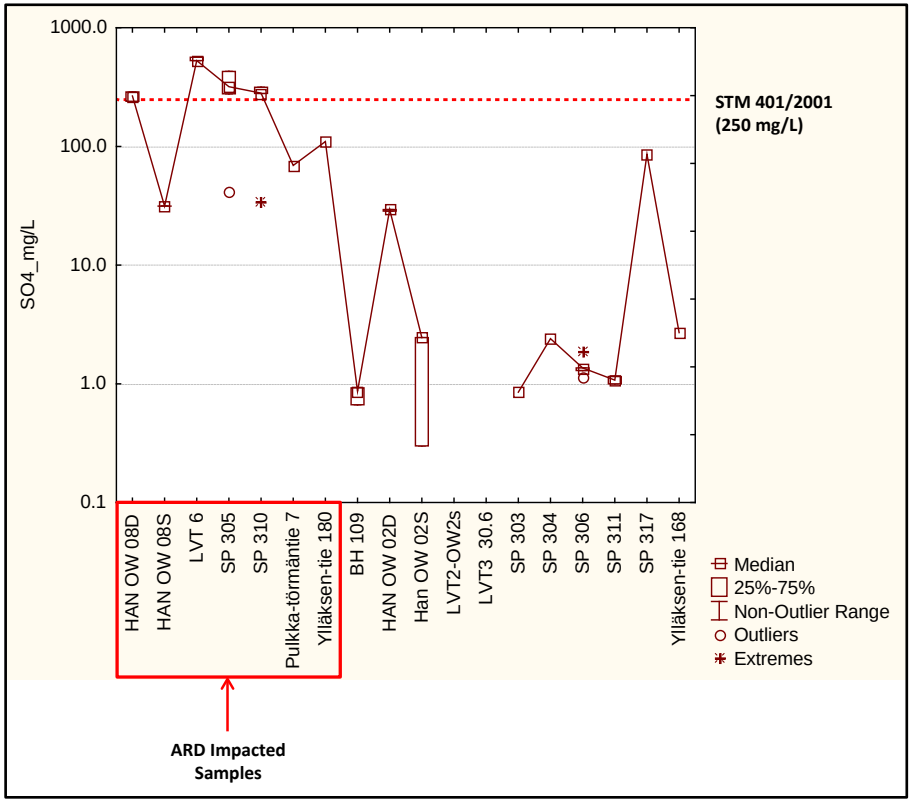


Figure 6-30: Box & Whisker plot showing sulphate concentrations in Hannukainen samples

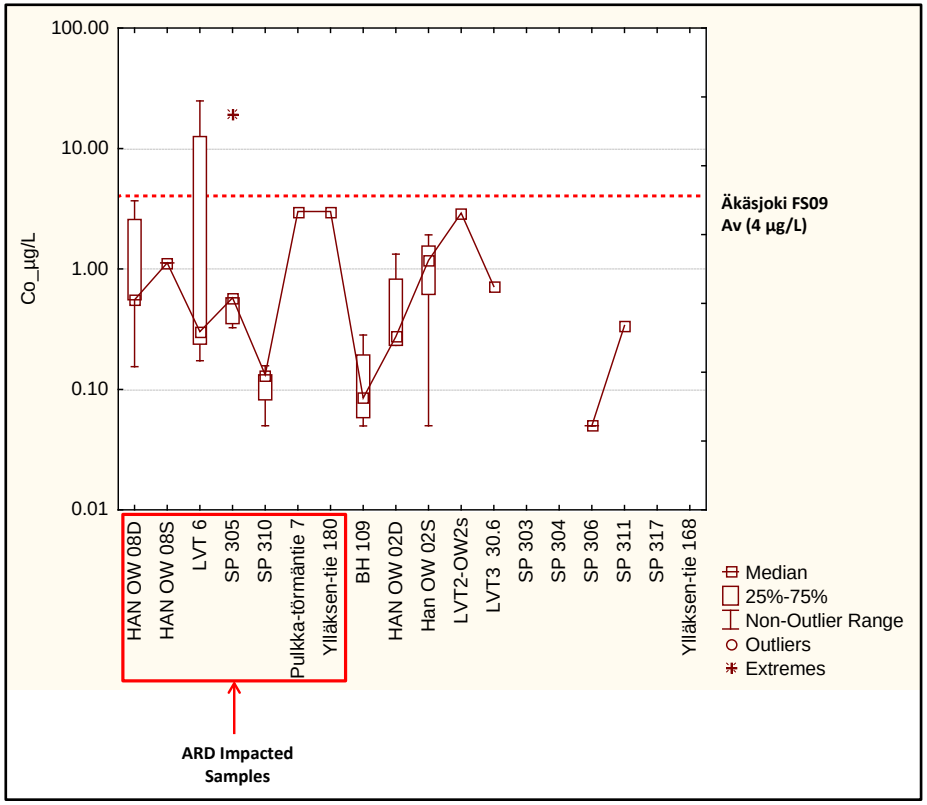


Figure 6-31: Box & Whisker plot showing cobalt concentrations in Hannukainen samples

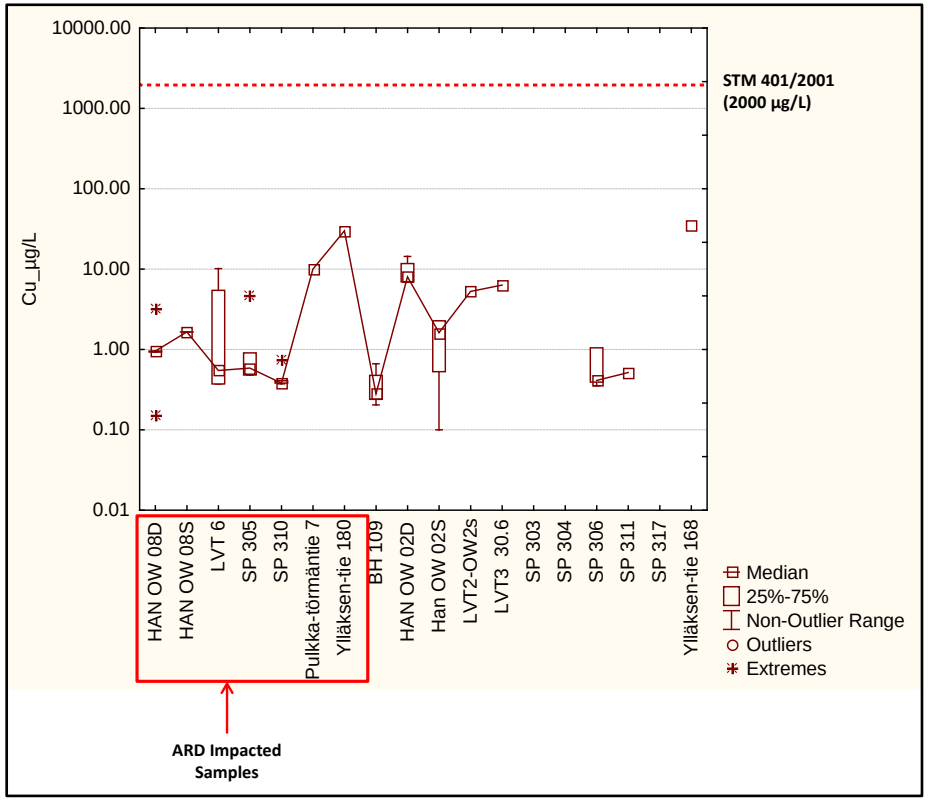


Figure 6-32: Box & Whisker plot showing copper values in Hannukainen samples

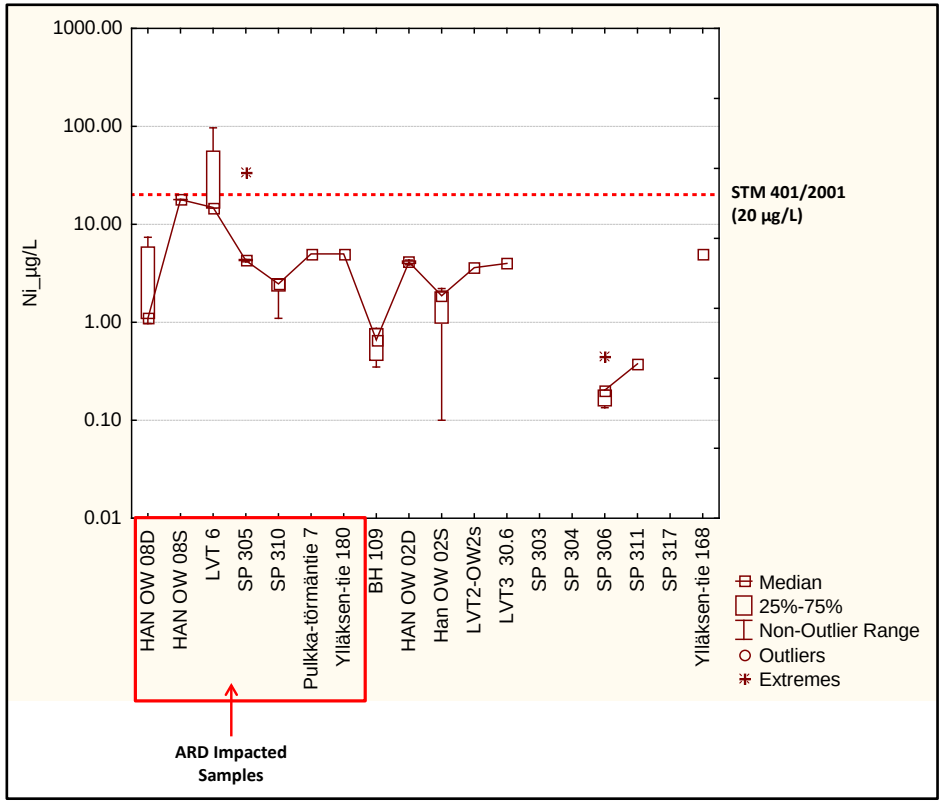


Figure 6-33: Box & Whisker plot showing nickel values in Hannukainen samples

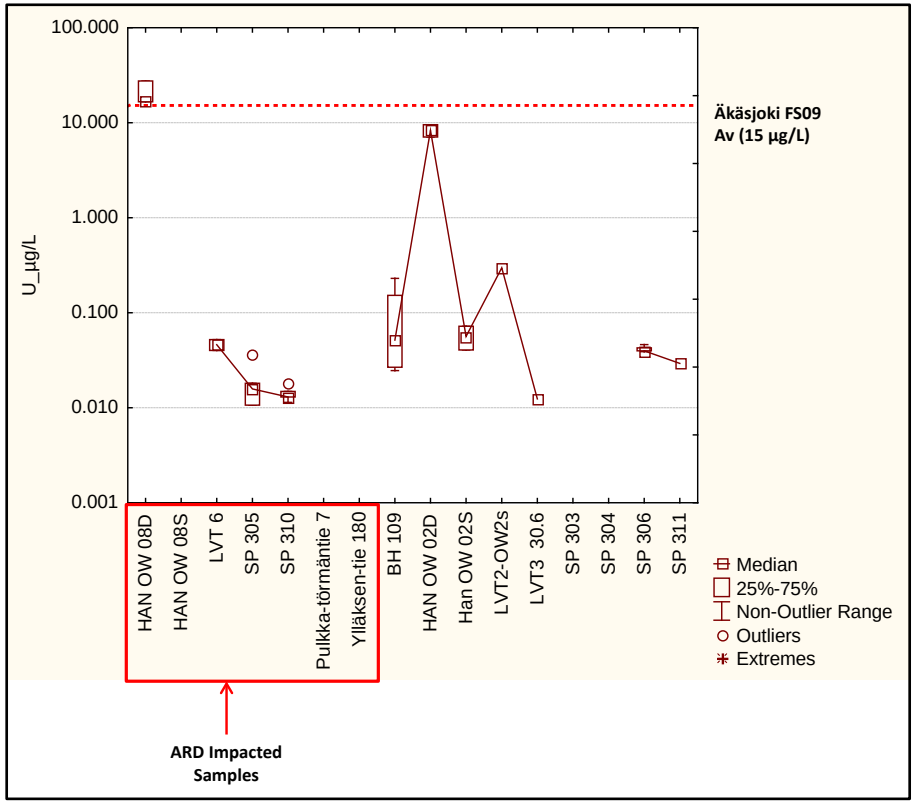


Figure 6-34: Box & Whisker plot showing uranium values in Hannukainen samples

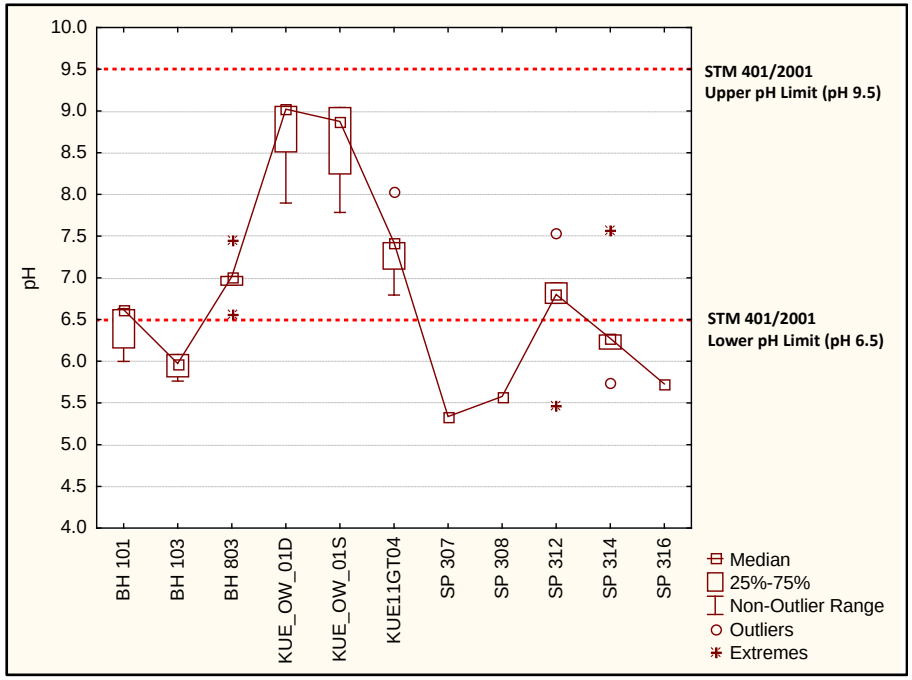


Figure 6-35: Box & Whisker plot showing pH values in Kuervitikko samples

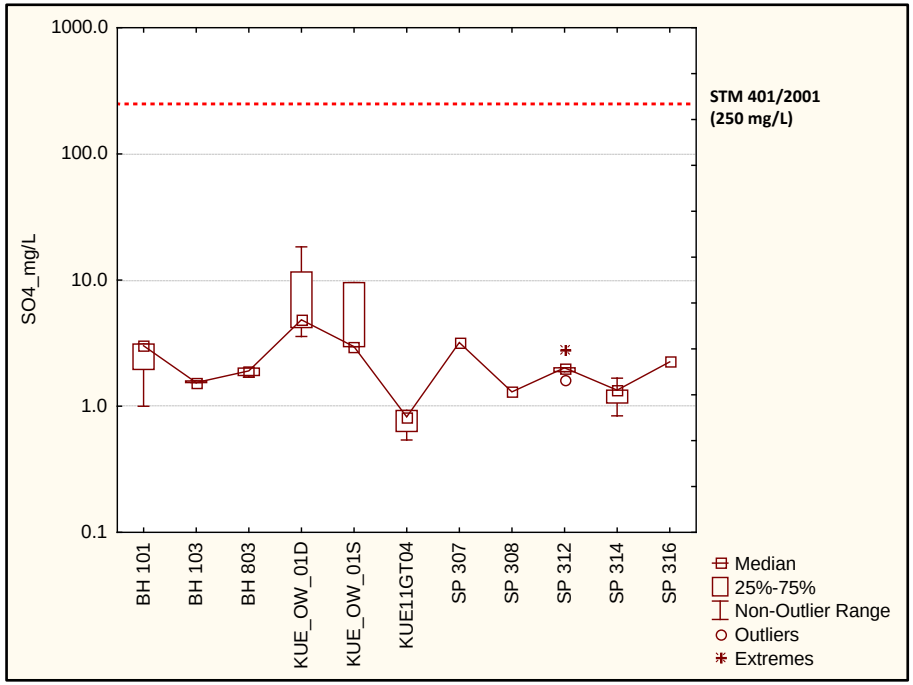


Figure 6-36: Box & Whisker plot showing sulphate concentrations in Kuervitikko samples

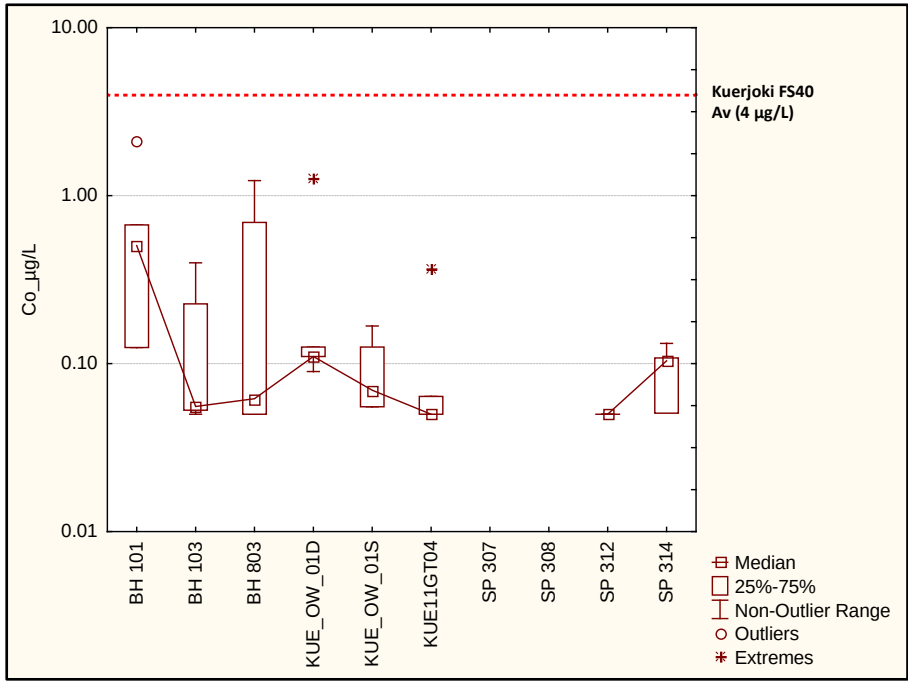


Figure 6-37: Box & Whisker plot showing cobalt concentrations in Kuervitikko samples

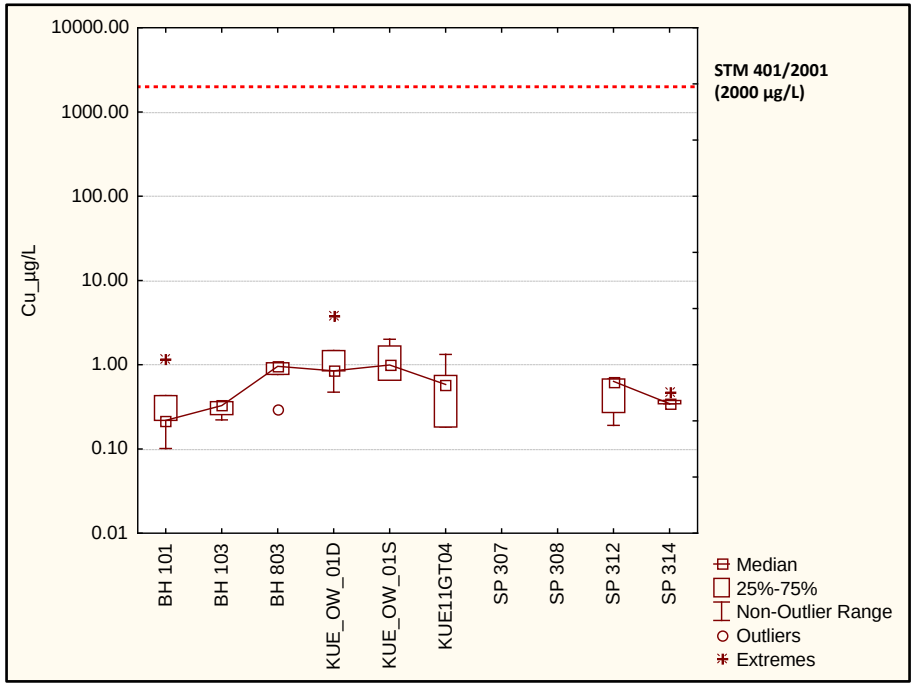


Figure 6-38: Box & Whisker plot showing copper concentrations in Kuervitikko samples

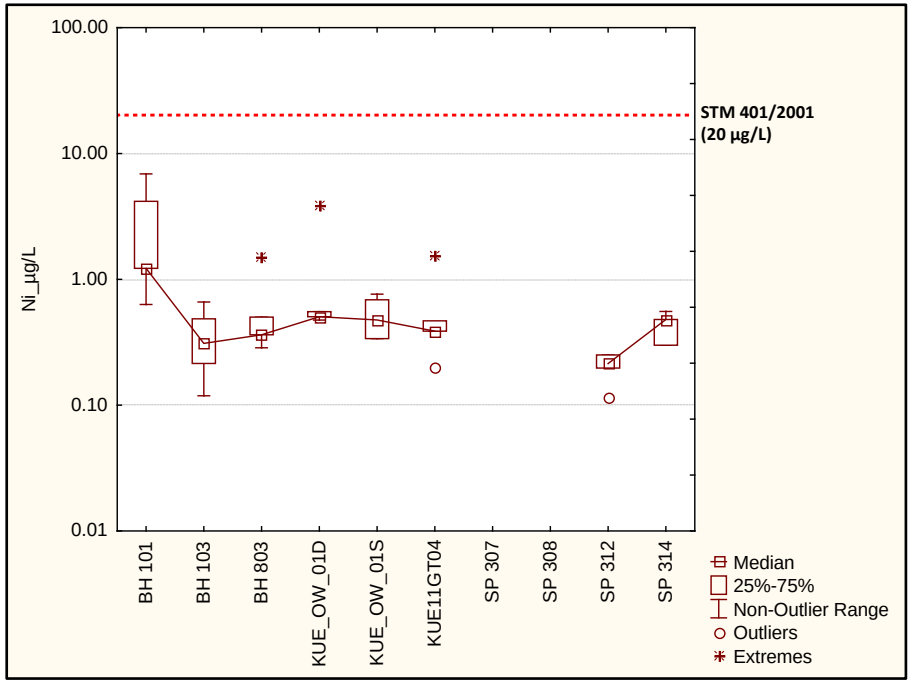


Figure 6-39: Box & Whisker plot showing nickel concentrations in Kuervitikko samples

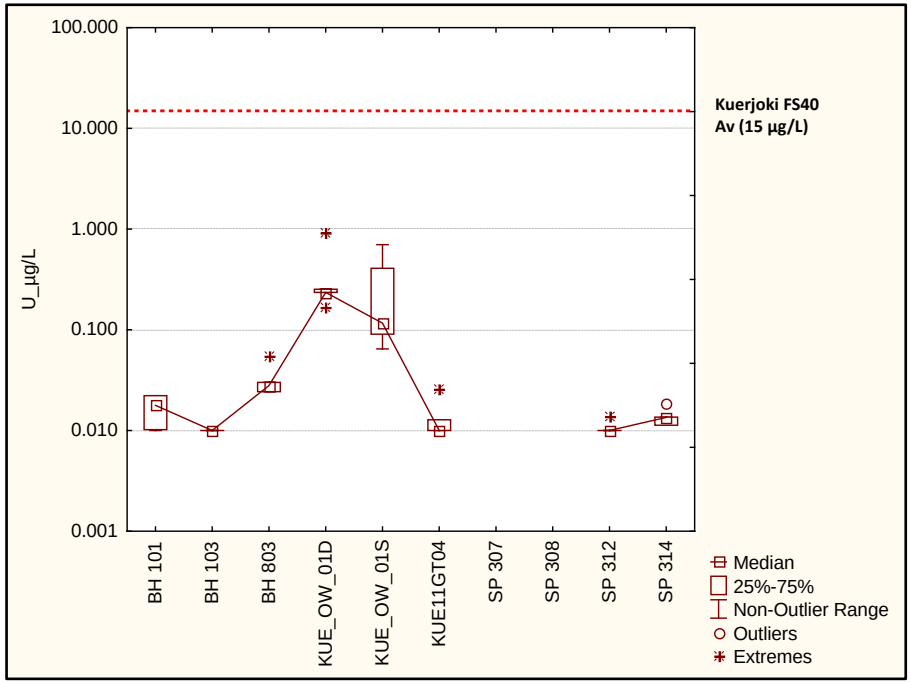
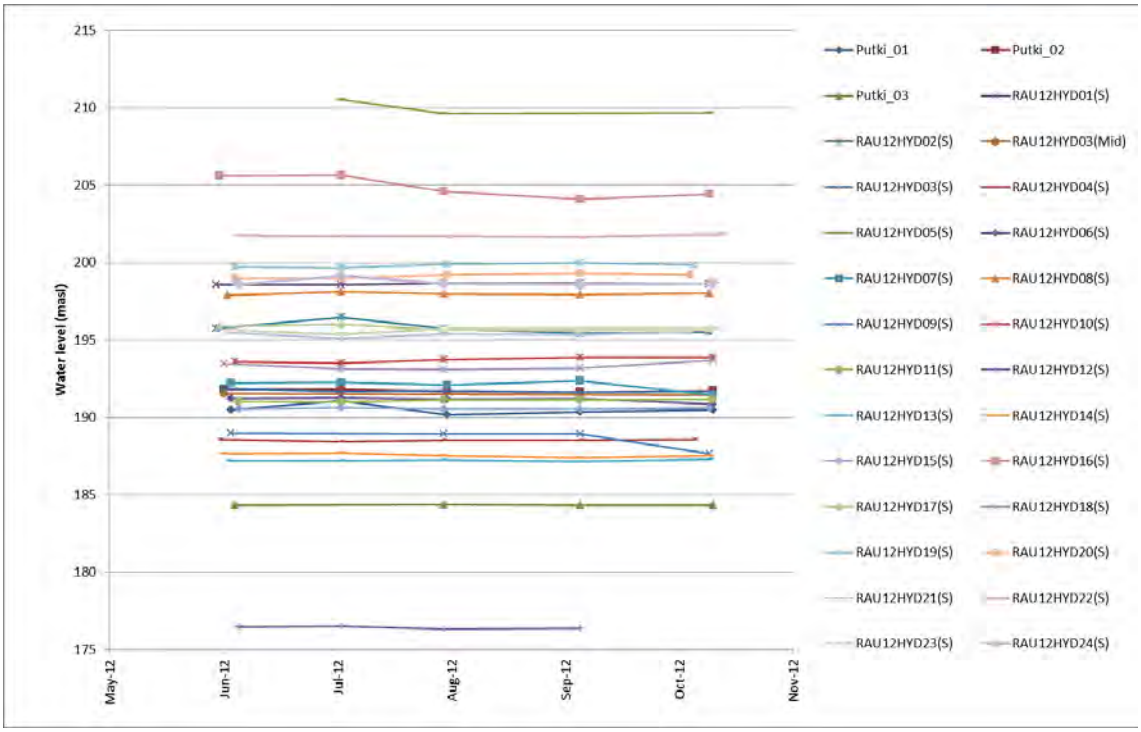


Figure 6-40: Box & Whisker plot showing uranium concentrations in Kuervitikko samples

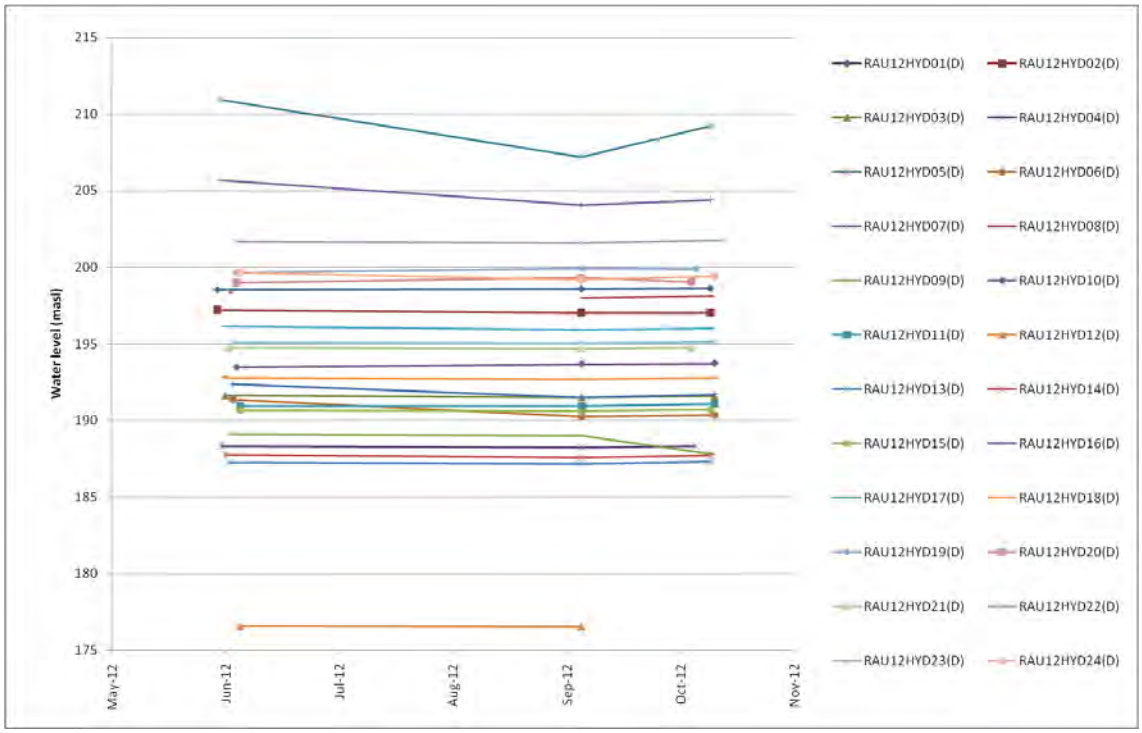
6.4.2 Rautuvaara

Groundwater Levels

Data collected manually from the Hav_putki_- and RAU12HYD- series monitoring locations is presented in Figure 6-41. Figure 6-41 contains three hydrographs; Hav_putki piezometers, RAU12HHYD- deep (D) piezometers and RAU12HYD- shallow (S) piezometers. Borehole locations are shown on Figure 5-7. A full record of the monitoring data is provided in Appendix H.



(a)



(b)

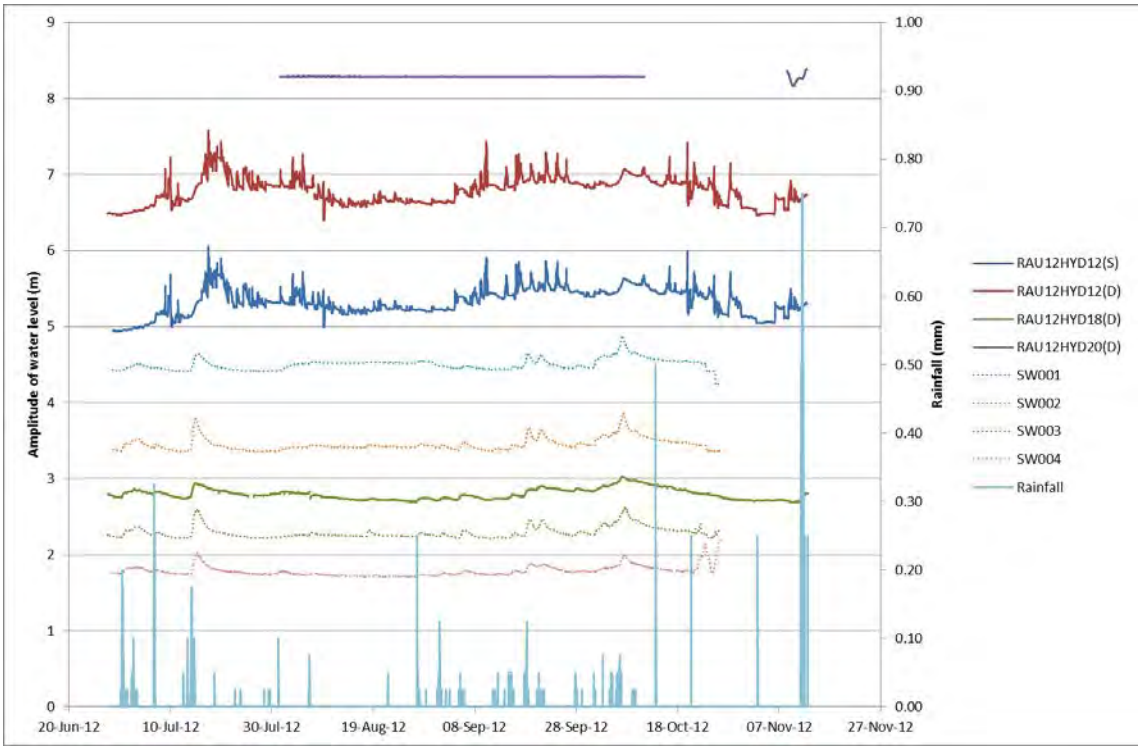
Figure 6-41: Groundwater levels recorded manually in the (a) shallow RAU12HYD-(S) and Hav_putki- series and (b) deep RAU12HYD-(D) series boreholes

Figure 6-41 demonstrates that at Rautuvaara:

- Recorded groundwater levels range from 176.31 masl to 210.95 masl;
- Groundwater is generally shallow. During the monitoring round in June 2012 the water table was recorded above ground surface at 12 (or 24%) of the piezometers, less than 1 mbgs at a further 7 (14%) of the piezometers, and less than 7 mbgs at approximately 75% of the monitoring locations;
- Generally groundwater levels do not vary significantly. Groundwater levels at an individual piezometer vary between 0.02 m to 3.72 m in the deep aquifer and 0.05 m to 1.56 m in the shallow aquifer. Approximately 80% of both shallow and deep monitoring locations record less than 0.5 m variation of water level over the monitoring period;
- Exceptions are noted below:
    - Water levels have decreased by more than 0.5 m over the monitoring period in both the shallow and deep aquifers at RAU12HYD05, RAU12HYD16, and in the deep weathered bedrock (deep) aquifer at RAU12HYD06 and RAU12HYD07 which are both located beneath the existing tailings. The majority of these locations have a small upward vertical hydraulic gradient;
    - Elevated groundwater levels are recorded in July in the shallow aquifer at RAU12HYD08(S), RAU12HYD12(S), RAU12HYD24(S) and Hav_putki-01 in response, it is assumed, to rainfall in late June / early to mid July. The three RAU12HYD- series boreholes all recorded a strong upward vertical hydraulic gradient during monitoring in June 2012. This was not observed at other boreholes in the site. Since Hav_putki-01 is a single level piezometer it is not possible to discern the nature of the hydraulic gradient at this location;
    - Water levels at RAU12HYD23(S) recorded lower water levels in July than in other months.
- Depth to groundwater at Rautuvaara ranges from -0.76 m below ground surface (bgs) (i.e. piezometric surface above ground surface) to 24.47 mbgs in the shallow piezometers and -0.59 to 24.43 mbgs in the deep piezometers. The range of 25th to 75th percentile groundwater depths in the shallow and deep piezometers is 0.49 to 4.40 mbgs and 0.12 to 7.15 mbgs respectively.

There is significant variation in seasonal recharge (Section 6.1), which may cause seasonal variations in groundwater recharge and therefore the groundwater surface. However, given the limited duration of the baseline groundwater monitoring it is not yet possible to quantify impact of seasonal recharge on groundwater levels.

The groundwater level records from the four pressure transducers are shown below in Figure 6-42 alongside surface water monitoring stations in the Niesa Basin and rainfall measured at the Kuervitikko weather station.



Note: The scale bar on the left hand side of the chart represents the amplitude of the change in water level not the absolute water level at any given monitoring location. Water level is not presented against an absolute datum and the scale is provided to demonstrate the amplitude of changes in water level at each monitoring location only.

Figure 6-42: Pressure Transducer Hydrographs Comparing Amplitude of Water Level Changes in Niesa Basin Monitoring Stations

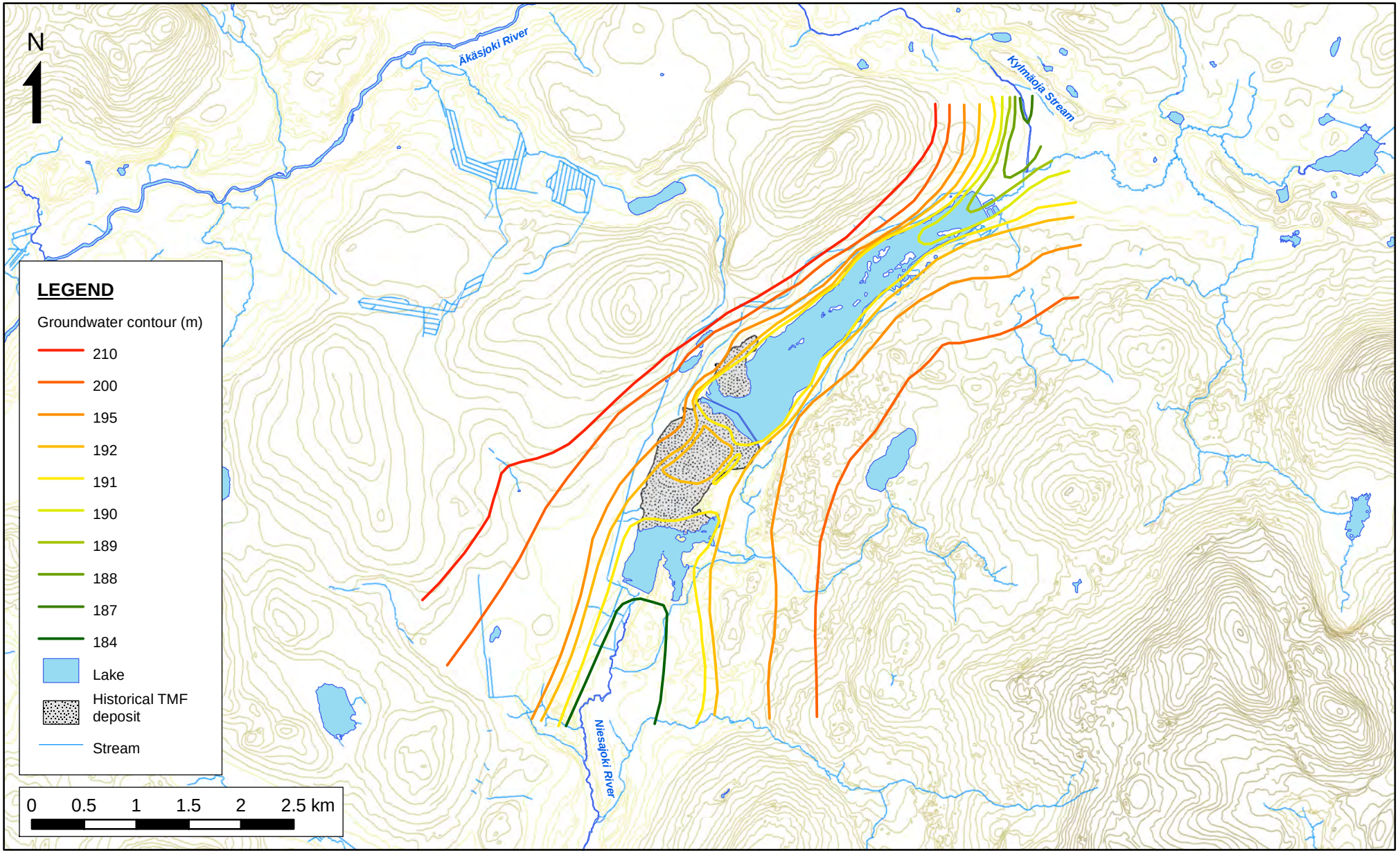
The groundwater hydrographs in Figure 6-42 show that:

- The largest range in water level response is observed in RAU12HYD12 (S+D). In contrast the response in RAU12HYD18(D) is much more subdued with no response recorded at RAU12HYD20(D);
- The records are currently not sufficient to discern seasonal groundwater trends. However, there has been a gradual increase in groundwater level at RAU12HYD12(S+D) and RAU12HYD18(D) since early to mid September which appears to correspond to the increase in rainfall with the onset of wetter, winter conditions. Since mid October groundwater levels have decreased at these locations which may be due to winter conditions and a corresponding reduction in groundwater recharge (precipitation falling as snow rather than rain);
- There is a clear response in the RAU12HYD12(S+D) and RAU12HYD18(D) records to a high rainfall event in mid July, which is also obvious in all of the surface water records. The response at RAU12HYD12(S+D) is greater than at RAU12HYD18(D), approximately 0.6 m and 0.2 m respectively;
- The response to the rainfall event on 14 July is immediate in the surface water system and occurs within about 4 hours at RAU12HYD12 and RAU12HYD18 indicating rapid groundwater recharge at these locations;

- There is an equal response in the shallow and deep piezometer at RAU12HYD12 which indicates that either the seal between the two piezometers has been compromised or that the bedrock and overburden are acting as a single aquifer at this location. Slug tests did not identify a problem with seal integrity and so it is suggested that there is a single aquifer at this well. This is the only position where loggers are installed in both the shallow and the deep piezometers; and
- The apparent static water table at RAU12HYD20 from July to September 2012 is due to equipment failure; manual readings record a change in water level of approximately 0.3 m between June and September 2012. This problem was highlighted to Northland by SRK and the issue was rectified by EHP; the logger now appears to be functioning correctly.

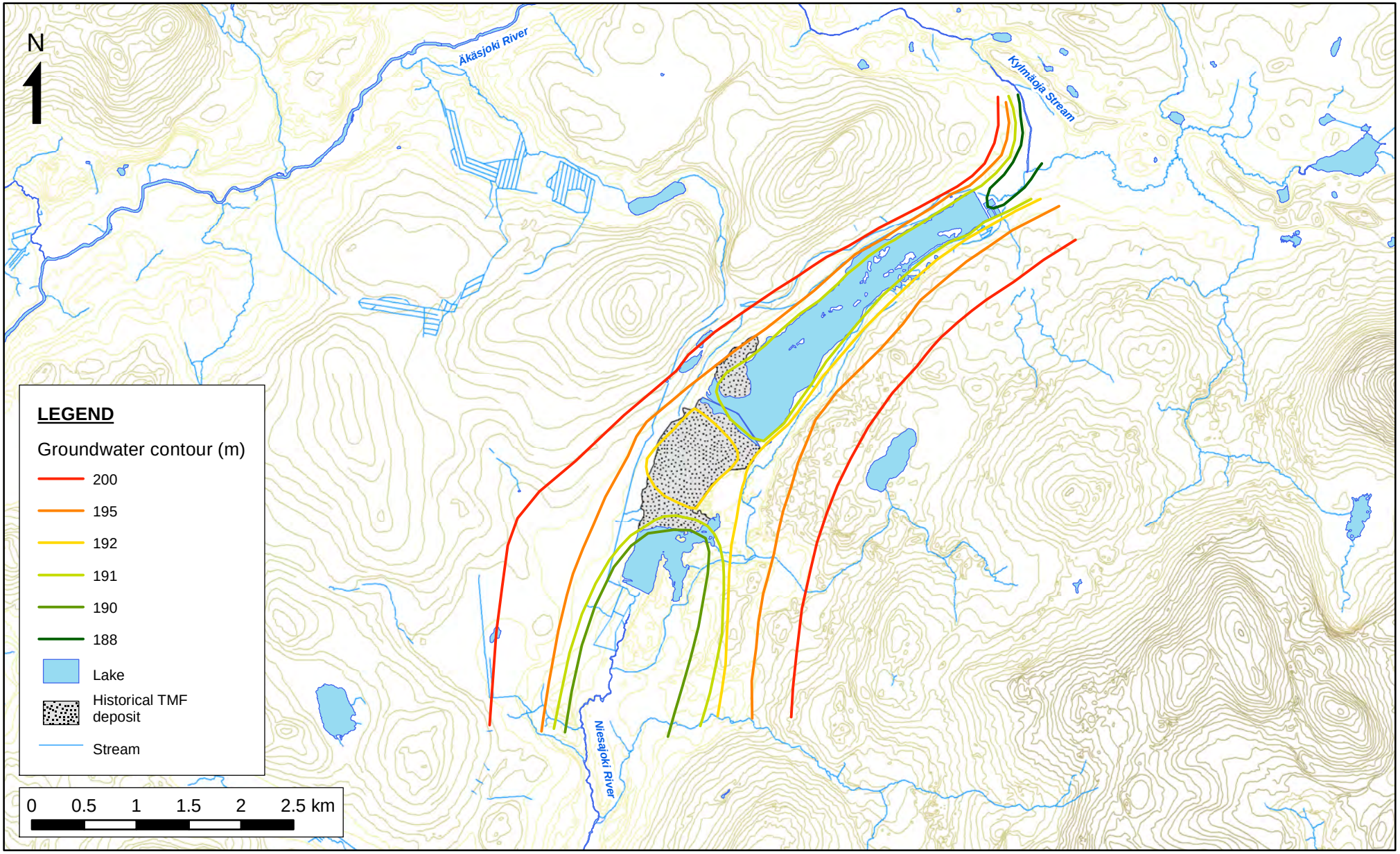
Groundwater Contours

Groundwater levels collected in June 2012 have been used to interpolate the groundwater surface in the shallow and deep aquifers in the vicinity of the existing TMF at Rautuvaara. The surfaces are provided in Figure 6-43 (shallow aquifer) and Figure 6-44 (deep aquifer).



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Groundwater Surface in the Shallow Aquifer	Figure 6.43

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-14_Shallow Water Aquifer Contours_PH2_HIA.mxd



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Groundwater Surface in the Deep Aquifer	Figure 6-44

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6-15_Deep Water Aquifer Contours_PH2.mxd

Figure 6-43 and Figure 6-44 illustrate that:

- Similar trends are observed in the groundwater surfaces of both shallow and deep aquifers;
- Groundwater surfaces generally mirror topography;
- On a semi-regional scale groundwater is generally unconfined and so there is a single groundwater surface (i.e. groundwater surface for the shallow and deep aquifers is the same). However, at a local scale there may be several groundwater bearing horizons separated by low permeability horizons which induce locally confined conditions meaning that there is not a single continuous groundwater body in the shallow and deep aquifers; and
- There is a groundwater divide located in the existing tailings pile which marks the limit between groundwater that flows north towards the North Pond and the Kylmäoja Stream and south towards the South Pond and the Niesajoki River. The location of the groundwater divide is consistent with the previous study by GTK (GTK, 2010a).

Surface water – Groundwater Interaction

The groundwater levels collected in June 2012 are summarised in Table 6-50. Geological logs and water level in each piezometer are show on the borehole logs in Appendix D.

From the data in Table 6-50 it can be observed that:

- Downward vertical hydraulic gradients are observed in the majority of wells located on the hillside to the southeast of the existing facility. Downward gradients are also observed in boreholes on the hillside to the northwest in dry areas (RAU12HYD22 and RAU12HYD05). A downward vertical hydraulic gradient in an unconfined system indicates that water is moving down from the surface to recharge the aquifer beneath;
- Groundwater at the northern crest of the existing tailings facility (RAU12HYD03) is more than 4 mbgs and indicated a downward vertical hydraulic gradient. Conversely, in the central and southern toe of the existing tailings facility (RAU12HYD07 and RAU12HYD06 respectively) groundwater level was recorded to be above ground surface in June 2012 and there was a slight upward vertical hydraulic gradient. In this case this may indicate that groundwater is moving upward from depth rather than representing a confined aquifer conditions;
- There is evidence of perched groundwater in some locations. For example, at RAU12HYD20 depth to groundwater in the shallow aquifer is approximately 24.4 m yet the well is located in a wetland. It is inferred that the wetland is sustained by a perched groundwater system;
- Upward vertical hydraulic gradients are observed in the boreholes located close to the Kylmäoja Stream and in the majority of the boreholes located in wetland areas, supporting the assertion that groundwater provides baseflow to local rivers and wetland areas; and
- Flowing artesian conditions were observed at one borehole (RAU12HYD24(D)), located in a wetland in the southern portion of the Niesa Basin. The flow rate recorded in June 2012 was approximately 0.001 L/s.

From the observed groundwater gradient (Figure 6-43 and Figure 6-44) and water level data it is inferred that groundwater flows from the interfluves (i.e. ridges and higher ground), down gradient towards the lakes and rivers in the base of the valleys. Groundwater emerges into these surface water bodies as baseflow and also sustains wetland areas which are present throughout the Niesa Basin.

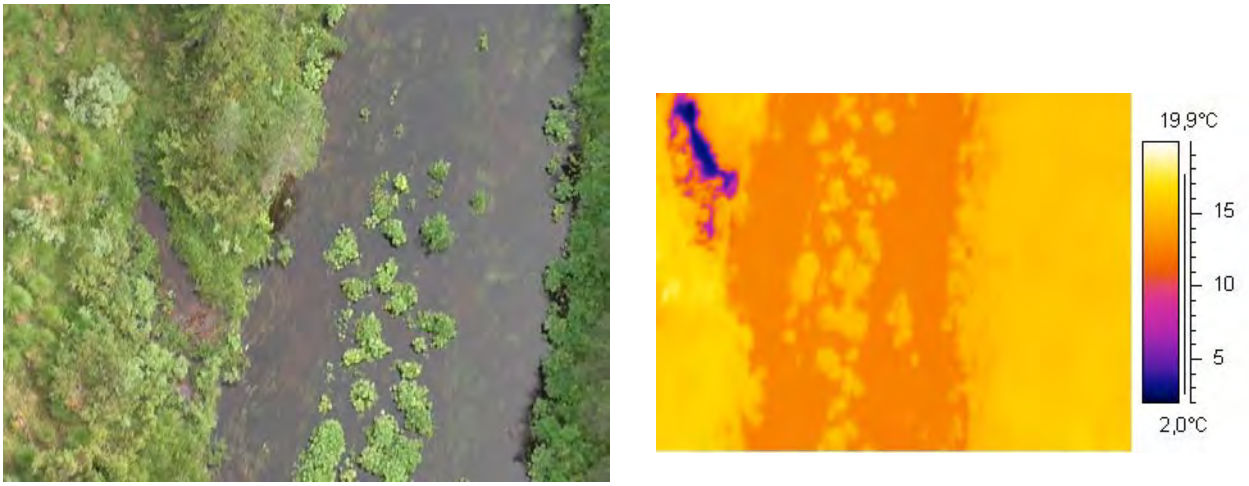
This model is supported by preliminary findings of the University of Helsinki aerial thermal imaging study, which has identified numerous areas where groundwater is seeping in to the surface water system (Figure 6-45). The images in Figure 6-45 show examples of the emergence of colder groundwater in to warmer surface water bodies.

Table 6-50: Groundwater Levels Collected in June 2012

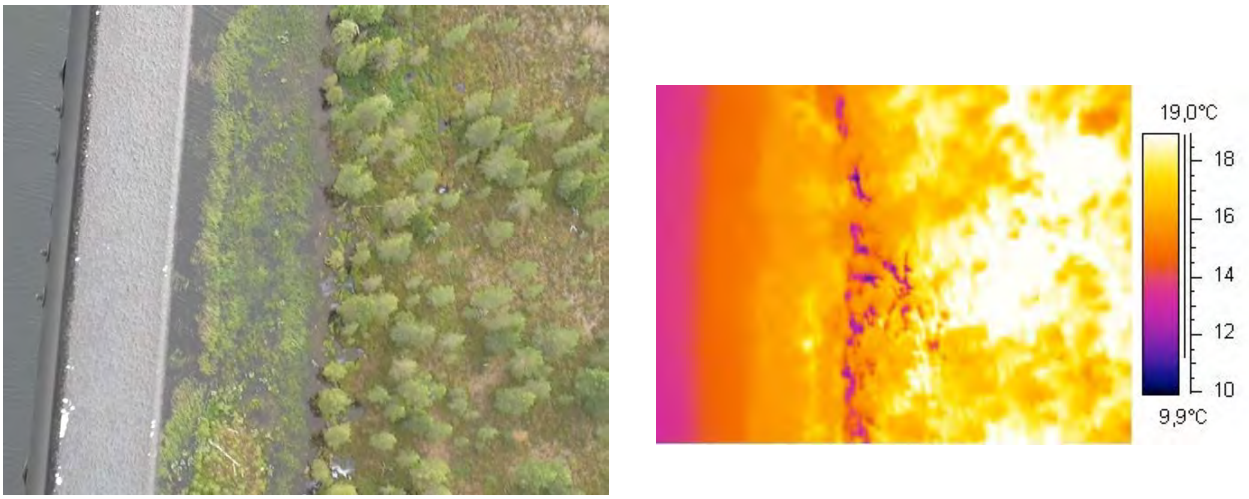
Borehole	Shallow WL (mbgs)	Deep WL (mbgs)	Hydraulic gradient	Aquifer characteristic[2]
Unconfined				
RAU12HYD01	8.07	8.11	Level	Unconfined
RAU12HYD03[1]	4.68	4.89	Downward	Unconfined
RAU12HYD04	1.14	1.41	Downward	Unconfined
RAU12HYD06[1]	-0.46	-0.58	Slight upward	Unconfined – upward hydraulic gradient thought to be due to upwelling of groundwater to the surface rather than confined aquifer conditions
RAU12HYD07[1]	-0.05	-0.19	Slight upward	Unconfined – upward hydraulic gradient thought to be due to upwelling of groundwater to the surface rather than confined aquifer conditions
RAU12HYD10	8.22	8.34	Downward	Unconfined
RAU12HYD11	5.39	5.49	Downward	Unconfined
RAU12HYD12	0.04	-0.02	Level	Unconfined
RAU12HYD13	7.14	7.13	Level	Unconfined
RAU12HYD14	2.69	2.58	Slight upward	Unconfined – upward hydraulic gradient thought to be due to upwelling of groundwater to the surface rather than confined aquifer conditions
RAU12HYD15	2.43	2.32	Slight upward	Unconfined –upward hydraulic gradient thought to be due to upwelling of groundwater to the surface rather than confined aquifer conditions
RAU12HYD16	-0.52	-0.59	Level	Unconfined
RAU12HYD18	0.84	1.48	Downward	Unconfined
RAU12HYD19	14.25	14.31	Level	Unconfined
RAU12HYD20	24.47	24.43	Level	Unconfined
RAU12HYD21	-0.76	-0.07	Downward	Unconfined
RAU12HYD22	3.03	3.14	Downward	Unconfined
RAU12HYD23	19.79	20.36	Downward	Unconfined
Confined				
RAU12HYD17	0.18	-0.08	Upward	Semi-confined
RAU12HYD02	1.86	0.37	Upward	Confined
RAU12HYD05	DRY	4.92	Upward	Confined
RAU12HYD08	0.10	-0.38	Upward	Confined
RAU12HYD09	5.00	4.87	Upward	Confined
RAU12HYD24	0.53	-0.54	Upward	Confined

[1] *Located in the existing tailings facility*

[2] *If the groundwater elevation is greater in the shallow aquifer than the deep aquifer the vertical hydraulic gradient is downwards indicating that water moves downwards from the shallow to the deep aquifer. The deep aquifer can generally be described as unconfined in these circumstances. Conversely, a higher water level in the deep aquifer than the shallow indicates that water is moving from the deep aquifer upwards to the shallow aquifer. This may indicate that the deep aquifer at this location is confined, or that groundwater is moving from the deep aquifer to the shallow aquifer at this location.*



(a)



(b)

Figure 6-45: Preliminary Thermal Imaging Results from the University of Helsinki Study

Aquifer Properties

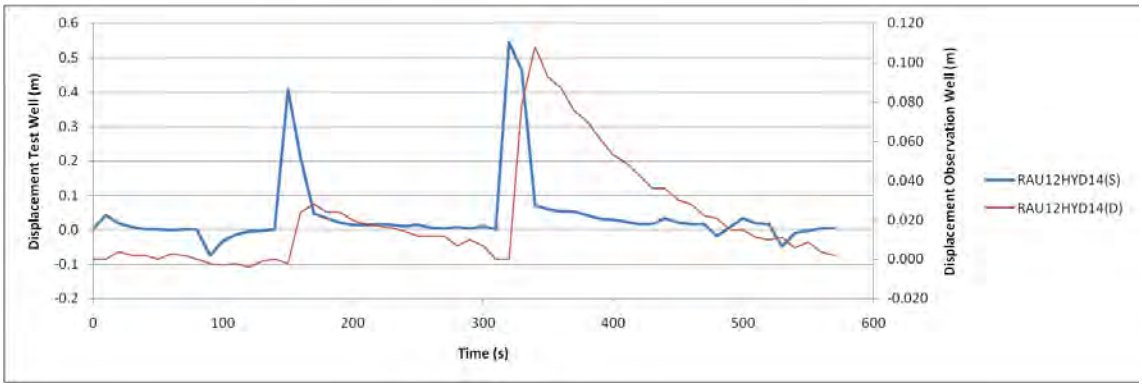
The aquifer properties of the shallow overburden and underlying weathered bedrock were investigated by means of blow yield testing and penetration rate monitoring during drilling and subsequently through groundwater level monitoring, slug tests and falling head tests in the piezometer installations.

Aquifer Characteristics

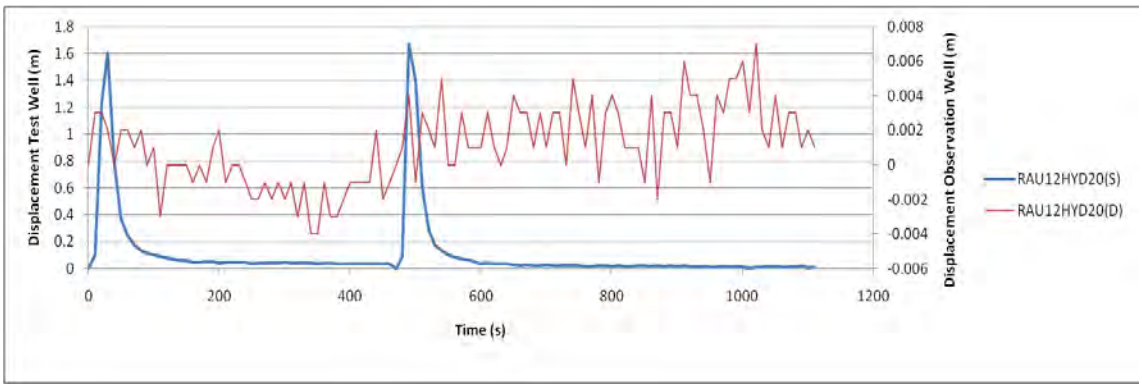
Geological logs, water levels and slug test observations at each well were used to determine the characteristics of the aquifer:

- Groundwater elevation was measured in the shallow and deep aquifer in June and September 2012 and they have been compared to one another within the context of the geological log; and
- During slug testing the groundwater level in the nested piezometer was monitored to capture any interaction between the bedrock and overburden aquifers.

Water levels have been discussed previously and are summarised in Table 6-50. An example of slug test response data is given in Figure 6-46.



(a)



(b)

Figure 6-46: Examples of slug test observation data from Rautuvaara showing (a) a strong response in the deep aquifer and (b) no response in the deep aquifer to tests in the shallow aquifer

Slug testing responses can broadly be divided into three categories

- Response - either full interaction between aquifers (9%) or response in only the deep aquifer (9%) or shallow (22%) aquifer;
- No response (35%); and,
- Response unknown due to inconclusive (22%) or insufficient (4%) data.

It can be seen from the slug test response data that the aquifer units at Rautuvaara are heterogeneous, i.e. connection between the shallow and deep aquifers varies throughout the site on a local scale.

As has been discussed previously, groundwater elevation in the shallow aquifer is generally higher than in the deep aquifer, indicating a downward hydraulic gradient and unconfined conditions across the majority of the Rautuvaara site.

Hydraulic Properties: Shallow and Deep Aquifers

Penetration rate, slug tests and falling head tests have been used to determine the hydraulic properties of the site. The methodologies are summarised in Section 5.3.2 and details are included in the interim Phase 4 report (SRK, 2012a).

The penetration rates are summarised in Figure 6-47.

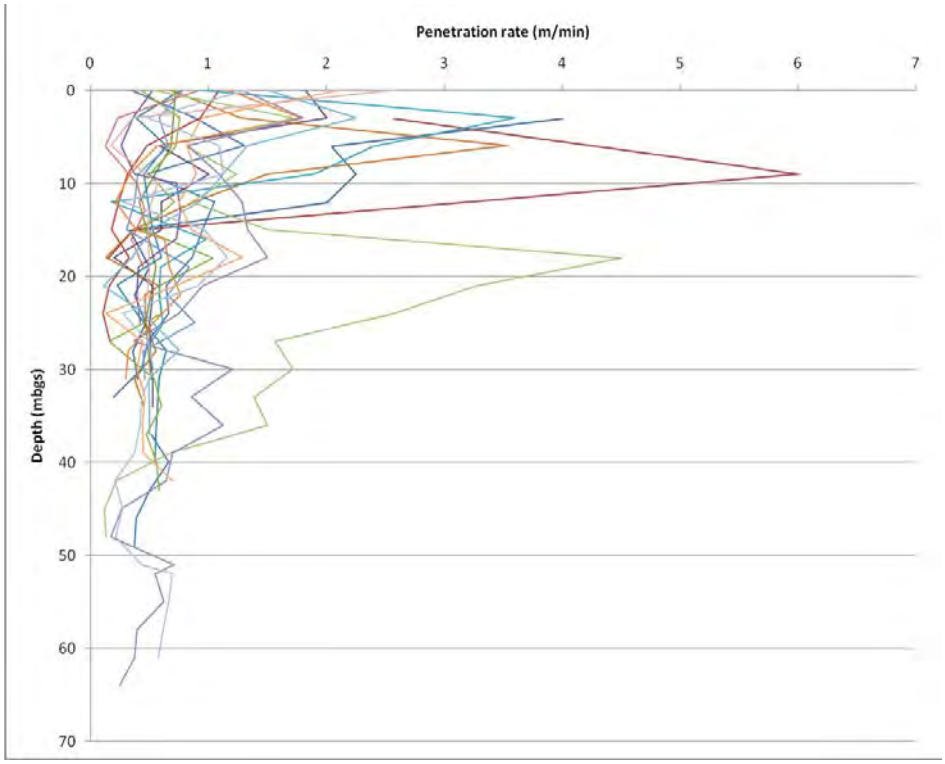


Figure 6-47: Penetration Rates Recorded During Drilling.

The drilling data indicates that penetration rate generally decreases with increasing depth. Penetration rate is generally in the order of 0.5 m/min to 2 m/min with rates up to 6 m/min recorded through the overburden sediments at 5 wells (RAU12HYD03(Mid) (red), RAU12HYD06 (dark blue), RAU12HYD10 (orange), RAU12HYD15 (light blue) and RAU12HYD19 (green)).

The penetration rate data is a useful indicator of the strength of the rock mass from which, to some degree, a broad inference on hydraulic properties can be made.

Slug tests and falling head tests (see Section 5.3.2) were used to estimate aquifer hydraulic conductivity. It was not possible to determine storage parameters because the duration of the tests was too short. A full record of the results is provided in Appendix E.

Generally the hydraulic conductivity of the tailings and the overburden are similar (approximately 3 – 4 m/d) and at most locations hydraulic conductivity of the weathered bedrock (deep aquifer) is lower (median of 0.3 m/d) than the overburden (shallow aquifer). There were five exceptions;

- RAU12HYD03 – located at the crest of the tailings dam so that the shallow piezometer is located in tailings rather than overburden material;
- RAU12HYD11 – very rapid oscillatory response in the deep aquifer;
- RAU12HYD12 – Similar K values in the deep and shallow piezometers. Considerable volume of water recorded in the drill logs in the bedrock unit. There was nothing noted in the geological log to explain this, and penetration rate was not recorded in the bedrock unit so it is not possible to determine the degree to which the rock may be fractured at this location. Hydrographs show the same response in the deep and shallow piezometers (Figure 6-42) suggesting that there is a single aquifer at this location;
- RAU12HYD15 – Generally the penetration rate decreases with depth but there is one high blow yield test result. This could indicate a weaker zone attributed to increased fracturing. A discrete fracture could be producing water therefore increasing K in the bedrock; and
- RAU12HYD17 – There is a high penetration rate in the upper part of the bedrock aquifer and one high blow test yield which may indicate a water bearing fracture in the bedrock at this location.

It should be noted that in three locations (RAU12HYD11(D), RAU12HYD16(S) and RAU12HYD21(S)) the water level oscillated in response to the slug testing. This may be due to very high K values or water oscillating in the gravel pack material rather than interacting with the aquifer.

Hydraulic Properties: Tailings Material

During the field visit, it was noted that the hydraulic properties of the existing tailings material at Rautuvaara vary depending on location relative to the point of discharge. The tailings are coarser in proximity of the northern boundary as it corresponds to the area where tailings were discharged. The tailings gradually become finer towards the southern boundary of the deposited tailings.

The piezometric level is about 5 m below ground surface in the northern area where the tailings are coarser. To the south, the piezometric level gradually becomes shallower relative to the ground surface until the tailings become submerged.

Excavation in the tailings beach indicated that the tailings can be sensitive to liquefaction, especially towards the southern areas where the tailings are finer. The excavation and the associated vibration were sufficient to induce pore pressure build-up within the tailings that subsequently triggered liquefaction of the tailings. Such phenomenon is typical of fine grained tailings that are subject to vibration. Additionally, it is possible that the fine grained tailings confine the aquifer and create artesian conditions in some areas, given that the tailings beach is located at the bottom of the valley.

Hydraulic Properties: Summary

A summary of the estimated hydraulic conductivity is given in Table 6-51 and Figure 6-48 below. Full results are provided in Appendix E.

Table 6-51: Summary of Aquifer Hydraulic Conductivity (K)

	Shallow Aquifer (or overburden) K (m/d)	Deep Aquifer (or weathered bedrock) K (m/d)	Tailings K (m/d)
Number of tests	54	52	4
Minimum	0.07	0.0002	0.64
Maximum	26.97	9.91	7.51
Average	3.02	1.18	3.67
25th Percentile	0.71	0.05	2.15
75th Percentile	4.10	0.44	5.19

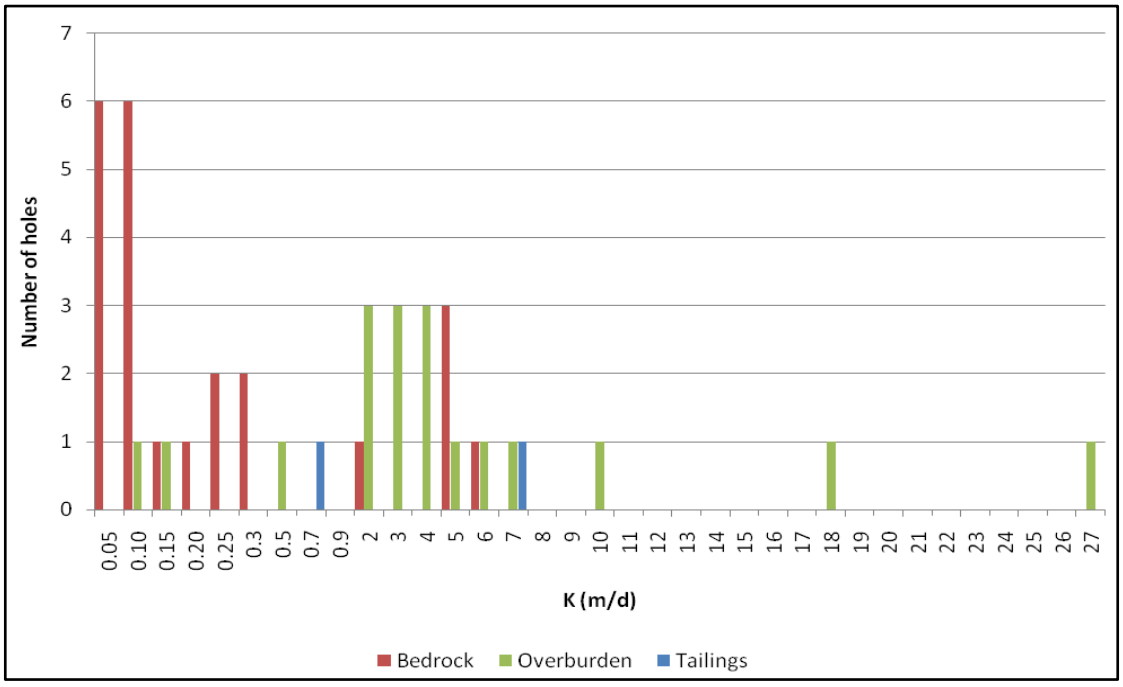


Figure 6-48: Summary of Hydraulic Conductivity Estimates at Rautuvaara

Water Quality

Water quality results for boreholes at the Rautuvaara site are included in Table 6-52 and Table 6-53. Water quality within the groundwater has been assessed against the water quality objectives determined for the Niesajoki River at FS15 in order to highlight potential elevated concentrations of parameters.

pH levels for all samples range from 6 to 8 (circum-neutral) apart from RAU12HYD01(S) which showed a slightly alkaline pH of 9.

Sulphate concentrations are taken to be an indicator of impact from historical mine workings (including the tailings facilities) and are significantly elevated above TVs or AVs in the following holes; RAU12HYD01 to RAU12HYD03 in both deep and shallow piezometers, all GTK holes and also in the deep piezometers of RAU12HYD07 and RAU12HYD15. In general samples with elevated sulphate also show elevated concentrations of cobalt, nickel, zinc, manganese and iron.

Arsenic concentrations are generally below AVs and TVs in all piezometers apart from at RAU12HYD07(D) where a concentration of 0.009 mg/L was reported, exceeding the AV WQO of 0.005 mg/L. Cadmium concentrations only exceed the AV of 0.00008 mg/L within sample RAU02HYD12(S) where it is reported as 0.00015 mg/L. Cobalt is elevated relative to AV WQOs in samples RAU12HYD02 and RAU12HYD19(S) and exceeds the AV in samples RAUHYD03, RAU12HYD18(S), Hav_putki_1 and Hav_putki_2. Chromium exceeds the AV WQO of 0.001 mg/L in samples collected from RAU12HYD17 plus RAU12HYD04(D), RAU12HYD08(D), RAU12HYD10(S) RAU12HYD19(S) RAU12HYD03, RAU12HYD13(S), Hav_putki_1 and RAU12HYD23(D).

Manganese concentrations are only slightly elevated relative to the AV in sample RAU12HYD02 with a maximum concentration of 0.728 mg/L reported compared to a WQO of 0.70 mg/L. Nickel is also elevated relative to the AV in sample RAU12HYD02 with a maximum value of 0.17 mg/L reported relative to a WQO of 0.02 mg/L. Lead exceeds the AV of 0.0072 mg/L in samples RAU12HYD19(D) and RAU12HYD20(D). Zinc only slightly exceeds the AV WQO level of 0.03 mg/L in sample RAU12HYD02(S) where a maximum concentration of 0.048 mg/L is reported. Uranium concentrations exceeded the FS15 TV in a number of wells however, the AV is only exceeded in samples RAU12HYD03(S) and RAU12HYD07(D)

Table 6-52: Water quality concentrations for key parameters in groundwater at the Rautuvaara site compared to FS15 WQOs

Parameter	Unit	WQO – FS15		HYD01		HYD02		HYD03			HYD04		HYD05	HYD06		HYD07		HYD08		HYD09	
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Shallow	Deep	Shallow	Deep	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
		Number of Samples		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.8	6.9	6	6.1	6	6.1	6.1	6.6	6.5	6.8	7.3	7.3	7.4	6.8	7.1	7.1	7.2	7
Suspended solids	mg/L	3	25	67	44	9	9	195	322	249	43	15	2	348	405	224	697	67	85	32	29
Ammonium	mg/L	0.101	1	0.003	0.003	0.013	0.025	0.25	0.003	0.105	0.145	0.003	0.003	0.233	0.038	0.113	0.16	0.02	0.003	0.003	0.02
Nitrate as N	mg/L	0.279	20	0.0042	0.3094	0.0035	0.0051	0.00358	0.00481	0.00446	0.005	0.0105	0.012	0.0522	0.0957	0.00219	0.00314	0.029	0.0428	0.00272	0.00835
Chloride	mg/L	3	150	2.68	2.12	6.4	4.81	11.6	20.5	28.2	1.27	0.33	0.69	1.56	1.19	4.21	4.19	1.22	0.75	1.35	1.08
Sulphate	mg/L	89	159	120	130	365	276	1306	2493	4881	16	3	5	37	3	92	54	17	1	4	9
Iron	mg/L	0.92	4.07	0.017	0.009	0.001	0.009	13.6	265	519	0.017	0.023	0.001	0.169	0.049	0.012	0.131	0.537	0.012	0.041	0.122
Aluminium	mg/L	0.05	0.1	0.0055	0.002	<0.0005	0.0435	0.0011	0.142	0.26	0.0467	0.0246	0.0042	0.284	0.034	0.0096	0.0034	1.047	0.0077	0.0097	0.0011
Arsenic	mg/L	0.0012	0.005	0.0001	0.0001	<0.00005	0.0001	0.0004	0.0001	0.0002	0.0003	0.0001	0.0001	0.0003	0.0006	0.0093	0.0006	<0.00005	<0.00005	0.0002	0.0001
Cadmium	mg/L	0.00001	0.00008	0.000011	0.000005	<0.00001	0.00015	0.0001	<0.000005	<0.000005	<0.000005	<0.000005	0.000025	<0.000005	0.00004	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005
Cobalt	mg/L	0.002	0.004	0.0038	0.0006	0.0214	0.0721	0.139	0.0579	0.0454	0.0011	0.0004	0.0001	0.0006	0.0006	0.0007	0.001	0.0006	<0.00005	0.0005	0.001
Chromium	mg/L	0.0003	0.001	0.0002	0.0002	<0.0001	<0.0001	0.0017	<0.0001	0.0038	0.0024	0.0006	0.0004	<0.0001	0.0004	0.0009	0.0002	0.0015	0.0005	<0.0001	<0.0001
Copper	mg/L	0.0048	0.005	0.0011	0.001	0.0006	0.103	0.0025	0.0008	0.0007	0.0017	0.0002	0.0006	0.0002	0.0003	0.0007	0.0001	0.0022	0.0001	0.0011	0.0017
Manganese	mg/L	0.294	0.7	0.444	0.128	0.726	0.728	9.66	27.35	57.76	0.111	0.054	0.0003	0.0377	0.0353	0.326	0.395	0.0591	0.0151	0.162	0.0274
Molybdenum	mg/L	0.0002	1	0.0004	0.0002	<0.00005	0.0001	0.0004	0.0009	0.0027	0.0005	0.0002	0.0005	0.0001	0.0005	0.0043	0.0008	0.0011	0.0003	0.0003	0.0001
Nickel	mg/L	0.007	0.02	0.0038	0.0028	0.0505	0.171	0.0641	0.025	0.0069	0.0048	0.0009	0.0004	0.0004	0.0026	0.0061	0.0026	0.0018	0.0004	0.0008	0.0017
Lead	mg/L	0.0001	0.0072	0.0001	0	0.0001	0	0.0001	0.0006	0.0002	0.0003	<0.00002	0	0.0001	0.0001	0.0001	0.0001	0.0003	<0.00002	0.0001	0
Zinc	mg/L	0.002	0.03	0.0065	0.0026	0.0098	0.0485	0.0265	0.0334	0.013	0.0119	0.0007	0.0007	<0.0005	<0.0005	0.0012	0.0006	0.0036	0.0006	0.0015	0.0073
Uranium	mg/L	0.0004	0.015	0.0001	0.0002	<0.00001	0.00004	0.0063	0.0118	0.1253	0.0001	<0.00001	0.0003	0.0001	0.0001	0.0203	0.0032	0.0002	0.0001	0.0006	0.00003

Note: Sample ID using Lab codes which omit the RAU12- suffix and parenthesis, i.e. HYD01D = RAU12HYD01(D);
Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Parameter	Unit	WQO – FS15		HYD10		HYD11		HYD12		HYD13		HYD14		HYD15		HYD16		HYD17		HYD18	
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
		Number of Samples		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*2*	*2*
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	7	6.9	7.1	7	7.1	9	6.9	7.3	7.2	6.5	7.0	6.6	7	6.9	7	7.1	6.9	6.1
Suspended solids	mg/L	3	25	30	70	27	34	9	12	293	50	5	98	4.7	149	243	146	95	515	37	1381
Ammonium	mg/L	0.101	1	0.022	0.039	0.019	0.01	0.038	0.013	0.092	0.062	0.021	0.003	0.015	0.007	0.02	0.009	0.011	0.257	0.022	0.028
Nitrate as N	mg/L	0.279	20	0.058	0.0702	0.0864	0.0197	0.0033	0.0033	0.00668	0.0041	0.0027	0.0225	0.0	0.0	0.018	0.0129	0.0144	0.0096	0.04117	0.1451
Chloride	mg/L	3	150	1.24	0.9	0.8	0.73	0.71	0.78	3.3	3.01	0.83	0.45	1.83	0.70	0.53	0.42	0.69	0.9	2.49	0.97
Sulphate	mg/L	89	159	14	2	9	10	21	25	42	44	22	4	238	6	7	2	20	18	64	19
Iron	mg/L	0.92	4.07	0.142	0.042	0.021	0.015	0.012	0.078	0.011	0.144	0.01	0.034	0.025	0.037	0.193	0.06	0.724	2.083	0.011	0.012
Aluminium	mg/L	0.05	0.1	0.0675	0.0533	0.0278	0.0386	0.0108	0.176	0.0108	2.01	0.025	0.0531	0.002	0.022	0.533	0.0731	2.11	4.66	0.0753	0.0194
Arsenic	mg/L	0.0012	0.005	0.0001	0.0001	<0.00005	<0.00005	0.0007	0.0002	0.0003	0.0017	0.0011	<0.00005	0.0001	0.0001	0.0001	<0.00005	0.0002	0.0002	0.0002	0.0001
Cadmium	mg/L	0.00001	0.00008	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	0.00001	<0.000005	0.00001	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	0.00004	0.00004
Cobalt	mg/L	0.002	0.004	0.0004	0.0004	0.0002	0.0003	0.0001	0.0004	0.0014	0.0007	0.0002	0.0009	0.0003	0.0008	<0.00005	0.0004	0.0001	0.0011	0.0014	0.0164
Chromium	mg/L	0.0003	0.001	0.0009	0.001	0.0005	0.0002	0.0005	0.0006	<0.0001	0.0036	0.0008	0.0002	0.0010	0.0008	0.0006	0.0007	0.0017	0.0033	0.0004	0.0003
Copper	mg/L	0.0048	0.005	0.001	0.001	0.0012	0.0006	0.0009	0.0028	0.0009	0.0039	0.0006	0.0001	0.0002	0.0002	0.0004	0.0002	0.0009	0.0114	0.0013	0.0009
Manganese	mg/L	0.294	0.7	0.135	0.0654	0.0565	0.116	0.0468	0.0115	0.2429	0.0885	0.0178	0.0576	0.451	0.1889	0.0029	0.0539	0.0142	0.193	0.355	0.352
Molybdenum	mg/L	0.0002	1	0.0002	0.0001	0.0002	<0.00005	0.0017	0.0006	0.0013	0.0021	0.0043	0.0001	0.0005	<0.00005	0.0016	0.0002	0.0009	0.0011	0.0012	0.0001
Nickel	mg/L	0.007	0.02	0.0015	0.0015	0.0014	0.0027	0.0002	0.0019	0.0031	0.0036	0.0006	0.0018	0.0010	0.0013	0.0003	0.0016	0.0011	0.0024	0.0027	0.0072
Lead	mg/L	0.0001	0.0072	0.0001	0.0001	0.00004	0.00003	0.0001	0.0003	0.0002	0.001	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	0.0002	0.0005	0.0002	0.0001
Zinc	mg/L	0.002	0.03	0.0073	0.0075	0.0059	0.0042	<0.0005	0.0033	0.0027	0.0023	0.002	0.0005	0.0007	<0.0005	<0.0005	<0.0005	0.0014	0.0024	0.003	0.0081
Uranium	mg/L	0.0004	0.015	<0.00001	0.00001	0.00004	<0.00001	0.0005	0.0002	0.0004	0.0048	0.0014	<0.00001	0.0010	0.00004	0.00005	<0.00001	0.0001	0.0001	0.0001	0.0001

Note: Sample ID using Lab codes which omit the RAU12- suffix and parenthesis, i.e. HYD01D = RAU12HYD01(D);
Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Parameter	Unit	WQO – FS15		HYD19		HYD20		HYD22		HYD23		HYD24		Putki 1 GTK	Putki 2 GTK	Putki 3 GTK
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow			
		Number of Samples		*1*	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*1*	*1*	*3*	*4*	*2*
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.6	7.8	6.7	7.2	7.7	7.3	6.6	6.5	7	6.8	5	6.1	6.7
Suspended solids	mg/L	3	25	78	1730	30	1323	48	69	28	465	11	237	35.9	374	74.4
Ammonium	mg/L	0.101	1	0.172	0.911	0.03	0.039	0.02	0.016	0.003	0.01	0.018	0.011	0.366	0.038	0.047
Nitrate as N	mg/L	0.279	20	0.0065	0.005	0.0077	0.0141	0.0075	0.0267	0.0151	0.0309	0.0323	0.0318			
Chloride	mg/L	3	150	0.58	1.06	1.12	0.93	4.08	0.72	1.23	0.87	2.04	0.6	6.07	14.1	4.08
Sulphate	mg/L	89	159	2	18	2	8	7	1	20	2	9	2	968	2622	210
Iron	mg/L	0.92	4.07	0.197	2.583	0.303	0.822	0.105	0.087	1.676	0.017	0.002	0.006	4.38	394	2.2
Aluminium	mg/L	0.05	0.1	0.139	3.86	0.141	0.303	0.0418	0.0309	0.121	0.003	0.0041	0.0019	2.06	0.114	0.001
Arsenic	mg/L	0.0012	0.005	<0.00005	0.0014	<0.00005	0.0003	0.0001	0.0003	0.0005	0.0001	0.0001	0.0002	0.0003	0.0002	0.0001
Cadmium	mg/L	0.00001	0.00008	<0.000005	0.00006	<0.000005	0.00003	0.00001	0.00001	0.00001	0.00001	<0.000005	<0.000005	0.0008	0.00001	0.00001
Cobalt	mg/L	0.002	0.004	0.001	0.0048	0.0031	0.0018	0.0018	0.0003	0.0019	0.0018	0.0004	<0.00005	0.734	0.554	0.002
Chromium	mg/L	0.0003	0.001	0.0005	0.0055	0.0009	0.0009	0.0005	0.0003	0.0012	0.0006	0.0004	0.0001	0.001	0.0004	0.0001
Copper	mg/L	0.0048	0.005	0.0103	0.0132	0.0045	0.0015	0.0006	0.0015	0.0008	0.0002	0.0006	0.0004	1.243	0.001	0.001
Manganese	mg/L	0.294	0.7	0.127	0.167	0.511	0.4	0.269	0.176	0.171	0.219	0.0055	0.0207	6.09	45.5	0.73
Molybdenum	mg/L	0.0002	1	0.0001	0.0016	0.0011	0.0011	0.0006	0.0015	0.0007	0.0001	0.0003	0.0014	0.0005	0.0015	0.0003
Nickel	mg/L	0.007	0.02	0.002	0.0102	0.0081	0.0022	0.0019	0.0017	0.0024	0.0022	0.0012	0.0002	0.187	0.133	0.004
Lead	mg/L	0.0001	0.0072	0.0101	0.0031	0.0195	0.0002	0.0001	0.0001	0.00002	0.00002	0.0001	<0.00002	0.00019	0.00017	0.00004
Zinc	mg/L	0.002	0.03	0.0133	0.0086	0.0051	0.001	0.0031	0.0058	0.0026	0.0007	0.0019	<0.0005	0.1592	0.0395	0.0133
Uranium	mg/L	0.0004	0.015	0.0001	0.0007	0.0002	0.0004	0.00003	0.0002	0.0007	0.00004	0.0001	0.0004	0.0005	0.0129	0.0011

Note: Sample ID using Lab codes which omit the RAU12- suffix and parenthesis, i.e. HYD01D = RAU12HYD01(D);
Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 6-53: Water quality concentrations for other parameters at the Rautuvaara site compared to FS15 WQOs

Parameter	Unit	WQO – FS15		HYD01		HYD02		HYD03			HYD04		HYD05	HYD06		HYD07		HYD08		HYD09		HYD10		HYD11		HYD12		HYD13	
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Shallow	Deep	Shallow	Deep	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
			Number of Samples	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Conductivity	mS/m	26	41	31.2	34.8	80.3	49.6	184	354	625	10.3	3.4	5.2	23.4	6.14	41.6	35.4	12.6	7.5	17.3	9.66	11.9	5.9	8.2	8	11.3	13.5	25	34.3
Calcium	mg/L	25	46	32.7	37.9	114.8	60.1	259	383	513	7.7	3.7	5.3	13.2	5.77	55.9	43.2	7.5	8	21.7	8.29	13.9	5.5	8.6	7.3	11.9	16.5	18.5	11
Potassium	mg/L	3	4.9	4.9	3	4.9	5	12	35	67	2.1	0.8	1.3	2.4	1.1	4.7	2.9	1.8	0.9	3.2	1.6	0.4	1.3	1.9	1.7	3.4	3.8	3.1	2.3
Magnesium	mg/L	10	17	12	14	32	13	90	267	587	1.7	0.6	1.7	4.2	2.6	12	14	2.8	2.9	4.7	3.3	3.4	2	2.3	2.6	3.1	2.8	3.7	3.2
Sodium	mg/L	5.3	9.1	7.3	8.6	7.3	5.1	20	31	33	9.5	1.5	2	29	3.6	6.3	5.9	18	3.1	4.9	4.6	6.4	3.5	4.1	4	3.8	5.7	25	55
Sulfur	mg/L	29	53	39	43	128	63	369	763	1725	5.3	0.8	1.6	12	1	30	18	6.4	0.5	1.6	2.8	4.7	0.7	2.9	3.2	6.8	8.9	14	13
Silicon	mg/L	4	11	6.2	7.8	9.9	9	13	14	21	4.1	3.7	6.9	7.4	10	8.4	17	11	11	14	13	6.7	11	8.1	7.7	7	6.2	4.1	4.8
Barium	mg/L	0.01	0.014	0.063	0.05	0.018	0.023	0.033	0.044	0.016	0.029	0.008	0.009	0.001	0.011	0.038	0.062	0.016	0.011	0.024	0.019	0.008	0.008	0.012	0.019	0.015	0.054	0.034	0.024
Strontium	mg/L	0.07	0.112	0.158	0.188	0.402	0.211	0.665	0.032	1.895	0.032	0.022	0.017	0.003	0.021	0.049	0.178	0.042	0.046	0.056	0.031	0.041	0.023	0.032	0.03	0.064	0.048	0.093	0.064

Parameter	Unit	WQO – FS15		HYD14		HYD15		HYD16		HYD17		HYD18		HYD19		HYD20		HYD22		HYD23		HYD24		Putki 1 GTK	Putki 2 GTK	Putki 2 GTK
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow			
			Number of Samples	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	2	1	1	3	4	2
Conductivity	mS/m	26	41	12.8	3.9	64.7	8.4	6.1	3.6	10.8	10.8	25.5	7.02	3.2	16.5	9.5	19.3	8.3	4.7	20.7	6.7	10.2	4.2	1118	2135	605
Calcium	mg/L	25	46	16.2	3.2	98.1	8.6	4.8	3.2	8.2	7.1	13.5	8.77	2.6	5.8	11.9	12.8	6.8	3.5	15.3	5.7	11.2	3.8	253	278	71.8
Potassium	mg/L	3	4.9	1.9	1.2	5.2	1.2	1.3	0.8	2.2	2.8	4.3	2.7	0.7	1.9	2.2	2.5	1.3	0.9	2.4	1.1	1.1	0.6	16.8	31.6	10.1
Magnesium	mg/L	10	17	2.8	1.2	16	2.7	1.4	1.1	4	4.3	5.8	3.1	0.8	1.9	2.6	3.8	2.3	1.3	3.9	2.2	3.2	1.2	55.4	226	23.2
Sodium	mg/L	5.3	9.1	4	1.9	8.7	3.8	3.1	1.9	5.8	5.1	25	5.6	2	30	3.8	24	6.6	2.9	18.8	3.8	4.5	2.2	11.9	18.5	10.8
Sulfur	mg/L	29	53	7.4	1.4	84	1.8	2	0.8	6.7	5.2	21	10	0.7	5.4	0.6	2.4	2	0.5	7.1	0.7	2.8	0.8	324	821	67.9
Silicon	mg/L	4	11	6.1	5.6	12	11	8	6	11	12	6.6	4.7	3.1	8.2	5.2	10	8.3	8.6	12	11	6.5	7.7	11.2	16.3	17
Barium	mg/L	0.01	0.014	0.028	0.016	0.034	0.016	0.016	0.012	0.015	0.018	0.038	0.031	0.01	0.036	0.019	0.029	0.058	0.014	0.132	0.166	0.024	0.015	0.017	0.012	0.011
Strontium	mg/L	0.07	0.112	0.034	0.011	0.204	0.034	0.014	0.011	0.03	0.034	0.065	0.057	0.014	0.031	0.044	0.061	0.038	0.038	0.072	0.044	0.028	0.036	0.407	0.498	0.26

Note: Sample ID using Lab codes which omit the RAU12- suffix and parenthesis, i.e. HYD01D = RAU12HYD01(D);
Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Water Quality: Existing WRD and TMF Seepage

During field work undertaken in 2012 trial pits were excavated within the existing tailings pile and WRD at Rautuvaara. Water samples were collected from these trial pits and represent the water quality of pore water within these facilities. Samples were also collected from seepages observed on the slopes of the WRD and existing tailings pile, referred to in this section as 'surface seepage' (Photo 6-8).



Photo 6-8: Surface seepage along the eastern margin of the exiting tailings at Rautuvaara

Table 6-54 and Table 6-55 show the water quality seepage water which collected in the trial pits excavated within the existing Rautuvaara WRD and TMF (refer to Figure 5.7 for locations). Surface seepage water quality is also shown.

As expected the trial pits at the existing WRD and TMF all show elevated concentrations for the majority of parameters relative to the Niesajoki River WQOs. A maximum sulphate concentration of 10,500 mg/L was reported from TP6 towards the northern tailings embankment compared with an AV WQO of 159 mg/L. Concentrations within the shallow TMF boreholes would be expected to be at similar levels to the trial pit localities but all trial pits record much higher concentrations suggesting a possible dilution within the shallow boreholes within the tailings possibly due to drilling fluids and the slow recharge of these wells due to the very fine nature of the tailings material.

The pH values within the WRD and northern most TMF trial pits and surface seepages are predominantly acidic to moderately acidic with a minimum pH of 2.9 reported for SWS02 seepage from the northern tailings embankment. TP7 and TP8 in the tailings fines area both showed circum-neutral pH indicating distinctly different behaviour amongst tailings locations.

Table 6-54: Water quality concentrations for key parameters at WRD and TMF trial pits plus surface seepage, compared to FS15 WQOs

				TMF Surface Seepage		WRD Surface Seepage		WRD Trial Pit				TMF Trial Pit		
Parameter	Unit	WQO – FS15 *TV	WQO – FS15 *AV	SWS01	SWS02	SWS04	SWS05	TP2	TP3	TP4	TP5	TP6	TP7	TP8
			Number of Samples	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	3.6	2.9	6.3	4.0	3.9	5.5	3.6	3.1	5.8	7.7	8.0
Chloride	mg/L	3.0	150	1.37	9.06	1.64	1.92	2.12	2.04	2.43	4.59	24.15	7.68	8.04
Sulphate	mg/L	89	159	148	1641	186	355	401	588	573	1660	10500	5409	464
Iron	mg/L	0.92	4.07	6.13	80.85	0.056	0.295	7.726	38.4	5.494	13.97	365	0.173	0.024
Aluminium	mg/L	0.050	0.1	3.96	11.95	0.0161	7.74	6.44	2.09	15.36	50.85	1.02	0.0346	0.0114
Arsenic	mg/L	0.0012	0.0050	0.0029	0.0027	0.0034	0.0031	0.0046	0.0013	0.0007	0.0029	0.0094	0.0170	0.0250
Cadmium	mg/L	0.00001	0.00008	0.0003	0.0005	<0.000005	0.0003	0.00024	0.00042	0.00027	0.00014	0.0014	0.00002	0.00004
Cobalt	mg/L	0.002	0.004	0.385	1.580	0.0024	0.0965	0.291	0.124	0.265	0.384	1.260	0.0136	0.0020
Chromium	mg/L	0.0003	0.001	0.0011	0.0012	0.0001	0.0007	0.0030	0.0007	0.0083	0.0672	0.0041	0.0003	0.0001
Copper	mg/L	0.0048	0.005	0.558	1.380	0.0101	0.335	1.94	0.0989	1.81	4.14	0.0633	0.0036	0.0044
Mercury	mg/L	0.000002	0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Manganese	mg/L	0.294	0.70	7.72	32.75	0.0332	0.690	1.63	2.35	1.12	1.57	76.91	1.155	0.084
Molybdenum	mg/L	0.0002	1	0.0003	0.0010	0.0001	<0.00005	0.0001	0.0001	0.0001	0.0001	0.0044	0.0201	0.0810
Nickel	mg/L	0.007	0.02	0.154	0.448	0.0066	0.168	0.275	0.239	0.323	0.498	0.904	0.0638	0.0209
Lead	mg/L	0.0001	0.0072	0.0003	0.0002	<0.00002	0.0020	0.0003	0.0006	0.0001	0.0001	0.0031	0.0001	0.00003
Zinc	mg/L	0.002	0.03	0.116	0.236	0.0032	0.186	0.149	0.148	0.134	0.0779	0.2310	0.0093	0.0018
Uranium	mg/L	0.0004	0.015	0.0100	0.0622	0.0002	0.0292	0.0043	0.0169	0.0105	0.0413	0.1150	0.2290	0.0128

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 6-55: Water quality concentrations for other parameters at WRD and TMF trial pits and surface seepage, compared to FS15 WQOs

				TMF Surface Seepage		WRD Surface Seepage		WRD Trial Pit				TMF Trial Pit		
Parameter	Unit	WQO – FS15		SWS01	SWS02	SWS04	SWS05	TP2	TP3	TP4	TP5	TP6	TP7	TP8
		*TV	*AV											
		Number of Samples		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Conductivity	mS/m	26	41											
Calcium	mg/L	25	46	25.2	239	60.6	87.7	104	150	127	183	456	349	62.1
Potassium	mg/L	3.0	4.9	2.70	19.4	2.61	8.03	9.65	12.4	5.99	5.35	109	59.1	31.9
Magnesium	mg/L	10	17	16	129	13	29	22	38	33	62	1104	675	52
Sodium	mg/L	5.3	9.1	2.9	11	4.3	5.2	4.3	5.4	3.3	5.6	30	48	119
Sulfur	mg/L	29	53	59	473	58	114	123	176	166	325	1947	1054	154
Silicon	mg/L	4	11	8.8	11	4.5	11	16	11	17	29	23	8.1	4.7
Barium	mg/L	0.010	0.014	0.003	0.011	0.004	0.005	0.004	0.005	0.003	0.006	0.030	0.048	0.119
Strontium	mg/L	0.070	0.112	0.059	0.473	0.058	0.114	0.123	0.176	0.166	0.325	1.947	1.054	0.154
Antimony	mg/L	0.00002	0.00006	0.009	0.011	0.005	0.011	0.016	0.011	0.017	0.029	0.023	0.008	0.005

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

6.4.3 Groundwater Users

In the vicinity of the Project:

- One Class II aquifer is located north of the existing TMF which intersects the Kylmäoja Stream approximately 1.5 km downstream of the TMF;
- Four Class III groundwater areas are located in the immediate vicinity of Hannukainen mine area, two of which partly extend into the proposed open Hannukainen pit; and
- Five Class III aquifers are located downstream of the existing TMF along the Niesa River. A portion of one of these aquifers (Kurtakko (12273128)) is located beneath the South Pond.

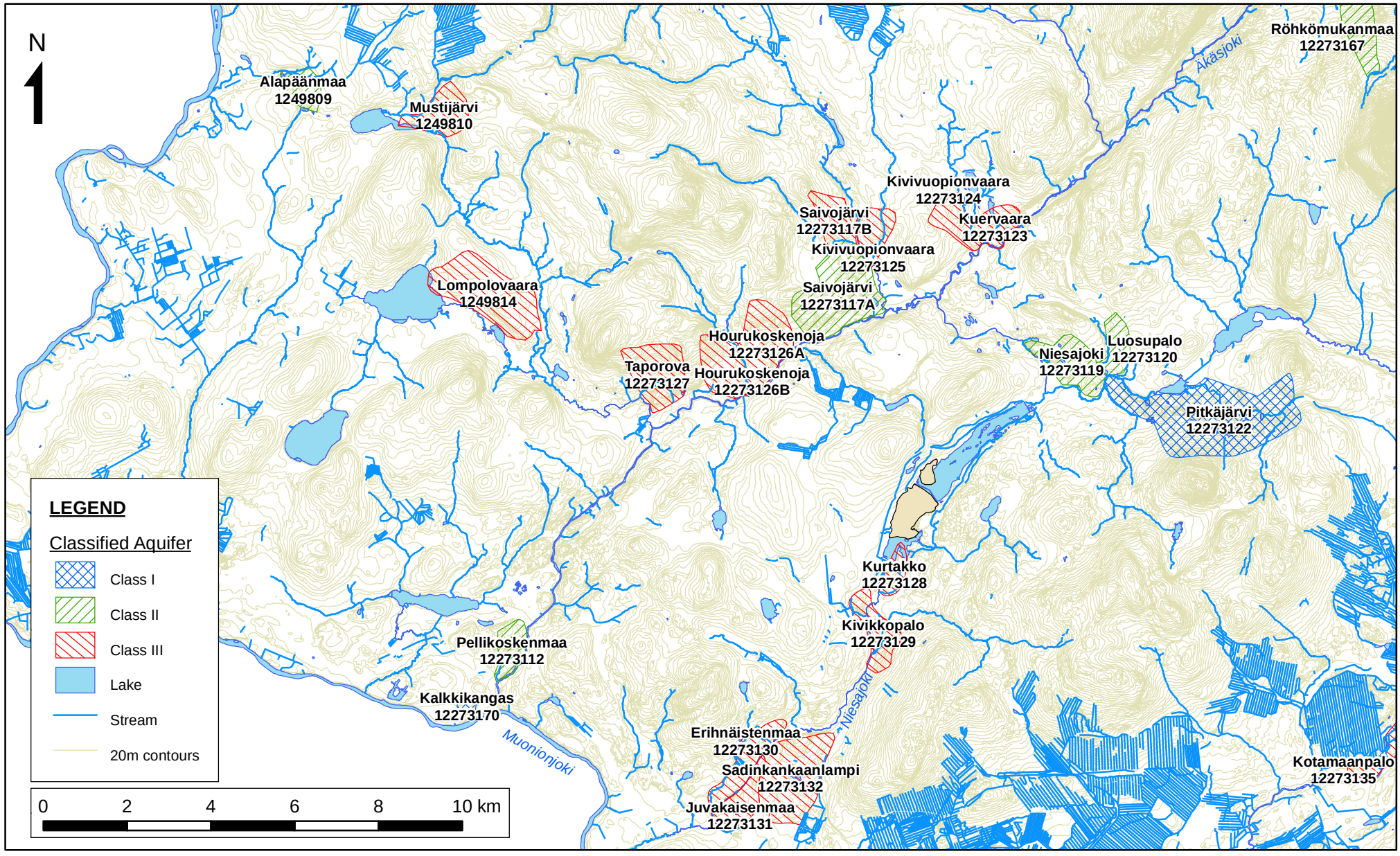
Three private wells have been identified at Hannukainen, two of which utilises a Class III aquifer. Otherwise, the aquifers are not utilized for potable water intake (Pöyry, 2008).

A summary of the classified aquifers in the vicinity of the Project is provided in Table 6-56 and Figure 6-49.

Table 6-56: Classified Aquifers Downstream of the proposed Rautuvaara TMF

Domain name	ID	Class	Location	Area (km^2)
Niesajoki	12273119	II	Kylmäoja catchment	1,480
Kuervaara	12273123	III	Hannukainen pit	785,225
Kivivuopionvaara	12273124	III	WRD W(OB)	871,690
Kivivuopionvaara	12273125	III	Downstream clarification pond	921,480
Kurtakko	12273128	III	South Pond	515
Kivikkopalo	12273129	III	Niesajoki River, mid catchment	1,135
Erihnäistenmaa	12273130	III	Niesajoki River, lower catchment	1,260
Juvakaisenmaa	12273131	III	Niesajoki River, lower catchment	960
Sadinkankaanlampi	12273132	III	Niesajoki River, lower catchment	2,705
Saivojärvi	12273117A	II	Beneath Saivojärvi wetland	3,179,440
Saivojärvi	12273117B	III	West of Valkeajoki	894,435

There are several operational well fields at Äkäslompolo and Ylläsjärvi. The closest well fields are at Revonkanto-oja and Aavahelukka, 5km and 2.5km from Hannukainen respectively. Neither site is in hydraulic connection with the Hannukainen area (Pöyry, 2008).



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Classified Groundwater Aquifers	Figure 6.49

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 6.50 Classified aquifers_PH2_HIA.mxd

6.4.4 Conceptual Hydrogeological Model

Groundwater is the primary pathway between potential sources and receptors (described in more detail in Section 3) and therefore it is important to develop a conceptual model of the hydrogeological regime, including the interaction between groundwater and surface water.

Hannukainen

The Hannukainen conceptual hydrogeological model was developed during the Open Pit Water Management Study (SRK, 2012a).

Overburden

Overburden extends across most of the site. It predominantly comprises sand with some silt and gravel fractions, and has an average hydraulic conductivity of 0.18m/d (SRK, 2012a). GPR shows that the overburden thickness ranges from 0 – 45 m across the site. The overburden is generally 10 – 20 m with thicker sediments attributed to buried valleys (Moreau and Koivisto, 2012). These features are discussed further in Section 6.2.2.

Groundwater monitoring indicates that the groundwater level is generally between 5 and 10 mbgs meaning that the upper sections of overburden deposits are largely unsaturated. The overburden is considered to be generally unconfined (SRK, 2012a). Perched water tables were identified in the upper sections of the overburden by the University of Helsinki GPR campaign (Moreau and Koivisto, 2012) (Section 6.2.2).

Artesian conditions, observed at some boreholes, suggest that the overburden may act locally as a partially confining layer (SRK, 2012a). This is consistent with deformation identified in the GPR survey which, the university study suggests, results in locally confined conditions (Moreau and Koivisto, 2012) (Section 6.2.2).

Bedrock

The bedrock is divided into three units; footwall, hanging wall and Hannukainen Thrust Zone (HTZ).

Weathering of the bedrock is generally limited to the top 10 m of the rock profile. Groundwater flow within the bedrock is considered to be restricted to open, connected fractures and therefore the primary control on groundwater flow is the fracture network rather than primary, inter-granular flow. Discrete fractures have been identified throughout the rock profile, denoted by shattered, crushed and sheared zones in the geotechnical borehole logs.

There appears to be distinctly different structural drivers at Hannukainen and Kuervitikko:

- Hannukainen - The hanging wall and footwall deposits are separated by a shallow dipping thrust fault which is located along the eastern edge of the proposed pit. Rock quality is generally good (average RQD = 90%). A strong sub-horizontal foliation striking southeast across the whole of the site results in a preferential horizontal flow path. A second sub-vertical joint set trending northwest-southeast is prevalent in the hanging wall only and reduces the degree of vertical anisotropy in this unit.

- Pumping tests indicate a hydraulic conductivity of 0.01 – 0.5 m/d and a specific storage for the bedrock of about E-04. Borehole flow impellar logging (”spinner testing”) highlights the potential for water-bearing fractures to occur at depth within the footwall (SRK, 2012a).
- Kuervitikko – Average RQD (74%) and fracture frequency isosurfaces indicate that the bedrock is more fractured at Kuervitikko than at Hannukainen. This increased fracturing is thought to be a result of the close proximity to the HTZ which is locally offset by two branch faults. The zone of increased structural deformation is called the HTZ unit. It is believed to extend from the HTZ eastwards to the fault implied by the north-south valley and westwards an equal distance.
- Pumping tests indicated a bulk hydraulic conductivity of the upper bedrock of approximately 0.2 – 1.2 m/d and a specific storage of about E-05. The elevated hydraulic conductivity at Kuervitikko, in comparison to Hannukainen, is attributed to the increased structural deformation noted in this area.

Rautuvaara

Overburden

Overburden extends across most of the site. It comprises sand with some silt and gravel fractions, and has an average hydraulic conductivity of 3 m/d, with a 25^{th} to 75^{th} percentile range of 0.7 – 4 m/d.

In the region of the existing tailings and the associated ponds there is a low permeability peat layer at the base of the overburden material (GTK, 2010a). This peat horizon is not present beneath the entire area of the existing TMF; GTK (2010a) reported that it is absent in the northeast and northwest portions of the existing TMF.

The peat horizon was observed during the SRK hydrogeological field campaign at RAU12HYD03 but was not been recorded in the drill logs at RAU12HYD06 or RAU12HYD07. This may be due to inadequate geological logging of the returns rather than an absence of the peat layer at these locations. The peat horizon was also reported in the lake sediments during the geotechnical drilling programme (Pöyry, pers. comm.).

GTK (2010a) report that the compressed peat provides an “impermeable floor” at the base of the existing tailings. However, analysis of water quality samples collected from above and below the peat layer shows that, while the quality of the bedrock is significantly better than the tailings pore water, seepage still propagates into the weathered bedrock supporting the observation that the peat horizon is not always present. It may also indicate that the peat does not act as a completely impermeable barrier to tailings seepage.

Drill logs show that the overburden thickness is variable, ranging from 3 – 46 m. The overburden is generally thickest on the high ground and decreases towards the bottom of the valley. The University of Helsinki notes the existence of paleo-channels, visible in the GPR data, but processing of the GPR data has not yet been completed and so the location of these features is not yet defined.

Groundwater monitoring indicates that the groundwater level in the overburden is generally between 0.5 mbgs and 5 mbgs (approximately the 25th to 75th percentile range). There is evidence of perched water tables, particularly higher up the hillsides. Artesian conditions, observed at some boreholes, suggest that the overburden may act locally as a partially confining layer or alternatively that there is an upward hydraulic gradient at some of the borehole locations which results in groundwater moving up in to the surface water system as baseflow to lakes, rivers or wetland areas.

Bedrock

Bedrock comprises meta-volcanics, meta-sediments, diorite, monzonite and granitic rocks with some clay rich horizons noted in the borehole logs. Groundwater flow within the bedrock is considered to be restricted to open, connected fractures and therefore the primary control on groundwater flow is fracture flow rather than inter-granular flow. Fractures have been identified in the rock profile, denoted by discrete zones with high inflow rates and zones of increased penetration rate.

Hydraulic tests suggest that bedrock is weathered in the top 20 m of the profile at the majority of locations. Weathered bedrock has an average hydraulic conductivity of approximately 1 m/d (2E-04 m/d – 10 m/d), with a 25th to 75th percentile range of 0.05 m/d to 0.4 m/d. At two locations the estimated hydraulic conductivity is an order of magnitude lower (4E-03 m/d) than the average, and a further order of magnitude lower (2E-04 m/d) at two additional wells suggesting that the rock is 'tight' at these locations and devoid of water bearing fractures. There does not appear to be a correlation between hydraulic conductivity and bedrock geology or well location. Local variation in hydraulic properties is typical in a fractured rock environment.

The hydrogeological drilling programme at Rautuvaara has targeted that the upper portion of the bedrock, which was assumed to be weathered. There is no information available from >20 m depth in the bedrock, i.e. beyond the perceived depth of the weathered rock to characterise the nature of the bedrock at depth or substantiate the aforementioned assumption. Additional drilling will be required to penetrate deep non-weathered aquifer in order to characterise this portion of the hydrogeological system.

Groundwater monitoring indicates that the groundwater level in the bedrock is generally between 0.1 mbgs and 7 mbgs (approximately the 25th to 75th percentile range). Generally, the static groundwater level measured in the piezometers following drilling was closer to ground surface than the recorded water strike indicating that groundwater has risen in the borehole. There were two exceptions; at RAU12HYD19 there were no groundwater strikes during drilling and at RAU12HYD23 the static groundwater level is lower than the recorded groundwater strike.

Artesian conditions were observed at the site, including one flowing well (RAU12HYD24), indicating that the deep aquifer may be locally confined. However, generally the bedrock aquifer appears to be unconfined and in hydraulic connection with the shallow overburden aquifer.

Groundwater Recharge

The principle source of groundwater recharge at Hannukainen and Rautuvaara is infiltration of

precipitation. Groundwater recharge is estimated to be approximately 74 mm/year across the project area (SRK, 2011). Since the groundwater is generally unconfined and there is little vertical anisotropy in the overburden, this recharge can infiltrate vertically downwards to the water table (SRK, 2012a).

Groundwater – Surface Water Interaction

Temporary piezometers in the Äkäsjoki river bed indicate that in the river reach immediately south of the proposed Hannukainen pit, groundwater enters the Äkäsjoki River as baseflow. Isotope analysis of water samples collected in the Äkäsjoki River and river bank sediments also identify mixing between groundwater and surface water bodies (Nurminen et al, 2011).

Furthermore, preliminary results from the University of Helsinki thermal imaging study at Rautuvaara indicate that groundwater reports to the local river system as baseflow. Springs and wetlands, located across the site, also indicate flow from the groundwater system up to the surface.

Generally, the groundwater surface appears to mirror the topographic surface. Groundwater flows from the higher ground down gradient towards the river valleys and flows up in to the local rivers, ponds and wetland areas.

7 PROJECT DESCRIPTION

The 'base case' Project infrastructure and mine site water balance is described below, highlighting potential impacts where appropriate.

7.1 Site Layout

The proposed site layout of the entire Hannukainen Project is shown in Figure 4-1.

7.1.1 Open Pits

Mining at Hannukainen will take place from two open pits, Hannukainen to the south and Kuervitikko to the north:

- Mining will start at Hannukainen in Q3 of 2014 and continue for 21 years to 2034. Initially, mined material is predominantly waste (i.e. a pre-stripping phase); ore production commences in Q4 2016 meaning that there will be 19 years of production when tailings will be deposited in the Rautuvaara TMF. Note that within this report the pre-stripping phase is referred to as Year -1 to Year 0, and the production phase is referred to as Year 1 to Year 19; and
- Mining will start at Kuervitikko in Q1 of 2028 and continue to 2034.

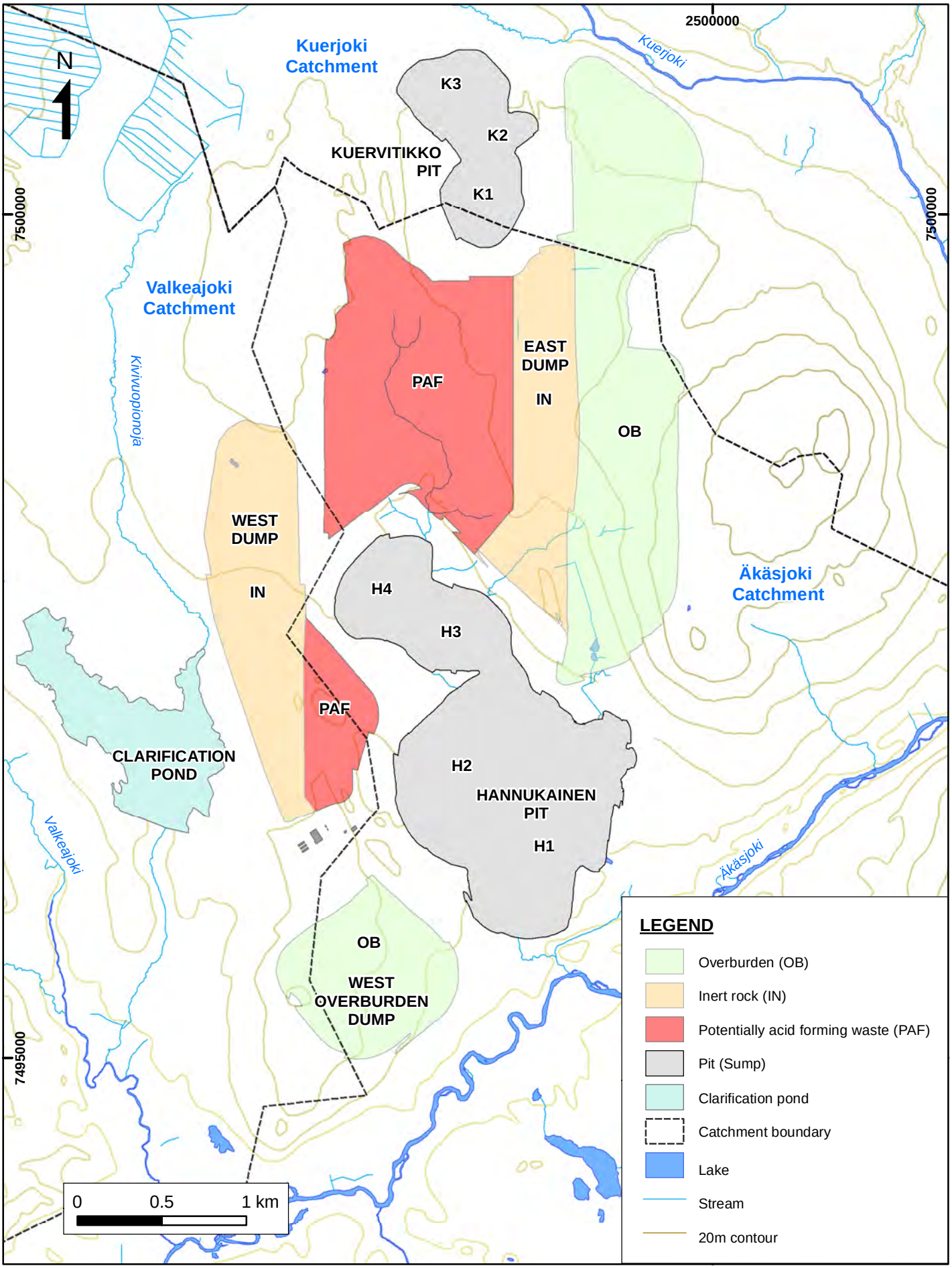
The current pit design has four pits in the Hannukainen excavation (H1, H2, H3 and H4) and three at Kuervitikko (K1, K2 and K3), shown in Figure 7-1.

Preliminary works will include the emptying of the existing Laurinoja and Kuervaara pit lakes. Waters pumped from the pit lakes will be discharged to the Clarification Pond (CP) through a sedimentation basin and wetland area. This water will be used in the construction of the site.

During operational mining, water will be pumped from in-pit sumps to sedimentation ponds, and then on to the CP. Water levels will be maintained by dewatering from each sump to ensure dry working conditions for the mining operations. The associated drawdown in the local groundwater level will affect the hydraulic regime surrounding the pits.

Upon cessation of mining the pits will be allowed to flood. Predictive numerical modelling undertaken during the Phase 1 Hannukainen HIA predicted that it would take >70 years for the pits to flood naturally. During this time the quality of the pit water is likely to deteriorate due surface water runoff across acid generating rock in the pit walls. Therefore, in Phase 2 it is proposed that the pits be artificially flooded following cessation of mining to minimise the time that potentially acid forming material is exposed in the pit wall.

The pits will receive water from direct precipitation, groundwater inflows, surface water runoff, WRD seepage and surface water runoff from the WRDs, which will be directed to the Hannukainen pit by means of a network of drainage ditches. In addition to these inflows, water will be pumped from the Hannukainen clarification pond and local rivers to artificially flood the pits.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Hannukainen Pit Sumps and Waste Rock Dump Locations	Figure 7.1

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 7-1 WRD and pits_PH2_HIA.mxd

7.1.2 Waste Rock Dumps (WRDs)

The waste rock will be deposited in three separate WRDs; WRD East (E), WRD West (W) and WRD West (overburden) (OB). Potentially acid forming waste (PAF), inert rock (IN) and overburden (OB) will be deposited in separate cells as shown in Figure 7-1.

During operational mining, surface water runoff from the PAF cells will be collected in surface water drainage ditches at the toe of the dumps, treated and then pumped to the CP. Surface water runoff from the IN and OB cells will be pumped directly to the CP (Pöyry, 2012a).

There is no bottom structure, i.e. no liner, beneath the WRD material and so water may infiltrate from the WRD to the groundwater table below.

Upon cessation of mining the WRDs will be covered with covered with approximately 0.3 m of till and re-vegetated (Pöyry, 2012a). In the case of the PAF cells, a bentonite liner will be laid over the WRD before placing the 0.3 m of till on top of it (Ramboll, pers. Comm.).

7.1.3 Clarification Pond (CP)

The CP (Figure 4-1) will be constructed on the Kivivuopionoja channel prior to operational mining. During operations it will receive water from throughout the site;

- Runoff from the PAF cells of the WRDs (treated prior to discharge);
- Runoff from the IN and OB cells of the WRDs;
- Pit sump water (treated passively in sedimentation ponds and aeration cascades before discharge); and
- Water from the concentrating plant area (treated passively in a sedimentation pond prior to discharge).

The quality of water in the CP has been calculated by Pöyry and the reader is referred to Pöyry (2013) for more detail of the water treatment process proposed at the Hannukainen site. The predicted CP water quality data combined with the flow rates for water pumped from the CP (from Pöyry 2012c) to the South Pond at Rautuvaara are used to calculate water quality parameter loadings for the geochemical modelling of South Pond, Section 9.8.

During operational mining water will be pumped from the CP to the South Pond of the TMF (Section 7.1.4).

Upon closure the CP will be removed and sediments deposited in the Hannukainen pit.

7.1.4 Tailings Management Facility

Tailings will be transported from the crusher at Hannukainen to the processing plant at Rautuvaara via a conveyor, and subsequently to the TMF via a pipeline. Tailings will be deposited in two distinct areas depending on their sulphide content:

- High-sulphide (High-S) tailings (approximately 5.7 Mm^3) will be contained within a fully lined (base and sides) facility in the northern portion of the TMF; and
- Low intensity magnetic separation (LIMS) tailings (approximately 42.8 Mm^3) will be deposited directly above the existing tailings.

The proposed TMF layout is shown in Figure 7-2. It should be noted that at the time of this HIA the final design of the TMF had not been completed and so it was agreed with Northland that we should estimate potential impacts for the 'Version 5' TMF design, which is described here. There have been some minor modifications to this design:

- The area of the High-S cell has increased from 46 ha to 60 ha; and
- The elevation of the North Pond will be raised to approximately 191.0 masl.

It was not possible to incorporate these changes due to constraints of time and budget however, it is the opinion of SRK that they are insufficient to cause a significant change in the predicted impacts.

High-S Tailings

In order to accommodate the proposed construction schedule at Rautuvaara deposition of the High-S tailings will initially be to the two flooded pits located north of the proposed High-S facility. Tailings will be deposited in the pits from Q2 of 2016 until Q1 of 2017 when deposition in the High-S cell will begin (Pöyry, 2012).

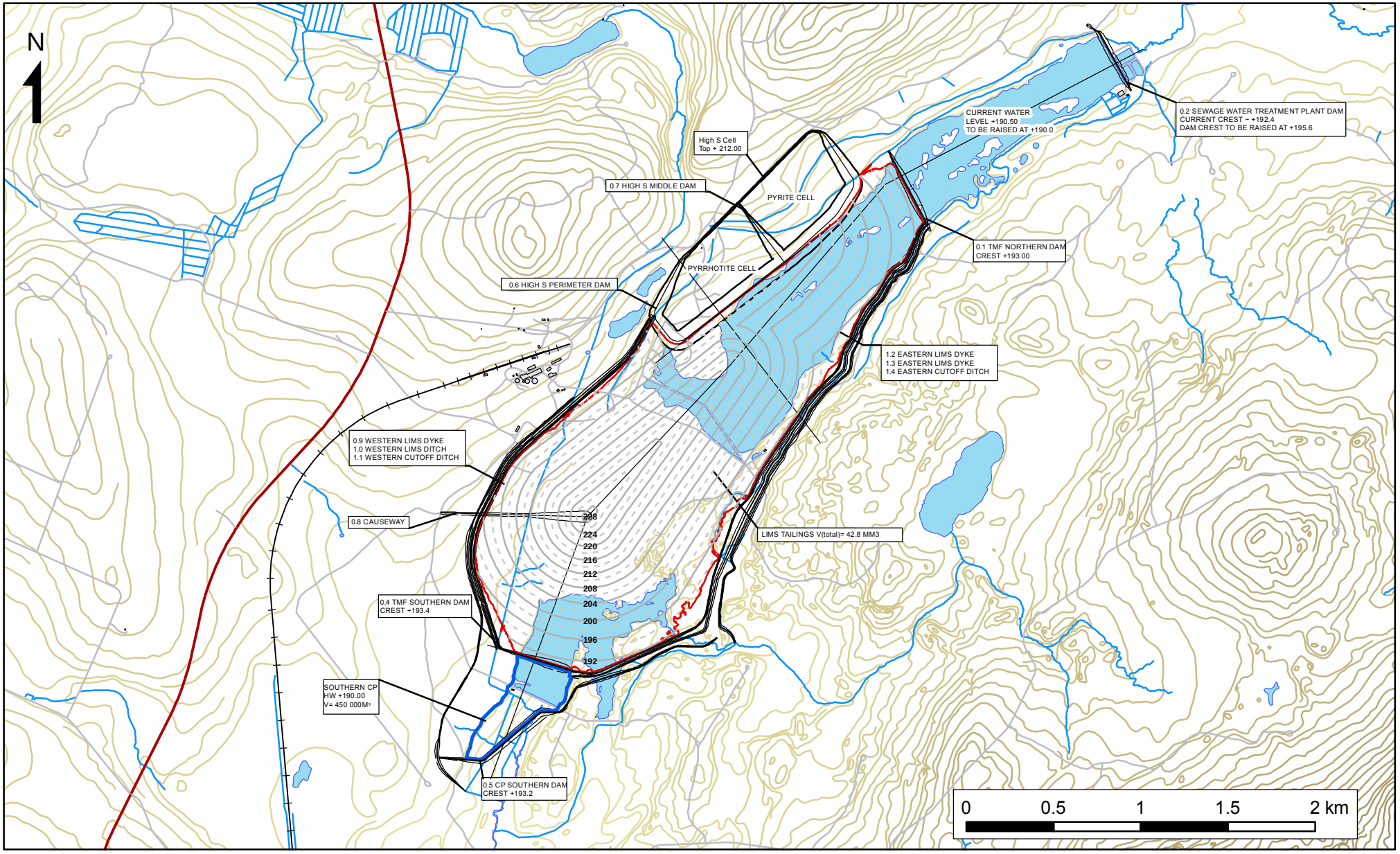
The High-S tailings will be subdivided in to pyrrhotite and pyrite rich tailings in the east and west portions of the lined facility respectively. The tailings will be lined with bentonite and a high-density polyethylene (HDPE) liner. Leakage from the High-S tailings has been estimated as 3 mm/yr (Nils Eriksson, 2011).

There will be a drainage network immediately above the liner and a network of surface water drains at the toe of the High-S facility. These drains will collect any seepage or surface water runoff and transport it to the water treatment facility for treatment prior to release into the South Pond (i.e. the southern clarification pond). Treatment of the High-S seepage is addressed by Pöyry and the reader is referred to Pöyry (2013) for more detail on the water treatment process.

LIMS Tailings

LIMS tailings will comprise the bulk of the material in the TMF. Deposition of the LIMS tailings will commence in the south-western portion of the facility in Q2 of 2022. At LOM this will be the highest part of the LIMS tailings. The tailings will be deposited directly on to the existing tailings and subsequently on top of the lake bed sediments that currently constitute the bottom of the North and South Ponds.

Dams will be constructed at either end of the tailings in order to contain the material.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Proposed Rautuvaara Tailings Management Facility (Version 5)	Figure 7.2

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Water Management

There will be a sedimentation clarification pond to the north of the LIMS tailings, called the North Pond, restricted at the northern end by the existing dam and at the southern end by the dam containing the LIMS tailings. In the Version 5 base case the elevation of this pond was 190.5 masl however, it is likely that this will rise to 191.0 masl in subsequent TMF designs.

There will be a surface water drainage ditch along the south-eastern edge of the LIMS pile to collect surface water runoff from the surrounding catchment, divert water from the North Pond south to the South Pond, and to capture seepage from the LIMS tailings and divert it south to the South Pond. This drainage ditch should maintain a constant water level in the North Pond.

A second clarification pond will be located to the south of the TMF, called South Pond. It will collect seepage from the tailings, surface water discharges from the diversion ditch described above, treated water from the Hannukainen site and treated water from the water treatment plant at Rautuvaara. Water from this pond will be pumped to the Muonionjoki River via a pipeline and released directly to the Muonionjoki River. During planned operations there should be no direct discharge of surface water from the South Pond to the Niesajoki River.

The proposed water management plan avoids any discharges of surface water from the TMF to the local hydrological system; the only discharge is to the Muonionjoki River. However, the groundwater contours described in Section 6.4 indicate that there will be seepage through the dams to the north and south of the facility. It is likely that this seepage will report to the local rivers. This has been quantified using numerical groundwater modelling, discussed in Section 8.1.1.

Closure

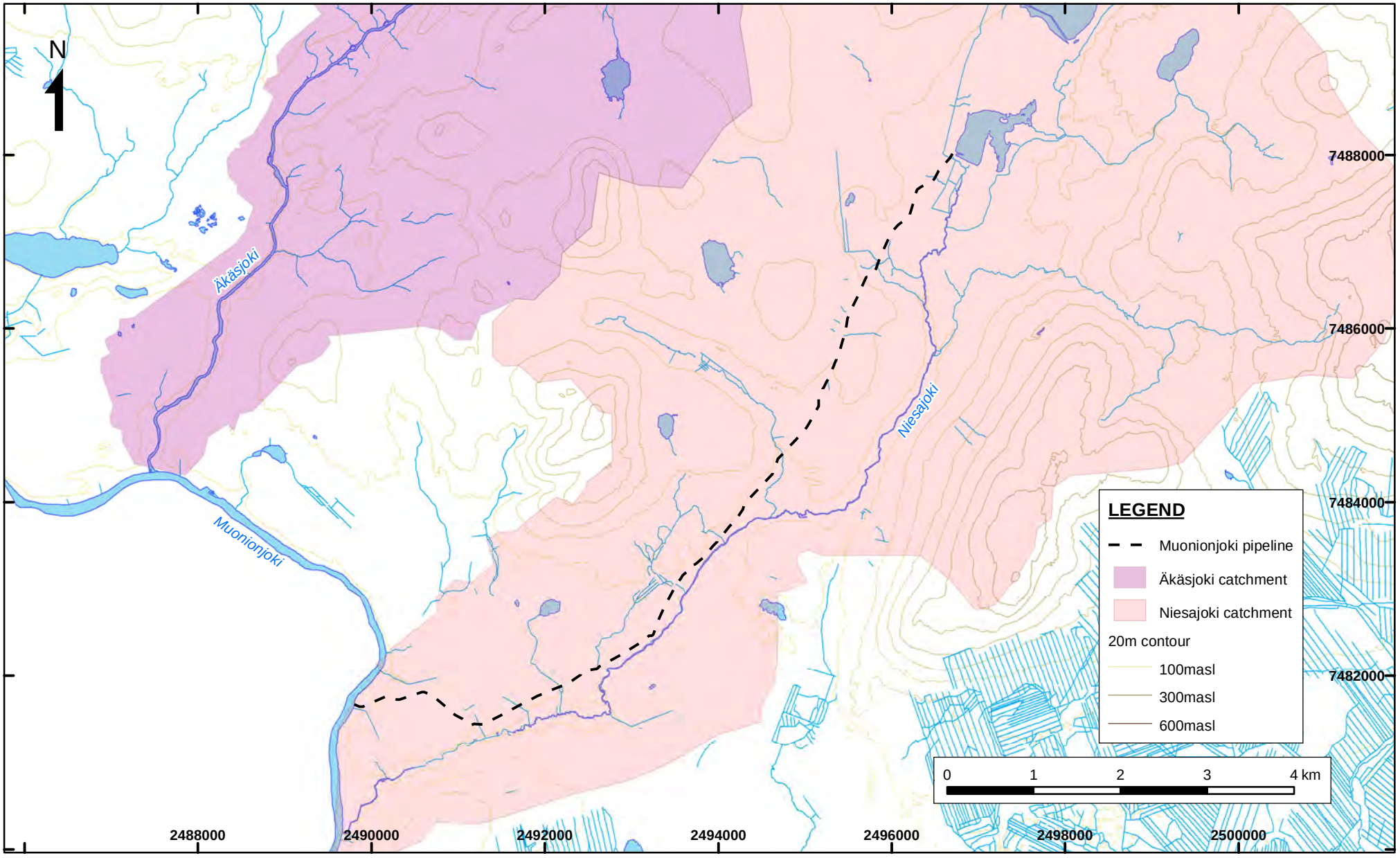
Upon closure the tailings will be shaped to give the appearance of natural topography and then covered. The High-S tailings will be covered with a HDPE liner with a protection of approximately 1 m of soil material and a growth medium. Soil material and a growth medium will be applied directly on top of the LIMS tailings. The entire area will be re-vegetated and then monitored to ensure that the closure strategy has been effective in managing potentially negative environmental impacts (Ramboll, pers. comm.).

7.1.5 Muonionjoki Outfall

A pipeline will extend from the South Pond to the Muonionjoki. The final position of the outfall to the Muonionjoki (termed the 'Muonionjoki Outfall'), has not yet been determined. However, potential locations are shown in Figure 7-3. Locations will be assessed during the next phase of mine planning based on:

- Existing habitation along the river bank;
- Channel bathymetry and bank geometry;
- Seasonal channel flow; and
- Discharge design.

The proposed pipeline is expected to be around 600 mm in diameter, with outfall rates provided in Table 9-37, based on water balance results from Pöyry (2012c).



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Muonionjoki Pipeline and Outfall Map	Figure 7.3

P:\U4784 Rautuvaara HIA\Project\Data\GIS\0. mxd\Figures for reports\Phase 5 FINAL report\Figure 7-3 Muonionjoki Pipeline and Outfall MapPH2_HIA.mxd

7.2 Site Water Balance

Figure 7-4 shows a summary of the project water plan that has been developed by Pöyry during the Hannukainen DFS study (Pöyry, 2012c). For a full description of the predicted mine site water balance, including quantitative predictions and the calculations that underpin them, the reader is referred to the Pöyry water balance report (Pöyry, 2012c).

The Pöyry water balance has been used in the HIA to:

- Identify potential receptors and sources (Section 4.1 and Section 4.2);
- Assess potential impacts on stream flows resulting from changes to catchments within the mine site footprint (Section 9);
- Estimate volume and quality of water discharge (Section 0); and
- Estimate runoff from WRDs to Hannukainen pit lake upon closure (Section 9.7).

7.2.1 Mine Site Catchments

During mine operations contact water with open pits, WRD and other mine infrastructure will be captured and routed to the CP, and subsequently pumped to the South Pond at Rautuvaara. Tailings contact water and surface water runoff captured around the TMF will be treated where necessary, as described above in Section 7.1.4, and also stored in the South Pond.

Excess water not required for mine operations will be discharged to the Muonionjoki River (Pöyry, pers. comm.). Hence, post-development, contact water from within the Project site will be diverted from its natural catchment to the Muonionjoki River, decreasing flows to the Äkäsjoki, Kuerjoki, Valkeajoki and Niesajoki River.

The magnitude of this impact is investigated in the impact assessment (Section 9).

7.2.2 Muonionjoki River

During operations excess mine water from the Hannukainen Project will be treated and then discharged to the Muonionjoki River. For most of the lifetime of the mine there will be a net increase in flows to the Muonionjoki compared to baseline conditions. Discharge rates to the Muonionjoki are shown in Table 9-37.

The impacts of these changes in flow are assessed in Section 9.6.

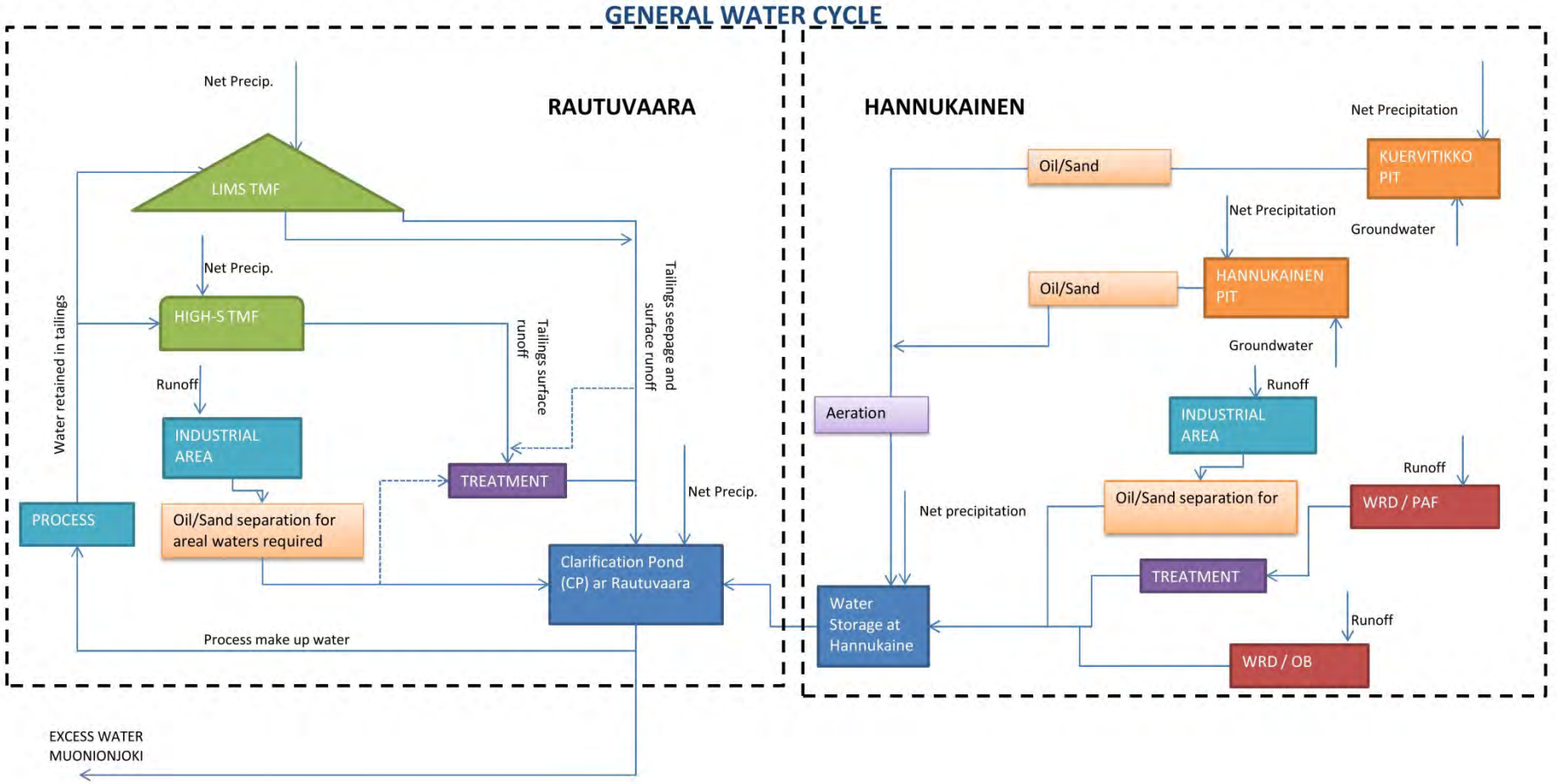


Figure 7-4: Water Cycle at the Hannukainen and Rautuvaara Sites (provided by Pöyry)

8 APPROACH TO IMPACT ASSESSMENT

This section focuses on quantifying the effects of the Hannukainen mine development (including Rautuvaara option), described in Section 6.4.4, on the groundwater system and on local stream hydrology and water quality in key watercourses potentially impacted by the development.

The initial scoping assessment was refined during the baseline assessment and development of the Project description to create a comprehensive list of key impacts that required quantitative assessment, described in Section 4 and summarised below:

1. Changes to the baseflow to Äkäsjoki and tributaries as groundwater is captured within the open pit (i.e. pit dewatering) and managed on site;

2. Changes to the baseflow to Äkäsjoki, Niesajoki and tributaries as the groundwater regime is altered by the proposed TMF;

3. Changes to surface runoff to Äkäsjoki, Niesajoki and tributaries as a result of the mine footprint, e.g. catchments removed / diverted, runoff captured and managed on site, overtopping from post-closure pit lakes;

4. Changes to water quality of the Äkäsjoki, Niesajoki and tributaries as a result of mine infrastructure;

5. Impact of mine site water management on flow and water quality in the Muonionjoki river;

6. Degradation of classified aquifers as a result of pit excavations, WRDs and the expansion of the TMF;

7. Impact of pit dewatering and mine infrastructure on springs and wetlands; and

8. Recovery of pit lakes post-closure once pits are left to flood, including water quality of the lakes and receiving water courses.

In order to inform the impact assessment, analytical and numerical modelling was undertaken.

An overview of the numerical modelling work is given below in Section 8.1 followed in Chapter 9 by an assessment of the effects on each of the key receptors identified in the scoping assessment in Section 4.

8.1 Impact Assessment Tools

Numerical groundwater models, surface water catchment models and geochemical mixing models have been developed to simulate pre-operational, operational and post-closure groundwater system, hydrological conditions and surface water quality at the Project site.

An introduction to the modelling work is given below in Section 8.1.1 to Section 8.1.3 highlighting the differences in work undertaken in Phase 1 and Phase 2 of the assessment.

The reader is referred to the Phase 1 HIA for more detail of the original modelling work (SRK, 2012a) and further details of the Phase 2 modelling methods are provided in appendices and referenced in the appropriate section.

The surface water modelling assesses the impact of mining on river flows, river stage and wetted area. The assessment is based on regional hydrological analysis using available gauged flow data, with the results of this analysis compared to on-site flow measurements. Geochemical mixing models have been used to derive source terms for the WRDs, tailings, tailings ponds and pit lakes. These source terms are mixed with groundwater and surface water in order to assess the potential impact on water quality. In all cases a conservative approach to modelling has been undertaken, for example considering dilution as the only mechanism for reducing the concentration of potential contaminants in the groundwater and surface water systems.

The hydrogeological regime at the Project site is controlled in part by the fracture network and also by the hydraulic properties of the various hydraulic units at the site (Section 6.4.4). Analytical models may provide a preliminary indication of impacts from the mine infrastructure to the local flow regime but more complex, 3-D numerical modelling is required to simulate the effect of the facilities on the local hydrology over the life time of the mine.

The model results are used along with results from the site water balance developed by Pöyry (Pöyry, 2012c) and calculations of treatment quality and flow rates from the Hannukainen CP (Pöyry, 2013) to predict potential impacts as follows:

1. Changes in river baseflow, predicted by the groundwater model, is used to predict the impact of reduced river baseflow on river stage and river flow volume;

2. Surface water catchment models are used to investigate the impact of mine infrastructure on surface water runoff to the local river system and consequently river flow and stage;

3. Operational and post-closure pit inflows and hydraulic gradients, predicted by the groundwater model, are incorporated with source term data in a geochemical mixing model to predict water quality of the pit sumps;

4. Pre-operational and operational tailings pond water balances, predicted by the groundwater model, are incorporated with source term data in a geochemical mixing model to predict water quality of the tailings ponds; and

5. Geochemical mixing models, source terms and seepage estimates are used to predict the impact on the water quality of the local hydrological system.

The numerical models consider the ‘base case’ described in Section 7.1.

It is important to bear in mind that a numerical model is a mathematical representation of a real life situation and therefore can only be, at best, an approximation of the groundwater flow processes. The results from the numerical model should be regarded with caution and with due consideration for the assumptions that underpin them (Harbaugh and McDonald, 1996).

8.1.1 Numerical Groundwater Modelling

Model Objectives

The principal objectives of the numerical groundwater models during Phase 1 were to:

- Provide an estimate of drawdown during operational mining;
- Quantify the impact on baseflow to the local river network; and
- Predict the hydrogeological regime post-closure.

In addition to these Phase 1 objectives, the Phase 2 groundwater modelling work aimed to:

- Provide a water balance for tailings lakes under current and LOM conditions; and
- Predict seepage from the North and South tailings ponds to the local river network.

Modelling summary

The groundwater numerical models of the Hannukainen mine site developed during Phase 1 have been updated to reflect the Phase 2 infrastructure and further adapted to investigate the Rautuvaara TMF site. A summary of the Phase 1 models and the Phase 2 updates is provided in Table 8-1 below.

The reader is referred to the Phase 1 Hannukainen HIA (SRK, 2012a) for more detail of the Hannukainen Phase 1 modelling work and Appendix I for the Rautuvaara modelling.

Table 8-1: Groundwater modelling techniques used in the HIA study

Modelling prediction component		Phase 1 modelling	Phase 2 update
Pre-operational			
Current conditions	Hannukainen	Steady state '**Hannukainen current conditions**' model, calibrated to groundwater levels collected at Hannukainen mine site during field work in May 2011 (SRK, 2012a). Current river baseflow extracted from the model and predicted groundwater surface used as the initial heads for the Hannukainen operational model (SRK, 2012a).	No update required
	Rautuvaara	Not required during Phase 1	Steady state '**Rautuvaara TMF current conditions**' models developed from the Phase 1 Hannukainen current conditions model: - Three steady state models produced (winter, summer and average climate conditions); - Bedrock, overburden and existing tailings hydrological units added to the Rautuvaara area; - Lake cell boundary conditions added to represent existing tailings ponds; - Rautuvaara models calibrated to groundwater levels collected during field work in June 2012 and existing pond levels. See Appendix I for more details
Operational			
Estimate of drawdown during operational mining due to pit dewatering	Hannukainen	Transient state '**Hannukainen operational model**' including Phase 1 pit shells, WRDs and TMF infrastructure covering the life of mine (18 years) (SRK, 2012a). Drawdown and river baseflow extracted for each year.	Phase 1 transient model updated to reflect Phase 2 infrastructure: - WRDs and annual pit shells updated with Phase 2 design; - Model duration extended to cover Phase 2 period of mining at Hannukainen (21 years); - Hannukainen TMF removed from the model; - Revised drawdown and baseflow extracted for each year.
Impact of dewatering on baseflow to the local river network			

Modelling prediction component	Phase 1 modelling		Phase 2 update
Water balance for tailings ponds at Rautuvaara	Rautuvaara	Not required during Phase 1	Steady state '**Rautuvaara LOM**' models developed from the Rautuvaara current conditions models: - Three steady state models (winter, summer and average climate conditions); - Topography and hydrogeological units modified to include LOM LIMS tailings; - High-S cell included as a zone of lower recharge. Transient modelling was not undertaken at Rautuvaara due to uncertainty of the storage properties at the site.
Seepage from the Rautuvaara tailings ponds to local rivers			
Post closure			
Pit flooding post closure	Hannukainen	Transient state '**Hannukainen post-closure**' model developed to simulate tailings backfill in the pits and pit lake flooding under average, 20-year-dry and 20-year-wet climate conditions (SRK, 2012a).	The Phase 1 modelling demonstrated that the pits will take decades to flood, during which time the water quality in the pit lakes will deteriorate. Therefore the decision was taken in Phase 2 to simulate artificial flooding of the pits ('**Hannukainen artificial flooding'**). Initial calculations have been undertaken using a relatively simplistic water balance approach developed in GoldSim modelling software which is described in Appendix K.
Hydrogeological regime post closure	Hannukainen	Steady state '**Hannukainen post-closure**' model under average, 20-year-dry and 20-year-wet climate conditions (SRK, 2012a). Groundwater gradients, WRD seepage and overtopping volume extracted from models.	Phase 1 CP and process water pond removed. Two scenarios modelled: - No runoff to pits from WRDs; and - Runoff from WRDs to Hannukainen pit.
	Rautuvaara	Not required during Phase 1	A model has not been developed specifically for post-closure at Rautuvaara because it is envisaged that the proposed closure plan would not result in significant changes to the hydrogeological regime in the basin and therefore the Rautuvaara LOM models can be considered representative of the long term hydrogeological regime.

8.1.2 Surface Water Flow Modelling

Model Objectives

The principal objectives of the surface water flow modelling during Phase 1 were to assess the:

- Impact of changes to the baseflow to the Äkäsjoki and tributaries as groundwater is captured within the open pit (i.e. pit dewatering) and managed on site;
- Impact of changes to surface runoff to the Äkäsjoki and tributaries due to changes to the natural drainage patterns as a result of the mine footprint;
- Combined impact to the Äkäsjoki, its tributaries and the Muonionjoki; and
- Potential impact on the Niesajoki stream flows resulting from mine water discharges to the Niesa Basin.

In addition to these Phase 1 objectives, the Phase 2 surface water flow modelling work aimed to assess the:

- Impact of changes to the Niesajoki as water is managed at the proposed Rautuvaara TMF;
- Impact of changes to the Kylmäoja Stream resulting from development of the proposed Rautuvaara TMF; and
- Impact of the proposed outfall on the Muonionjoki.

Modelling summary

The surface water flow modelling undertaken during Phase 1 have been updated to reflect the Phase 2 infrastructure. Additional work has been completed to investigate the Rautuvaara TMF site. A summary of the Phase 1 and Phase 2 works is provided in Table 8-2 below.

The reader is referred to the Phase 1 Hannukainen HIA (SRK, 2012a) for more detail of the Hannukainen Phase 1 modelling work and Appendix C for the Rautuvaara modelling.

Table 8-2: Surface water modelling techniques used in the HIA study

Modelling prediction component	Phase 1 modelling		Phase 2 update
Pre-operational			
Impact on the Laurinoja Channel and downstream rivers as existing pit lake dewatering is discharged to the stream	Hannukainen	Typical section of the Laurinoja stream generated based on field measurements. Changes in flow and wetted area predicted based on flow rates dictated in the BRC discharge permit (Section 2.2.1) (SRK, 2012a).	Not required during Phase 2.
Operational			
Changes to the baseflow to Äkäsjoki and tributaries as groundwater is captured within the open pit (i.e. pit dewatering) and managed on site	Hannukainen	Based on the predicted changes in baseflow in Year 18 generated by the numerical groundwater model an assessment is made of the impact of these changes on flows and water levels in the Äkäsjoki adjacent to the mine, Kuerjoki at its mouth and Muonionjoki at the confluence with Äkäsjoki (SRK, 2012a). River sections are based on field measurements.	Changes in baseflow and associated impacts updated using outputs of the Phase 2 groundwater numerical modelling.
Changes to surface runoff to local rivers due to changes to the natural drainage patterns as a result of the project footprint	Hannukainen	Baseline catchments delimited for the Äkäsjoki, Kuerjoki and Valkeajoki. Catchments areas diverted from each river estimated by Pöyry. For the purpose of the impact assessment it is assumed that the lost runoff volumes to each river is proportional to the lost catchment area, i.e. a 1% loss in catchment area reduces runoff to the river by 1%. The changes in catchment area are assumed to impact stream flows in open water / non-winter months (May to October) due to decreases in surface runoff (SRK, 2012a).	Lost runoff volumes updated to reflect Phase 2 infrastructure.
	Rautuvaara	Not required during Phase 1	Baseline catchments delimited for the Niesajoki River and Kylmäoja Stream. Modelling of the impact of development of flows in Niesajoki, Kylmäoja and Muonionjoki are based on application of the same methods used to estimate baseline flow conditions (Section 5.2.2).

Modelling prediction component	Phase 1 modelling		Phase 2 update
Combined impact to local rivers	Hannukainen	The combined impact on river flow due to changes to baseflow and changes to surface water runoff have been estimated for the Äkäsjoki, Kuerjoki, Valkeajoki and Muonionjoki. In terms of impact on aquatic life changes in hydraulic parameters such as water depth and wetted perimeter are of more significance than changes in flow alone. Hence, the impact of the predicted flow reductions on river depth and wetted perimeter are illustrated on a cross-section of each river. The analysis is based on the cross-sections and flow measurements taken as part of the baseline monitoring program (SRK, 2012a).	Combined impact predictions for Äkäsjoki, Kuerjoki and Valkeajoki updated to reflect Phase 2 updates in baseflow and surface water runoff. Combined impact on Muonionjoki expanded to include the potential impact of the outfall discharge as described below and in Appendix C.
	Rautuvaara	Not required during Phase 1	Combined impact prediction extended to include Niesajoki River and Kylmäoja Stream.
Potential impact on Niesajoki stream flows resulting from mine water discharges to Niesa Basin	Rautuvaara	An assessment of the impact of the mine on flows in the Niesajoki River is assessed at three locations (downstream of Niesa basin, mid-point of Niesajoki River and mouth of Niesajoki River) as well as in the Muonionjoki River downstream of the confluence of the Niesajoki. The effects assessment is based on water balance results presented in Pöyry (2012a) (SRK, 2012a).	Not required during Phase 2.
Muonionjoki outfall	Combined	Not required during Phase 1	Modelling of the impact of development of flows in the Muonionjoki due to the proposed discharge from the Rautuvaara TMF are based on application of the same methods used to estimate baseline flow conditions (Section 5.2.2) (Appendix C).
Post-closure			
Overtopping of pit lakes to Äkäsjoki and Kuerjoki Rivers	Hannukainen	Changes to river flow and wetted area assessed using same methodology as the operational impacts (SRK, 2012a).	Updated to include volumes predicted by the Phase 2 groundwater numerical models.

8.1.3 Hannukainen Site Geochemical Modelling

Model Objectives

The principal objectives of the geochemical modelling during Phase 1 were to:

- Calculate source terms for the WRDs, pit sumps and treated discharge water during operational mining;
- Predict water quality impacts in classified aquifers receiving WRD and TMF seepage;
- Predict water quality impacts in receiving surface water courses following receipt of discharge from Hannukainen mine site; and
- Estimate pit lake water quality following cessation of mining and flooding of the pit voids.

In addition to these Phase 1 objectives, the Phase 2 geochemical modelling work aimed to:

- Generate source terms for the Rautuvaara TMF under current conditions, during LOM and post closure;
- Predict the impact of the Rautuvaara TMF on the Niesajoki River and Kylmäoja Stream; and
- Predict the impact of the Muonionjoki outfall on the river's water quality.

Modelling summary

The geochemical models developed during Phase 1 have been updated to reflect the Phase 2 infrastructure. Additional work has been completed to investigate the Rautuvaara TMF site. A summary of the Phase 1 models and the Phase 2 updates is provided in Table 8-3 below. The various sources of contamination at Rautuvaara TMF and their descriptions are given in Table 8-4 below.

The reader is referred to the Phase 1 Hannukainen HIA (SRK, 2012a) for more detail of the Hannukainen Phase 1 modelling work and Appendix J for the Rautuvaara modelling.

Table 8-3: Geochemical modelling techniques used in the HIA study

Modelling prediction component	Phase 1 modelling		Phase 2 update
Pre-operational			
Discharge of pit dewatering water to the Laurinoja Stream, and subsequently Äkäsjoki	Hannukainen	Geochemical mixing model developed to predict discharge water quality of pre-mining dewatering water. The modelling considers water treatment comprising a wetland / sedimentation pond and aeration cascade (SRK, 2011).	Water will be discharged to the CP rather than the Laurinoja Stream, therefore impact prediction for the Laurinoja and Äkäsjoki not required in Phase 2. Predicted water quality of discharge included in the Phase 2 HIA at the request of the client. No modification to treatment technique, therefore no update to the water quality predictions required.
Operational			
Water quality impacts in classified aquifers receiving WRD and TMF seepage	Hannukainen	Initial proportional mixing of WRD source term solution chemistry with baseline groundwater quality. Proportions determined based on volumetric flow rates of solutions beneath the WRD footprint. Secondary dispersion / dilution taken into account along groundwater flow path through calculation of recharge which is used to calculate a second proportional mixing scenario. This final mixing gives the predicted solution chemistry at discharge to the receiving water course. In addition, water quality within aquifers is taken to be within the range of the initial and secondary groundwater mixing scenarios. Modelling was undertaken using the thermodynamic equilibrium numerical code PhreeqC8 and following mixing of waters saturated mineral were allowed to precipitate and adsorption of metals to mineral phases was permitted (SRK, 2012a).	Mixing models updated with Phase 2 WRD proportions and footprints. TMF loadings removed from the Hannukainen calculations.
Prediction of water quality of groundwater impacted by WRD and TMF seepage at diffuse discharge to surface water receptors, i.e. source term for groundwater discharge to surface water receptors	Hannukainen		

Modelling prediction component	Phase 1 modelling		Phase 2 update
Water quality impacts in receiving surface water courses following receipt of discharge from Hannukainen mine site	Hannukainen	Prediction of metals concentrations within the receiving streams and rivers was undertaken using a conservative mass balance approach using the Golders Associates GoldSim software. In the software volumetric loadings were mixed from each of the potential impacted contaminate sources with the background water quality. This method is conservative in that it is non-thermodynamic equilibrium dependant and does not take into account such things as mineral saturation, pH equilibrium, atmospheric gas equilibrium or attenuation through adsorption. Due to the short residence times in the receiving water courses, it is justified to use such a model as it cannot be guaranteed that equilibrium will be reached and also that any precipitates are likely to form a colloidal and / or suspended load (SRK, 2012a).	Mass balance models updated with Phase 2 loadings predicted by the updated mixing models. Loadings from Hannukainen TMF removed from Phase 2 calculations.
Source term water quality prediction for the Rautuvaara TMF	Rautuvaara	Not required during Phase 1	Water quality predictions were made for the north and south Rautuvaara tailings facility ponds for current pre-mining conditions, LOM tailings emplacement conditions and for the tailings facility post closure. In each case steady state conditions were assumed in line with the steady state groundwater modelling described in Section 8.1.1. A numerical mass balance approach was used to calculate chemical concentrations in the Rautuvaara TMF ponds. The mass balance calculated concentrations were then subjected to thermodynamic equilibration to determine if any components were oversaturated with respect to common mineral phases using the USGS thermodynamic numerical speciation code PhreeqC[8]. Model inputs are given in Table 8-4. See Appendix J for further details.

[8] *PhreeqC (Version 2.18.3.5570) released August 16, 2011 coupled with an adapted Minteq.v4 thermodynamic database*

Modelling prediction component	Phase 1 modelling		Phase 2 update
Surface water quality prediction for rivers downstream of the Rautuvaara TMF	Rautuvaara	Not required during Phase 1	Post-development concentrations are calculated based on a conservative dilution modelling approach described in more detail in Appendix J. The model considers the baseline load and flow, and loads from the TMF. The modelling considers the source terms predicted by the geochemical modelling described above and in Table 8-4. Geo-chemical modelling predictions are provided for average July flow conditions, average annual flow conditions and average winter flow conditions and dilution calculations are undertaken for the same periods (Appendix J).
Water quality of the Muonionjoki River	Combined	Not required during Phase 1	Calculations of post-development water quality in the Muonionjoki due to the proposed outfall were calculated using three methods: - Box model: At the outfall where the effluent undergoes initial dilution. A simple model was set-up in the GoldSim modelling software and the calculations were run until a steady state was achieved (i.e., concentrations in the box did not change over time). - Plume model: Close to the outfall where the effluent has formed a plume, but has not fully mixed across the river. This is modelled using a 2D advection-diffusion equation; and - Complete mixing model: At a distance from the outfall when the effluent has fully mixed with the river flows. This is modelled using a standard conservative dilution modelling approach. Source terms were provided for year 5, 10 and LOM and water quality calculations were undertaken for the same periods. See Appendix C for further details.

Modelling prediction component		Phase 1 modelling	Phase 2 update
Post-closure			
Water quality impacts of Hannukainen and Kuervitikko pit lakes following mine closure	Hannukainen	Transient pit lake water quality was determined at 14 time steps spanning a 750 year filling period. The long time steps were required to allow the pit lakes to fully reach geochemical steady state. At each time step water quality within the pit lake is determined through proportional mixing of inflows to the pit lake minus outflows from the pit lake (including evaporation) with the pit lake water from the previous time step. Inflows of groundwater, surface runoff and direct precipitation are calculated based on the hydrogeological modelling. In addition, inputs from WRD seepage and backfilled tailings seepage are also. Modelling was undertaken using the thermodynamic equilibrium numerical code PHREEQC8 and at each time step over saturated mineral were allowed to precipitate and adsorption of metals to mineral phases was allowed.	Phase 2 considers artificial flooding of the pits using the volumes provided by the artificial flooding model (Section 8.2.1). Pit lake water quality was determined at two stages during mine development, 1) at time of first spill and 2) at hydrogeochemical steady state. In each case models were single step (i.e. they do not consider transient filling) as the short fill time made this approach unnecessary. Modelling incorporated a mass balance approach in which chemical loadings from various sources including high wall run-off and WRD seepage were mixed. This was coupled with thermodynamic equilibration using the numerical geochemical equilibration code PhreeqC[9] which allows oversaturated mineral phases to precipitate and solid: solution, gas: solution interaction.
Source term water quality prediction for the Rautuvaara TMF post-closure	Rautuvaara	Not required during Phase 1	Same techniques applied to closure scenario as operational source term prediction. Predictions consider three scenarios, varying depending on the effectiveness of encapsulation of High-S tailings during closure: - Worst case that assumes 100% of High-S tailings are available to contribute to loadings in the TMF; - Medium case that assumes 50% of High-S tailings are encapsulated at closure; and - Best case that assumes 0% of High-S tailings are available to contribute to loadings in the TMF (Appendix J).
Surface water quality prediction for rivers downstream of the Rautuvaara TMF post-closure	Rautuvaara	Not required during Phase 1	Same techniques applied to closure scenario as operational predictions and replace Phase 1 predictions for the Niesajoki River (Appendix C).

Table 8-4: Table describing details of mass balance model inputs and sources for the Rautuvaara water quality predictions model.

Source	Applicable to	Chemical constituent	Volumetric flow constituent
Existing tailings Seepage (Fines)	**Current / LOM / Close**	Average water quality of pore water reported in tailings fines area trial pits (TP06, 07 and 08).	Seepage volumes from the existing tailings are assumed to be equal to the predicted LOM seepage volumes for winter, June and Average scenarios. Chemical load taken to be constant following closure and increased rate of pore water release through additional loading is assumed to be negligible
Existing tailings seepage (Corse acidic tailings)	**Current**	Water quality taken to be equal to the toe seepage at the Northern boundary to the existing TMF. Following closure, load from the high sulphur tailings is not incorporated into the model as it is assumed that sulphide oxidation will largely cease due to emplacement of LIMS tailings and onset of saturated conditions. Therefore this source term is removed from the closure model and total seepage load is assumed to share fines seepage characteristics.	Seepage volumes as predicted in the current conditions groundwater scenario
Historic waste rock dump seepage	**Current / LOM / Close**	Water quality of seepage from the historic WRD taken to be equal to the average water quality of pore water from 4 trial pits. Loading release from the dump is taken to stay constant once LIMS tailings cover is taken into account.	Seepage volume taken to be equal to 50% annual average precipitation onto WRD area.
Clean groundwater inflow to the South Pond and tailings	**Current / LOM / Close**	Water quality taken to be equal to the average of all deep and shallow groundwater quality for wells showing no impact from historic mining or mineralisation	Flows taken as the total groundwater flow into the pond proportioned by the non-mine impacted flow path
Groundwater impacted by historic mining flowing into the South Pond and tailings area	**Current / LOM / Close**	Water quality taken to be equal to the average of RAU12HYD01 and RAU12HYD02 wells located down gradient of the historic mine workings	Flows taken as the total groundwater flow into the pond proportioned by the mine impacted flow path
Clean groundwater inflow into the North Pond	**Current / LOM / Close**	Water quality taken to be the average water quality of all groundwater wells in the flow path entering the North Pond	Flows taken to be the total predicted groundwater inflow into the North Pond
LIMS tailings seepage water quality and quantity LOM and Closure	**LOM**	LOM chemical loadings taken from Erikson (2012) – Hannukainen DFS tailings characterisation report – These loadings were calculated for the Phase 1 tailings placement and have been taken to be equal to the loadings in the LIMS tailings at the Phase 2 Rautuvaara site.	LOM Seepage volumes as predicted from hydrogeological modelling undertaken as part of this study + the additional contribution from entrained process water. Seepage volumes in the post closure seepage scenario are assumed to be identical to the LOM scenario with the exception of the entrained process water volume no longer contributes to the total seepage volume. Addition of a till cover is assumed to have no impact on infiltration into the tailings itself. In each case loadings are proportioned to estimated seepage volumes flowing into the North or South TMF Pond (10% of load assumed to report to the North Pond and 90% of the South Pond)
	Close	Closure Chemical loadings taken from Erikson 2012 – Hannukainen DFS tailings characterisation report – These loadings were calculated for the Phase 1 tailings placement and have been taken to be roughly equal to the loadings in the Phase 2 tailings placement at Rautuvaara.	
High S tailings seepage water quality and quantity LOM and closure	**LOM**	High S source term chemical loadings (mass/time) were taken from the Hannukainen DFS tailings characterisation report for predicted seepage through liner. This assumes that tailings are neutralised with lime to prevent ARD generation during LOM. No segregation was made between seepage from the pyrite and pyrrhotite tailings fractions in the High S impoundment.	Chemical constituents added as direct loadings the receiving TMF ponds proportioned to approximate seepage volumes (10% of load assumed to report to North Pond and 90% to South Pond).
	Close	Source terms taken to be a proportion of the total load predicted in the Erikson 2012 report for post closure oxidation of High S tailings. Four scenarios were run: 1) Zero release – assuming full encapsulation of the tailings post closure; 2) 10% load release – assuming 10% of the potential predicted load is release; 3) 50% load release – assuming 50% of the predicted total load is released; and 4) 100% load release – assuming that 100% of the predicted total load is released. Each of the four scenarios highlights potential variation between idealised planned closure case in which the tailings are drained down and fully encapsulated post closure assuming zero release of seepage to the environment and the case highlighted by Erikson 2012 in which the integrity of a HDPE lined cell degrades over time (100 to 1000 year timescale) and therefore full seepage to the environment should be assumed.	
Precipitation and catchment runoff	**Current / LOM / Close**	Direct precipitation to the North and South Pond and also all non-impacted runoff is assumed to show characteristics of pure rainwater (global mean estimate).	Volumes are taken directly from the groundwater modelling undertaken in the current study
Water from the Hannukainen site (LOM model only)	**LOM**	Volumes and water quality of Hannukainen drainage taken from Pöyry 2012 (Kirsi-Marja-Haanpaa pers comm). This source is excluded from the post closure water quality prediction	
Treated water from the High S tailings decant during LOM operation	**LOM**		
Backfilled tailings in the Rautuvaara pits	**LOM / Close**	Source term for the backfilled tailings in the Rautuvaara pits taken to be equal to the loading calculated for backfilling of the High S tailings in the Hannukainen pits proportioned to a reduced final backfilled volume of 2Mt of tailings. The loading from this material was added to the model without a flow component (i.e. was assumed to be additive to the background water quality)	

9 ASSESSMENT OF IMPACTS

9.1 Äkäsjoki River

Operational Phase: Pit dewatering and changes to the natural drainage pattern

The SRK groundwater model results indicate that, prior to mining, groundwater flow is from the mine development area towards the rivers. However, pit dewatering during operational mining will produce a cone of depression around the pits that will cause a reversal of this groundwater gradient to the extent that water from the rivers is predicted to recharge the groundwater system and contribute to groundwater inflows to the pits. Hence, dewatering activities associated with the open pits at the Hannukainen mine have the potential to decrease baseflow in the Äkäsjoki (including the contribution from the Kuerjoki) adjacent to the mine site.

The largest decrease is predicted to occur in Year 19 of mining operations (i.e. LOM), with a reduction in baseflow of 2,556 m^3/day (equivalent to 30 L/s 0.03 m^3/s). This is the sum of the predicted flow losses from both the Äkäsjoki and Kuerjoki Rivers, which will affect flows in the Äkäsjoki adjacent to the mine site.

Construction of the mine site will also result in a decrease in catchment area of around 1.6% compared to baseline conditions, impacting stream flows in summer months (Table 9-1).

Table 9-1: Mine site areas potentially impacting flows to Äkäsjoki adjacent to mine site

Mine Component	Area of mine component within Äkäsjoki catchment (km^2), including catchments in Kuerjoki catchment
Hannukainen pit	2.08
Kuervitikko pit	0.56
PAF EAST WRD	1.62
NAF EAST WRD	0.81
OB EAST WRD	2.05
PAF WEST WRD	0.27
NAF WEST WRD	0.41
OB WEST WRD	0.64
Water Collection Pond	0
Total area removed	8.44
Natural Catchment	523
% of catchment removed	1.6%

The predicted percentage reduction of monthly flows in the Äkäsjoki River at the mine site is presented in Table 9-2. Predicted changes in 7-day low flow and 7-day Q_{10} estimates are presented in Table 9-3.

Table 9-2: Predicted change in Äkäsjoki River flows resulting from decrease in post-development baseflow and changes to surface water runoff (LOM)

	Percentage decrease in flow from baseline conditions %											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	4	4	4	4	2	2	3	4	4	3	3	3
1 in 50 DRY	4	4	4	4	2	2	3	4	3	3	2	3
1 in 10 DRY	3	3	3	2	2	2	3	3	3	3	1	2
Average	2	2	3	1	2	2	2	2	2	2	1	1
1 in 10 WET	1	2	2	1	2	2	2	2	2	2	0	1
1 in 50 WET	1	1	1	0	2	2	2	2	2	2	0	1
1 in 100 WET	1	1	1	0	2	2	2	2	2	2	0	1

Months in orange are considered impacted by changes in baseflow only. Months in white are impacted by changes in runoff from catchment and decrease in baseflow.

Table 9-3: Predicted change in 7-day low flow and 7-day Q_{10} estimates for Äkäsjoki River

Low Flow Parameter	Baseline Flow (m^3/s)	Predicted decrease in baseflow (m^3/s)	Percentage decrease in stream flows
7-day annual average low flow (m^3/s)	1.01	0.03	3
7-day Jul-Sep average low flow (m^3/s)	1.34	0.03	2
7-day annual average Q_{10} flow (m^3/s)	0.55	0.03	5
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.79	0.03	4

Based on predicted change in baseflow only

The results indicate no more than a 2% decrease in stream flows during an average year, with the impact increasing to 4 – 5% for even the most extreme dry flow conditions (e.g. 1 in 100 year dry average monthly flow and 7-day annual average Q_{10} flow).

Hydraulic calculations of water level and wetted area for the channel are based on Manning's equation calibrated for the water level and flow measured in May 2011 (Photo 9-1).



Photo 9-1: Äkäsjoki River upstream of Valkeajoki River junction (SRK 10/05/2011), taken at river flow monitoring point SW012

Water levels were calculated for low flow conditions. The impact of decreasing baseflow is shown in Figure 9-1 and Table 9-4. The results indicate negligible changes in water levels and stream flow area in response to the predicted changes in baseflow conditions due to mine dewatering.

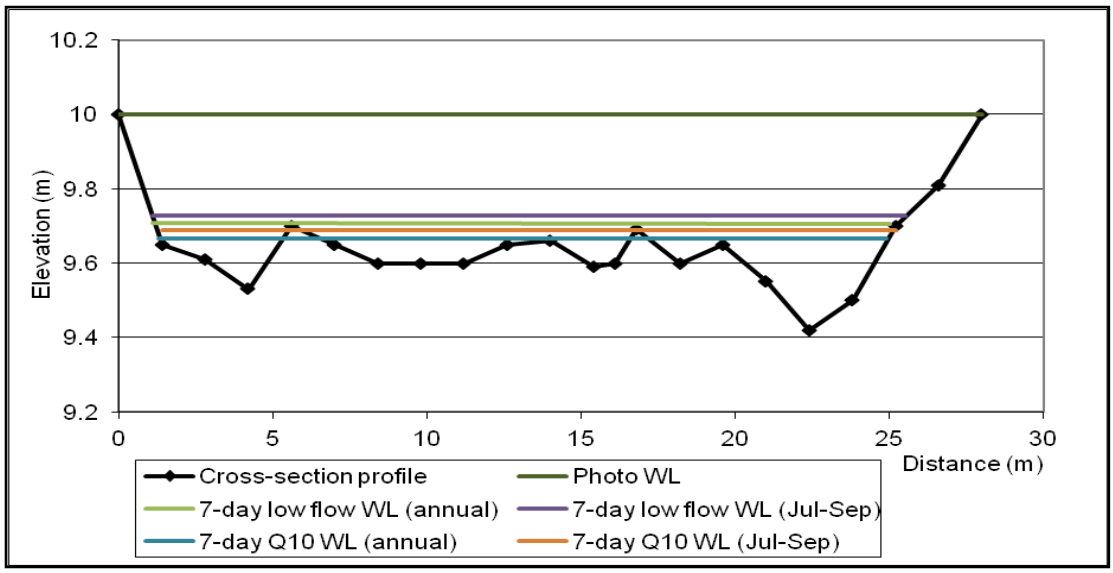


Figure 9-1: Cross-section of Äkäsjoki River at river gauging point, showing water levels at time of survey and predicted water levels under low flow conditions

Table 9-4: Predicted impact of decrease in baseflow on channel section for Äkäsjoki River

Flow Condition	Baseline				Change in parameters at LOM			
	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2
7-day low flow (Annual)	1.1	9.71	24.24	2.6	-0.003	<0.01	-0.03	<0.1
7-day low flow (Jul-Sep)	1.34	9.72	24.47	2.9	-0.003	<0.01	-0.03	0.1
7-day Q_{10} (Annual)	0.55	9.67	22.19	1.6	-0.003	<0.01	-0.15	<0.1
7-day Q_{10} (Jul-Sep)	0.79	9.69	23.41	2.1	-0.003	<0.01	-0.15	<0.1

Operational Phase: Impact of seepage from waste dumps on stream water quality

During operations contact water from the mine site, such as surface water runoff over disturbed surfaces, pit sump water and surface runoff from waste dumps will be captured and passed to a water collection pond on site. This water will be re-used on site or treated before being pumped to the Rautuvaara TMF area. Hence, surface water runoff is not expected to result in significant changes to surface water quality in the Äkäsjoki River. However, seepage to groundwater from water passing through waste dumps has the potential to impact the quality of baseflow to the streams.

Estimates of the quantity and quality of groundwater seepage to the Äkäsjoki River have been made using methods described in Section 8.1.3 and the resultant water quality in the Äkäsjoki River were predicted through conservative dilution calculations during spring and winter flow conditions. A constant rate of seepage from WRD is considered in the assessment. Predicted concentrations in the river are outlined in Table 9-5.

The model results indicate that no exceedances of TVs are predicted for key parameters for spring flow conditions. During winter months exceedances of TVs for cadmium, chromium, mercury and uranium are predicted. However, predicted concentrations of chromium and uranium need to be viewed with caution as predicted concentrations of these parameters in waste dump runoff may be overly conservative, as discussed in Section 3.2.

Table 9-5: Predicted end of mine life water quality predictions for Äkäsjoki

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration - End of Life of Mine (mg/L)		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters								
Nitrite	mg/L	0.0019	0.01	0.001				
Nitrate	mg/L	0.073	20	0.012	0.012	0.013	2.5	5.4
Chloride	mg/L	0.992	150	0.0008	0.0032	0.020	300	2400
Sulphate	mg/L	4.4	65	3.2	3.3	3.3	2.1	2.9
Iron	mg/L	0.4	0.98	0.28	0.29	0.29	2.1	2.4
Aluminium	mg/L	0.05	0.1	0.021	0.022	0.022	2.6	6.3
Arsenic	mg/L	0.000098	0.005	0.000065	0.000067	0.000074	3.5	13
Cadmium	mg/L	0.0000031	0.00008	0.0000025	0.0000028	0.0000044	11	74
Cobalt	mg/L	0.000077	0.004	0.00004	0.000043	0.000059	7.6	47
Chromium	mg/L	0.00032	0.001	0.00028	0.00032	0.00057	14	100
Copper	mg/L	0.00047	0.005	0.00036	0.00037	0.00038	2.6	6.6
Mercury	mg/L	0.0000026	0.00005	0.0000016	0.0000019	0.0000035	16	120
Manganese	mg/L	0.018	0.7	0.010	0.010	0.010	2.1	2.8
Molybdenum	mg/L	0.00019	1	0.00017	0.00018	0.00019	3.3	13
Nickel	mg/L	0.0003	0.02	0.00021	0.00022	0.00023	3.1	11
Lead	mg/L	0.000052	0.0072	0.000036	0.000037	0.000037	2.1	2.2
Uranium	mg/L	0.0001	0.015	0.000092	0.00010	0.00015	0	0
Zinc	mg/L	0.0016	0.03	0.00088	0.00092	0.0011	0	0

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration - End of Life of Mine (mg/L)		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters								
Phosphate	mg/L	0.011	0.017	0.0085	0.0063	0.0075	4.8	24
TOC	mg/L	7.7	14	5				
Calcium	mg/L	3.1	4.8	2.7	3.2	3.2	2.2	3.1
Potassium	mg/L	0.49	0.82	0.39	0.38	0.40	2.6	6.9
Magnesium	mg/L	0.96	1.4	0.87	0.93	0.95	2.3	4.0
Sodium	mg/L	1.8	2.5	1.6	1.5	1.6	2.4	4.6
Silicon	mg/L	6.1	10	4.8	4.2	4.2	2.1	2.3
Barium	mg/L	0.0052	0.01	0.0046	0.0082	0.0082	0	0
Strontium	mg/L	0.02	0.03	0.017	0.017	0.018	2.2	3.4
Antimony	mg/L	0.00001	0.000014	0.000010	0.000012	0.000020	12	84

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Post-closure: Impact of seepage from waste dumps and overflow from Hannukainen pit lake on stream water quantity and quality

Description

Following the end of mine operations the Hannukainen pit will be artificially flooded as summarised in Section 7.1.1 and described in full in Appendix K. Once filled the Hannukainen pit lake will have a positive water balance (Appendix K) and excess water accumulating in the pit lake will flow to the Äkäsjoki. Water from the Kuervitikko pit will flow to the Kuerjoki and subsequently in to the Äkäsjoki. At closure there is predicted to be no direct seepage from any WRDs to the Äkäsjoki; seepage will enter the pit lake and mixing processes within the pit lake will determine the quality of water released to the Äkäsjoki from the surface layers of the pit lake.

Water quality predictions for the Hannukainen and Kuervitikko pit lakes are described fully in Section 9.7. Predictions are made for initial overflow from pit lake and steady state. In addition, two pit lake water quality predictions are provided, one assuming that seepage from PAF WRDs are consistent with data from Humidity Cell Testing (HCT in Table 9-7) and the second assuming that seepage from the PAF waste rock materials are consistent with data from Net Acid Generation testing (NAG data in Table 9-7). Water quality predictions based on these two model inputs are considered in Table 9-7 to provide bounds for likely river water quality; the actual WRD runoff quality is expected to lie somewhere between these two data sets. Full details are provided in Section 9.7.

The impact of pit lake water quality on stream water quality in the Äkäsjoki is outlined in Table 9-7, which provides the results of dilution calculations considering over-spill from the Hannukainen and Kuervitikko pit lakes.

Assessment of flow

Under average runoff conditions, modelling predicted the annual flow volume from Hannukainen pit lake to the Äkäsjoki to be around 1,200,000 m^3/year (Appendix K). The monthly distribution of flows from the pit lake is shown in Table 9-13 where they are presented as a percentage of the stream flow in the Äkäsjoki close to the mine site. During operations there was a decrease in flows to the Äkäsjoki due to a decrease in baseflow and a reduction in the catchment area flowing to the river. At closure the catchment area diverted to Hannukainen pit lake will be re-connected to the catchment of the Äkäsjoki and baseflow is predicted to return to pre-development conditions as the regional groundwater table returns close to pre-development levels. Hence, at closure flows in the Äkäsjoki are predicted to return close to baseline conditions. Increases in flows to the Äkäsjoki due to overflow from Hannukainen pit lake are shown in Table 9-6 to be similar to losses during operations, as in Table 9-2.

Assessment of Impacts without mitigation

The results indicate that, for the 'initial overflow' of water from the pit lakes to the river, TVs are predicted to be exceeded for a number of key parameters including cadmium, cobalt, copper, mercury, molybdenum, nickel and uranium for a number of combinations of flow conditions and WRD runoff quality. Copper predictions are predicted to exceed AVs under average winter flow conditions and based on NAG data for WRD runoff quality. However, it is noted in Section 9.7, that copper predictions are extremely sensitive to pH of WRD runoff and within the pit lake. Hence, it is likely that the copper predictions for NAG data are over estimated, assuming pH in the pit lakes is less than used in the NAG predictions.

Results for the 'steady state' inflow conditions indicate poorer quality water in the pit lakes, compared to those for the initial spill. This is not unexpected as the initial spill results include dilution from river water pumped to the pit lakes to decrease the time taken to fill the pits. The model results suggest the potential for exceedances of AVs for iron, aluminium, cobalt, chromium and copper, with most exceedances (all but chromium) for the scenario with WRD seepage based on NAG data. TV exceedances are predicted for all key parameters apart from nitrate and chloride.

Pit lake water quality predictions suggest the potential for low pH within the Hannukainen pit (pH 5.5 for the initial overflow; pH 3.5 for steady state) and Kuervitikko pit (pH 3.8 for the initial overflow; pH 6.2 for steady state). Hence, without mitigation there is a risk of the pH in the Äkäsjoki falling outside the AV limits between pH6 and pH 9.

As noted above and in Section 9.7, the 'steady state' results should be considered as conservative (high), but they indicate that there is potential for poor quality water in the pit lakes and resultant impact in the Äkäsjoki. The results indicate that further modelling work and development of mitigation measures will be required to produce acceptable water quality in the Äkäsjoki.

Assessment of Impacts with mitigation

As outlined in Section 9.7, the water quality of the surface layer of the Hannukainen pit lake will depend on a number of chemical (e.g. quality of runoff from WRD and pit walls) and physical factors (e.g. presence of physical layering or stratification in the pit lake). However, irrespective of these uncertainties two potential mitigation measures that could be implemented are:

1) Addition of alkaline rock (limestone, $CaCO_3$) to PAF rock dumps; and

2) Addition of alkaline amendment[9] (such as lime, CaO) to the Kuervitikko pit lake to correct initial poor water quality.

Calculations of the mass of $CaCO_3$ required to neutralise the PAF dumps and CaO required to neutralise (i.e. raise the pH) the Kuervitikko pit lake are provided in Section 9.7, along with the resultant pit lake water quality estimates. The impact of adding $CaCO_3$ on water quality in

[9] *In this context an alkaline amendment is substance that is added to a mine facility (WRD, pit lake, tailings facility) in sufficient quantity to neutralise any acidity generated and ensure neutral pH*

Äkäsjoki is summarised in Table 9-8. The results indicate a marked improvement in water quality predictions for the NAG data, especially for the Steady State model results, with the neutralised WRD runoff showing potential exceedances of AV's for chromium only. No parameters are shown to exceed AVs for the initial overflow case, with a substantial reduction in copper concentrations. Adding CaO to Kuervitikko pit lake only also produces improvements in water quality compared to the base case NAG prediction. Results are not provided that consider the combined effect of adding $CaCO_3$ to PAF WRD and lime to the Kuervitikko pit lake, as it is thought that this would be an unnecessary measure.

The impact that detection limits have on WRD predictions for selected parameters such as chromium are discussed in Section 9.7.

Table 9-6: Predicted monthly discharge from Hannukainen pit lake, once full

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly overflow from Hannukainen pit (m^3/s)	[a]0.016	[a]0.016	[a]0.016	[a]0.015	0.208	0.024	0.036	0.043	0.049	0.058	[a]0.015	[a]0.016
Overflow as percentage of stream flow in Äkäsjoki	1	1	1	1	1	0.3	1	1	1	1	0.4	1

a These are estimates and discharged from the pit lake may not occur in winter months when the pit lake and downstream water courses are frozen

Table 9-7: Predicted post-closure water quality predictions for the Äkäsjoki without mitigation

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition			
					WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data		WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters												
Nitrate	mg/L	0.073	20	0.012	0.016	0.018	0.016	0.018	0.042	0.035	0.044	0.036
Chloride	mg/L	0.992	150	0.0008	0.029	0.074	0.021	0.055	0.83	0.58	0.5	0.29
Sulphate	mg/L	4.4	65	3.2	3.5	3.7	3.7	4.2	5.6	5.1	19	17
Iron	mg/L	0.4	0.98	0.28	0.28	0.28	0.33	0.4	0.29	0.28	1.8	1.6
Aluminium	mg/L	0.05	0.1	0.021	0.021	0.022	0.024	0.029	0.031	0.023	0.57	0.49
Arsenic	mg/L	0.000098	0.005	0.000065	0.000072	0.000086	0.00007	0.000081	0.00017	0.0001	0.0002	0.00013
Cadmium	mg/L	0.0000031	0.00008	0.0000025	0.000004	0.0000068	0.0000039	0.0000064	0.000034	0.000017	0.000046	0.000027
Cobalt	mg/L	0.000077	0.004	0.00004	0.00006	0.0001	0.00035	0.00085	0.00077	0.00054	0.016	0.013
Chromium	mg/L	0.00032	0.001	0.00028	0.00036	0.00067	0.00035	0.00063	0.0036	0.0012	0.0039	0.0015
Copper	mg/L	0.00047	0.005	0.00036	0.00038	0.00042	0.0031	0.0076	0.00089	0.00049	0.16	0.13
Mercury	mg/L	0.0000026	0.00005	0.0000016	0.0000023	0.0000044	0.0000022	0.0000041	0.000036	0.000019	0.000027	0.000012
Manganese	mg/L	0.018	0.7	0.01	0.011	0.013	0.011	0.012	0.055	0.047	0.05	0.043
Molybdenum	mg/L	0.00019	1	0.00017	0.00021	0.00028	0.00019	0.00022	0.00069	0.00049	0.00074	0.00053
Nickel	mg/L	0.0003	0.02	0.00021	0.00026	0.00035	0.00057	0.0012	0.0008	0.00058	0.018	0.015
Lead	mg/L	0.000052	0.0072	0.000036	0.000039	0.000041	0.000042	0.000047	0.000048	0.000046	0.00042	0.00037
Uranium	mg/L	0.0001	0.015	0.000092	0.00016	0.00026	0.00016	0.00027	0.0033	0.0024	0.0029	0.0021
Zinc	mg/L	0.0016	0.03	0.00088	0.00099	0.0012	0.0011	0.0015	0.0029	0.0016	0.0094	0.0071

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition			
					WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data		WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters												
Phosphate	mg/L	0.011	0.017	0.0085	0.0068	0.0089	0.0068	0.0087	0.02	0.01	0.033	0.023
TOC	mg/L	7.7	14	5								
Calcium	mg/L	3.1	4.8	2.7	3.2	3.4	3.2	3.3	6.7	5.9	4.1	3.7
Potassium	mg/L	0.49	0.82	0.39	0.45	0.57	0.41	0.48	4.1	3.5	2.6	2.1
Magnesium	mg/L	0.96	1.4	0.87	0.93	0.97	0.94	0.98	1.8	1.5	2	1.7
Sodium	mg/L	1.8	2.5	1.6	1.6	1.7	1.5	1.6	3.3	2.8	2.8	2.3
Silicon	mg/L	6.1	10	4.8	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Barium	mg/L	0.0052	0.01	0.0046	0.008	0.0081	0.008	0.0081	0.0081	0.0081	0.008	0.008
Strontium	mg/L	0.02	0.03	0.017	0.018	0.019	0.017	0.018	0.042	0.037	0.025	0.022
Antimony	mg/L	0.00001	0.000014	0.00001	0.000064	0.00015	0.000014	0.000025	0.0021	0.0017	0.00015	0.000073

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-8: Predicted post-closure water quality predictions for Äkäsjoki, with mitigation through $CaCO_3$ addition to PAF waste dumps or Kuervitikko pit lake

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition	
					WRD Water Quality based on NAG Data, CaO added to Kuervitikko		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD	
		TV	AV		Spring)May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters										
Nitrate	mg/L	0.073	20	0.012	0.018	0.016	0.016	0.018	0.043	0.036
Chloride	mg/L	0.992	150	0.0008	0.055	0.021	0.021	0.055	0.49	0.28
Sulphate	mg/L	4.4	65	3.2	4.2	3.7	3.6	4	11	9.4
Iron	mg/L	0.4	0.98	0.28	0.28	0.28	0.28	0.29	0.29	0.28
Aluminium	mg/L	0.05	0.1	0.021	0.022	0.021	0.022	0.025	0.03	0.022
Arsenic	mg/L	0.000098	0.005	0.000065	0.000071	0.000065	0.00007	0.000081	0.00016	0.000098
Cadmium	mg/L	0.0000031	0.00008	0.0000025	0.0000064	0.0000038	0.0000035	0.0000055	0.000027	0.000011
Cobalt	mg/L	0.000077	0.004	0.00004	0.00084	0.00035	0.00011	0.00021	0.0011	0.00084
Chromium	mg/L	0.00032	0.001	0.00028	0.00056	0.00031	0.00035	0.00063	0.0035	0.0011
Copper	mg/L	0.00047	0.005	0.00036	0.00063	0.00049	0.00049	0.00066	0.00077	0.00047
Mercury	mg/L	0.0000026	0.00005	0.0000016	0.0000039	0.0000021	0.0000021	0.000004	0.000024	0.000009
Manganese	mg/L	0.018	0.7	0.01	0.012	0.011	0.01	0.011	0.014	0.013
Molybdenum	mg/L	0.00019	1	0.00017	0.00021	0.00019	0.00019	0.00022	0.00063	0.00043
Nickel	mg/L	0.0003	0.02	0.00021	0.0011	0.00055	0.00025	0.00032	0.00063	0.00044
Lead	mg/L	0.000052	0.0072	0.000036	0.000036	0.000036	0.000039	0.000041	0.000046	0.000043
Uranium	mg/L	0.0001	0.015	0.000092	0.00027	0.00016	0.00016	0.00027	0.0029	0.0021

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition	
					WRD Water Quality based on NAG Data, CaO added to Kuervitikko		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD	
		TV	AV		Spring)May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Zinc	mg/L	0.0016	0.03	0.00088	0.0014	0.0011	0.00096	0.0011	0.0029	0.0015

Parameter	Unit	WQO – FS09		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition	
					WRD Water Quality based on NAG Data, CaO added to Kuervitikko		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD		WRD Water Quality based on NAG Data, $CaCO_3$ added to PAF WRD	
		TV	AV		Spring)May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters										
Phosphate	mg/L	0.011	0.017	0.0085	0.0075	0.0062	0.0068	0.0086	0.018	0.01
TOC	mg/L	7.7	14	5						
Calcium	mg/L	3.1	4.8	2.7	3.6	3.4	3.2	3.3	4.1	3.8
Potassium	mg/L	0.49	0.82	0.39	0.48	0.41	0.42	0.49	2.4	2
Magnesium	mg/L	0.96	1.4	0.87	0.98	0.94	0.93	0.98	1.4	1.2
Sodium	mg/L	1.8	2.5	1.6	1.6	1.5	1.5	1.6	2.8	2.3
Silicon	mg/L	6.1	10	4.8	4.1	4.1	4.1	4.1	4.1	4.1
Barium	mg/L	0.0052	0.01	0.0046	0.0081	0.008	0.008	0.0081	0.008	0.008
Strontium	mg/L	0.02	0.03	0.017	0.018	0.017	0.017	0.018	0.025	0.022
Antimony	mg/L	0.00001	0.000014	0.00001	0.000025	0.000014	0.000014	0.000025	0.00018	0.000092

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

9.2 Kuerjoki River

Operational Phase: Pit dewatering and changes to the natural drainage pattern

The SRK groundwater model results indicate that dewatering activities associated with the open pits at the Hannukainen mine have the potential to decrease baseflow contribution to the Kuerjoki, with the largest decrease, 1,124 m^3/day (equivalent to 13L/s or 0.0133 m^3/s) occurring in Year 19 of mining operations (i.e. LOM) (SRK, 2012a).

Construction of the mine site will also result in a decrease in catchment area of around 0.7% compared to baseline conditions, impacting stream flows in summer months (Table 9-9).

Table 9-9: Kuerjoki mine site areas

Mine Component	Area of mine component within Kuerjoki catchment (km^2)
Hannukainen pit	0
Kuervitikko pit	0.46
PAF EAST WRD	0
NAF EAST WRD	0
OB EAST WRD	0.65
PAF WEST WRD	0
NAF WEST WRD	0
OB WEST WRD	0
Water Collection Pond	0
Total area removed	1.11
Natural Catchment	162
% of catchment removed	0.7%

The predicted percentage reduction of monthly stream flows for the assessed return period flows are presented in Table 9-10. Predicted flow and percentage change in 7-day low flow and 7-day Q_{10} estimates are presented in Table 9-11.

Table 9-10: Predicted change in the Kuerjoki River flows resulting from decrease in post-development baseflow and surface water runoff (LOM)

	Percentage decrease in flow from baseline conditions %											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	6	7	7	7	1	2	4	5	4	3	4	5
1 in 50 DRY	6	7	7	6	1	2	3	4	4	3	4	4
1 in 10 DRY	4	5	5	4	1	2	3	3	3	2	2	3
Average	3	4	4	2	1	1	2	2	2	2	1	2
1 in 10 WET	2	3	3	1	1	1	1	1	1	1	1	1
1 in 50 WET	1	2	2	1	1	1	1	1	1	1	0	1
1 in 100 WET	1	2	2	1	1	1	1	1	1	1	0	1

Months in orange are considered impacted by changes in baseflow only. Months in white are impacted by changes in runoff from catchment and decrease in baseflow.

Table 9-11: Predicted change in 7-day low flow and 7-day Q_{10} estimates for the Kuerjoki River

Low Flow Parameter	Baseline Flow (m^3/s)	Predicted decrease in baseflow (m^3/s)	Percentage decrease in stream flows
7-day annual average low flow (m^3/s)	0.27	0.013	5
7-day Jul-Sep average low flow (m^3/s)	0.27	0.013	5
7-day annual average Q_{10} flow (m^3/s)	0.15	0.013	9
7-day Jul-Sep average Q_{10} flow (m^3/s)	0.15	0.013	9

Based on predicted change in baseflow only

The results indicate changes in stream flows during winter months in an average year of no more than 4%. However, in drier years or during extreme dry periods of stream flows are predicted to decrease by 7 – 9 % (e.g., 1 in 100 year dry average monthly flow and 7-day annual average Q_{10} flow).

The predicted flow reductions are illustrated at a cross-section of Kuerjoki River upstream the junction with Äkäsjoki River where SRK took flow monitoring measurements in May 2011, Photo 9-2.



Photo 9-2: Kuerjoki River upstream of junction with the Äkäsjoki River (SRK 11/05/2011), taken at river flow monitoring point SW017

Figure 9-2 shows the water level at the cross-section on the day of the monitoring and the predicted water levels under low flow conditions.

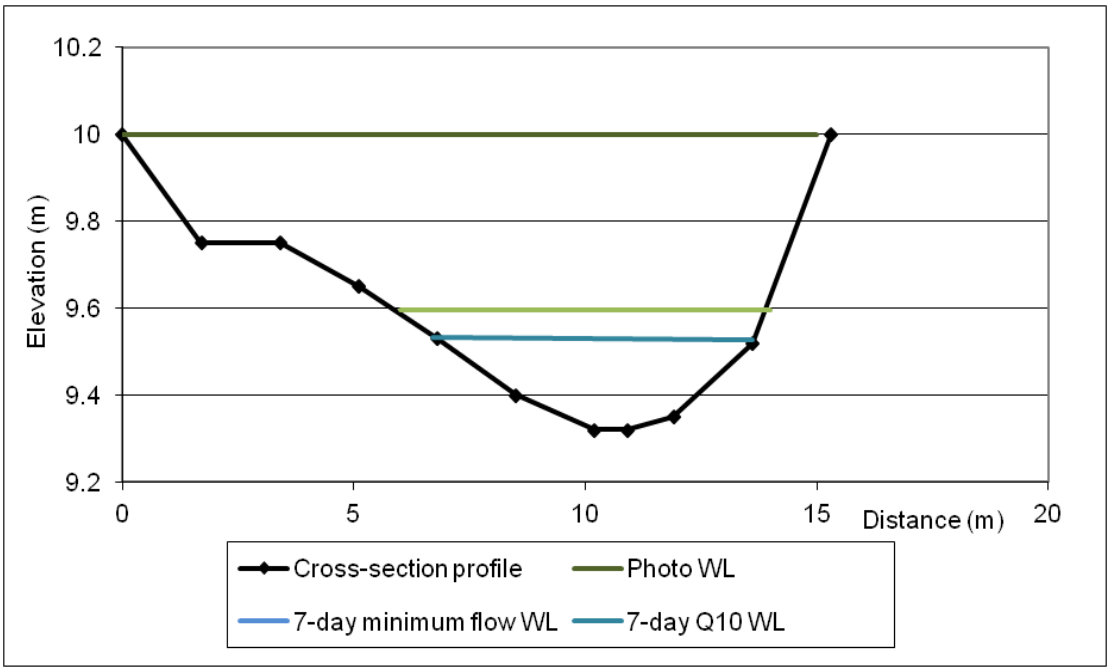


Figure 9-2: Cross-section of the Kuerjoki River at river gauging point SW17, showing water levels at time of survey and predicted water levels under low flow conditions

Hydraulic calculation predictions of flow, water level, wetted perimeter and cross-sectional area changes on the Kuerjoki river channel sections are presented in Table 9-12. The results indicate the changes to result in more than 0.01 m change in water levels and <0.1 m^3 change in stream flow area.

Table 9-12: Predicted impact of decrease in baseflow on channel section for the Kuerjoki

Flow Condition	Baseline				Change in parameters at LOM			
	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2
7-day low flow (Annual)	0.27	9.60	8.04	1.4	-0.013	-0.01	-0.11	<0.1
7-day low flow (Jul-Sep)	0.27	9.60	8.04	1.4	-0.013	-0.01	-0.11	<0.1
7-day Q_{10} (Annual)	0.15	9.53	6.84	0.9	-0.013	-0.01	-0.21	<0.1
7-day Q_{10} (Jul-Sep)	0.15	9.53	6.84	0.9	-0.013	-0.01	-0.21	<0.1

Operational Phase: Impact of seepage from waste dumps on stream water quality

During operations contact water from the mine site, such as surface water runoff over disturbed surfaces, pit sump water and surface runoff from waste dumps or stacked tailings will be captured and passed to the CP. This water will be re-used on site or treated before discharge to the Rautuvaara TMF area.

The only surface water derived from areas impacted by mining activities that will flow to the Kuerjoki River will be runoff water from overburden dumps located close to Kuervitikko pit. Runoff from these overburden dumps is not predicted to have an adverse impact on water quality in the river.

Groundwater modelling predicts that there will be no seepage from the mine site to the Kuerjoki.

Post-closure: Impact of overspill from Kuervitikko pit lake on stream water quantity and quality

Description

Following the end of mine operations the Kuervitikko pit will be artificially flooded as described in Section 7.1.1. Details of the infilling process and the main sources of water infilling the pit lake are provided in Appendix K. Once filled the Kuervitikko pit lake will have a positive water balance and excess water accumulating in the pit lake will flow to the Kuerjoki. At closure there is predicted to be no direct seepage from any waste dumps to the Kuerjoki.

Water quality predictions for the Kuervitikko pit lake are described fully in Section 9.7. Predictions are made for initial overflow from pit lake and steady state. In addition, two pit lake water quality predictions are provided, one assuming that seepage from PAF WRDs are consistent with data from Humidity Cell Testing (HCT in Table 9-14) and the second assuming that seepage from the PAF waste rock materials are consistent with data from Net Acid Generation testing (NAG data in Table 9-14). Water quality predictions based on these two model inputs are considered in Table 9-14 to provide bounds for likely river water quality; the actual WRD runoff quality is expected to lie somewhere between these two data sets. Full details are provided in Section 9.7.

The impact of pit lake water quality on stream water quality in the Kuerjoki is outlined in Table 9-14 which provides the results of dilution calculations considering over-spill from the Kuervitikko pit lake.

Assessment of flow

Under average precipitation conditions modelling predicted the annual flow volume from Kuervitikko pit lake to the Kuerjoki to be around 690,000 m^3/year (Appendix K). The monthly distribution of flows from the pit lake is shown in Table 9-13 where they are presented as a percentage of the stream flow at the mouth of the Kuerjoki. During operations there was a decrease in flows to the Kuerjoki due to a decrease in baseflow and a reduction in the catchment area flowing to the river. At closure the catchment area diverted to Kuervitikko pit lake will be re-connected with the Kuerjoki and baseflow would be predicted to tend to pre-development conditions as the regional groundwater table returns close to pre-development levels. Hence, at closure flows in the Kuerjoki are predicted to return to baseline conditions. Increases in flows to Kuerjoki from Kuervitikko pit lake are shown in Table 9-13 to be similar to losses during operations in Table 9-10.

Assessment of Impacts without Mitigation

The results indicate for the 'initial overflow' of water from the pit lakes to the river, TVs are predicted to be exceeded for all key parameters and AVs are predicted to be exceeded for chromium (winter conditions) and copper. Copper predictions are predicted to exceed AVs for scenarios with NAG data for WRD runoff quality. However, it is noted in Section 9.7, that copper predictions are extremely sensitive to pH of WRD runoff and within the pit lake. Hence, it is likely that the copper predictions for NAG data are high, assuming pH in the pit lakes is less than used in the NAG predictions. In addition, predictions of chromium concentrations in the WRD runoff may also be overly conservative, as discussed in Section 9.7 and as a result the high chromium concentrations should also be viewed with caution.

Results for the Steady State inflow conditions are subtly different. During infilling of Kuervitikko pit lake, seepage from PAF WRD's are predicted to flow to Kuervitikko pit; however, once the Hannukainen pit lake is full and groundwater levels have returned close to pre-development levels, PAF WRD seepage is predicted to flow to Hannukainen pit lake only. As a result, the Steady State predictions for some parameters (e.g., copper) are lower than the initial spill predictions. However, Steady State predictions do suggest that all key parameters apart from iron could exceed TVs and chromium and mercury concentrations are predicted to exceed AVs.

Pit lake water quality predictions suggest the potential for low pH within the Kuervitikko pit (pH 3.8 for the initial overflow; pH 6.2 for steady state). Hence, without mitigation there is a risk of the pH in the Kuerjoki falling outside the AV limits between pH6 and pH 9.

Assessment of Impacts with Mitigation

As outlined in Section 9.7, the water quality of the surface layer of the Kuervitikko pit lake will depend on a number of chemical (e.g. quality of runoff from WRD and pit walls) and physical factors (e.g. presence of physical layering or stratification in the pit lake). However, irrespective of these uncertainties one potential mitigation measure that could be implemented at the site would be the addition of alkaline amendment (lime, CaO) to the Kuervitikko pit lake as it fills. As outlined above, PAF WRDs will contribute seepage to the pit lake during the infilling process; hence, neutralising the pit lake as it fills has the potential to decreases concentrations of a number of parameters.

The impact of adding CaO on water quality in Kuerjoki is summarised in Table 9-15. The results indicate a marginal improvement in water quality predictions from the original NAG data (Table 9-14), with improvements for some metals such as aluminium, copper, and iron. The most notable improvement in water quality is for copper, with copper concentrations reduced below AV following the addition of CaO. However, the results indicate exceedances of TVs for most key parameters and an exceedance of AV for chromium. Additional modelling and further mitigation measures are likely required to improve water quality in Kuervitikko pit lake.

Table 9-13: Predicted monthly discharge from Kuervitikko pit lake, once full

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly overflow from Kuervitikko pit (m^3/s)	a0.017	a0.017	a0.017	a0.017	0.069	0.024	0.026	0.028	0.030	0.033	a0.017	[a]0.017
Overflow as percentage of stream flow in Kuerjoki	+4	+5	+5	+2	+1	+1	+2	+2	+2	+2	+2	+3

a These are estimates and discharged from the pit lake may not occur in winter months when the pit lake and downstream water courses are frozen

Table 9-14: Predicted post-closure water quality predictions for Kuerjoki

Parameter	Unit	WQO – FS40		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition			
					WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data		WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters												
Nitrate	mg/L	0.0068	20	0.002	0.0041	0.01	0.004	0.0099	0.018	0.0045	0.018	0.0045
Chloride	mg/L	0.6	150	0.5	0.54	0.68	0.53	0.63	1.2	0.59	1.2	0.59
Sulphate	mg/L	2.3	65	2	2.3	3	2.7	4.5	2.9	2.1	2.9	2.1
Iron	mg/L	0.43	0.72	0.32	0.32	0.33	0.42	0.68	0.35	0.32	0.34	0.32
Aluminium	mg/L	0.0381	0.1	0.027	0.028	0.032	0.033	0.049	0.061	0.031	0.06	0.031
Arsenic	mg/L	0.000086	0.005	0.000059	0.000072	0.00012	0.000068	0.0001	0.00032	0.000096	0.00029	0.000092
Cadmium	mg/L	0.0000035	0.00008	0.0000025	0.0000049	0.000015	0.0000046	0.000013	0.000063	0.00001	0.000063	0.00001
Cobalt	mg/L	0.000043	0.004	0.000025	0.000067	0.00021	0.0007	0.0024	0.00063	0.0001	0.00063	0.0001
Chromium	mg/L	0.00038	0.001	0.00035	0.00055	0.0016	0.00053	0.0015	0.01	0.0016	0.0097	0.0015
Copper	mg/L	0.00033	0.005	0.0002	0.00024	0.00037	0.0063	0.022	0.0018	0.00041	0.0014	0.00035
Mercury	mg/L	0.000001	0.00005	0.000001	0.0000026	0.00001	0.0000023	0.0000093	0.000061	0.0000086	0.000061	0.0000086
Manganese	mg/L	0.0039	0.7	0.0029	0.0053	0.011	0.0048	0.0096	0.0065	0.0035	0.0065	0.0035
Molybdenum	mg/L	0.00022	1	0.00014	0.00022	0.00046	0.00017	0.00028	0.00079	0.00023	0.00078	0.00023
Nickel	mg/L	0.0002	0.02	0.00012	0.00023	0.00055	0.00091	0.0029	0.00077	0.00021	0.00077	0.00021
Lead	mg/L	0.000046	0.0072	0.000037	0.000039	0.000044	0.000044	0.000062	0.000042	0.000038	0.000041	0.000038
Uranium	mg/L	0.00011	0.015	0.00011	0.0002	0.00053	0.00022	0.00062	0.0021	0.00036	0.0021	0.00036
Zinc	mg/L	0.0018	0.03	0.001	0.0012	0.0021	0.0014	0.0027	0.0064	0.0017	0.0064	0.0017

Parameter	Unit	WQO – FS40		Baseline Concentration	Predicted Concentration – Initial Spill				Predicted Concentration – Steady State Condition			
					WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data		WRD Water Quality based on HCT Data		WRD Water Quality based on NAG Data	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters												
Phosphate	mg/L	0.011	0.017	0.0085	0.01	0.018	0.01	0.017	0.046	0.014	0.037	0.013
TOC	mg/L	7.7	14	5								
Calcium	mg/L	3.1	4.8	2.7	2.9	3.6	2.8	3.1	3.8	2.8	3.8	2.8
Potassium	mg/L	0.49	0.82	0.39	0.55	0.98	0.47	0.71	1	0.47	1	0.47
Magnesium	mg/L	0.96	1.4	0.87	0.91	1	0.92	1.1	1.5	0.95	1.5	0.95
Sodium	mg/L	1.8	2.5	1.6	1.7	2	1.7	2	3	1.8	3	1.8
Silicon	mg/L	6.1	10	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Barium	mg/L	0.0052	0.01	0.0046	0.0047	0.0049	0.0047	0.0048	0.0047	0.0046	0.0047	0.0046
Strontium	mg/L	0.02	0.03	0.017	0.018	0.021	0.017	0.019	0.025	0.018	0.025	0.018
Antimony	mg/L	0.00001	0.000014	0.00001	0.00013	0.00044	0.000018	0.000055	0.00031	0.000048	0.00031	0.000048

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-15: Predicted post-closure water quality predictions for Kuerjoki, with mitigation through $CaCO_3$ addition to PAF waste dumps and/or Kuervitikko pit lake

Parameter	Unit	WQO – FS40		Baseline concentration	Predicted Concentration – Initial Spill			
					WRD Water Quality based on NAG Data, CaO added to Kuervitikko		Percentage change from baseline concentrations %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters								
Nitrate	mg/L	0.0068	20	0.002	0.004	0.0099	100	390
Chloride	mg/L	0.6	150	0.5	0.53	0.63	5.2	26
Sulphate	mg/L	2.3	65	2	2.7	4.5	35	130
Iron	mg/L	0.43	0.72	0.32	0.32	0.32	-0.11	0.35
Aluminium	mg/L	0.0381	0.1	0.027	0.027	0.029	0.68	9
Arsenic	mg/L	0.000086	0.005	0.000059	0.000062	0.000085	5	44
Cadmium	mg/L	0.0000035	0.00008	0.0000025	0.0000046	0.000013	82	430
Cobalt	mg/L	0.000043	0.004	0.000025	0.00068	0.0024	2600	9400
Chromium	mg/L	0.00038	0.001	0.00035	0.00048	0.0014	37	300
Copper	mg/L	0.00033	0.005	0.0002	0.00036	0.00082	81	310
Mercury	mg/L	0.000001	0.00005	0.000001	0.0000022	0.0000087	120	770
Manganese	mg/L	0.0039	0.7	0.0029	0.0047	0.0095	63	230
Molybdenum	mg/L	0.00022	1	0.00014	0.00017	0.00026	18	89
Nickel	mg/L	0.0002	0.02	0.00012	0.00086	0.0028	620	2200
Lead	mg/L	0.000046	0.0072	0.000037	0.000037	0.000036	-0.75	-2.3
Uranium	mg/L	0.00011	0.015	0.00011	0.00022	0.00062	100	460
Zinc	mg/L	0.0018	0.03	0.001	0.0013	0.0025	33	150

Parameter	Unit	WQO – FS40		Baseline concentration	Predicted Concentration – Initial Spill			
					WRD Water Quality based on NAG Data, CaO added to Kuervitikko		Percentage change from baseline concentrations %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters								
Phosphate	mg/L	0.011	0.017	0.0085	0.0091	0.014	7.6	63
TOC	mg/L	7.7	14	5				
Calcium	mg/L	3.1	4.8	2.7	3	3.9	12	46
Potassium	mg/L	0.49	0.82	0.39	0.47	0.71	21	82
Magnesium	mg/L	0.96	1.4	0.87	0.92	1.1	5.6	24
Sodium	mg/L	1.8	2.5	1.6	1.7	2	5.2	23
Silicon	mg/L	6.1	10	4.8	4.8	4.8	-0.041	0.31
Barium	mg/L	0.0052	0.01	0.0046	0.0047	0.0048	1.1	4.5
Strontium	mg/L	0.02	0.03	0.017	0.017	0.019	2.3	11
Antimony	mg/L	0.00001	0.000014	0.00001	0.000018	0.000055	76	450

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

9.3 Valkeajoki River

Construction Phase: Site Runoff

During Phase 1 it was proposed that excess water from the starter pit and drainage ditches would be discharged to a sedimentation basin and a wetland southwest of the Hannukainen pit, from where water would flow to the downstream part of the Valkeajoki River. In Phase 2 water from the sedimentation pond and wetland will be routed to the Hannukainen Clarification Pond (refer to Figure 7-1) from where it will either be used in the process or pumped to Rautuvaara. Hence, in Phase 1 the additional runoff had the potential to increase flows in the Valkeajoki; however, in Phase 2 excess water will not be discharged to this watercourse.

Impacts on the Valkeajoki during this period (i.e. due to water retention in the CP) are expected to be similar to those during operations and are discussed in detail below.

Operational Phase: Changes to the natural drainage pattern

The SRK groundwater model predicts no change in baseflow to the Valkeajoki River. In addition all waste dumps will be positioned outside of the groundwater catchment of the Valkeajoki, with all groundwater from the dumps flowing towards the Äkäsjoki or to the open pits (Figure 7-1). However, there are WRDs that are located close to the topographical divide between the Valkeajoki and Äkäsjoki and parts of the dumps lie within the surface water catchment of Valkeajoki. The Hannukainen CP also lies within the Valkeajoki catchment. The total natural catchment upstream of this pond is large (around 11 km^2), but the headwaters will be diverted around the pond and the flow pathway to the Valkeajoki will be maintained.

Surface water runoff from the waste dumps will be captured and diverted for treatment before reporting to the CP. Excess water in the CP will be pumped to the Rautuvaara TMF area.

Overall, the construction of the mine site decreases the natural surface water catchment area of the river by around 3.5%, but does not impact baseflow. As a result this will impact the stream flows in summer months (Table 9-6).

The predicted percentage reduction of summer flow for the assessed return period flows are presented in Table 9-17. The results indicate a 3.5% decrease for the summer months for all conditions, consistent with the loss in surface catchment area to the river.

Table 9-16: Valkeajoki mine site areas

Mine Component	Area of mine component within Valkeajoki catchment (km^2)
Hannukainen pit	0
Kuervitikko pit	0
PAF EAST WRD	0
NAF EAST WRD	0
OB EAST WRD	0
PAF WEST WRD	0.08
NAF WEST WRD	0.6
OB WEST WRD	0.1
Water Collection Pond	1.1
Total area removed	1.88
Natural Catchment	53.3
% of catchment removed	3.5%

Table 9-17: Change in Valkeajoki River flows resulting from decrease in post-development baseflow and surface flows (LOM)

	Percentage decrease in flow from baseline conditions %											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1 in 100 DRY	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
1 in 50 DRY	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
1 in 10 DRY	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
Average	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
1 in 10 WET	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
1 in 50 WET	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0
1 in 100 WET	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	0	0

Months in orange are considered impacted by changes in baseflow only. Months in white are impacted by changes in runoff from catchment and decrease in baseflow.

The effect of the predicted flow reductions are illustrated at a cross-section of the Valkeajoki upstream the junction with the Kivivuopionoja where SRK undertook flow monitoring measurements in May 2011 (Photo 9-3).



Photo 9-3: Valkeajoki River downstream of junction with the Kivivuopionoja (SRK 09/05/2011), taken at river flow monitoring point SW006

Photo 9-3 shows the water level at the cross-section on the day of the monitoring, the predicted water levels under low flow conditions, the average July water level and the July water level after 3.5% decrease. Based on Table 6-16 the lowest summer flows in the Valkeajoki occur in July.

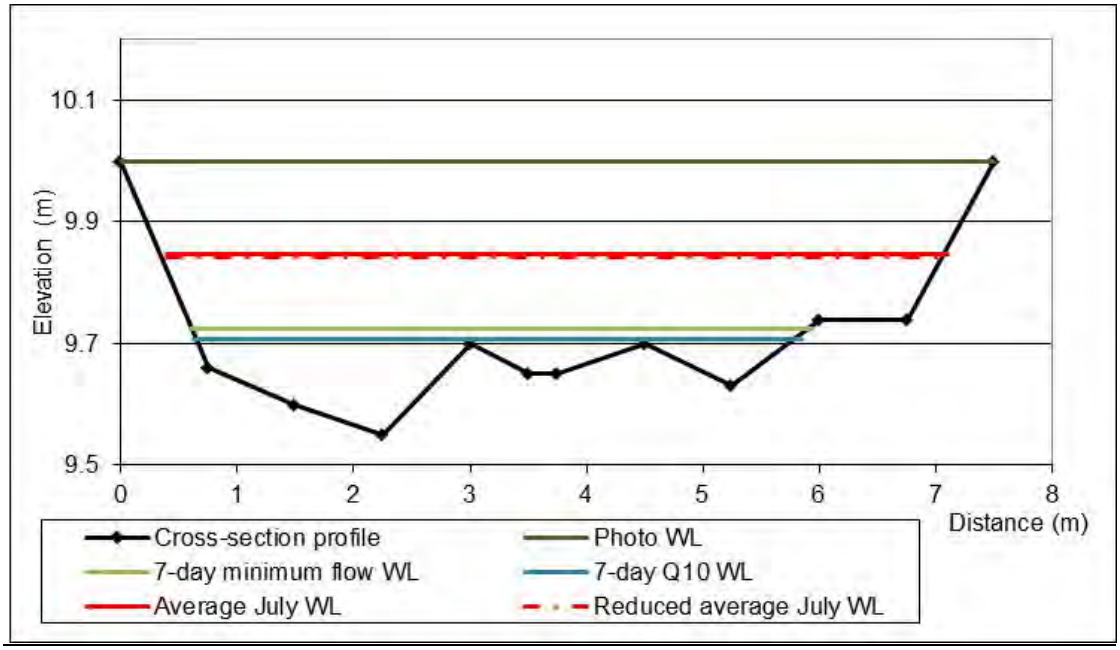


Figure 9-3: Cross-section of Valkeajoki River at river gauging point SW006, showing water levels at time of survey, predicted water levels under low flow conditions and predicted change in July water levels

Predicted changes in flow, water level, wetted perimeter and cross-sectional area changes are presented in Table 9-18. The results indicate the changes to result in no more than 0.01 m change in water levels and <0.1 m^3 change in stream flow area.

Table 9-18: Predicted impact of decreased catchment on channel section for the Valkeajoki River

Flow Condition	Baseline				Change in parameters at LOM			
	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2
Average July	0.39	9.8	6.8	1.2	-0.01	-0.01	-0.03	-0.03

Operational Phase: Impact of seepage from waste dumps on stream water quality

During Phase 1 seepage from stacked tailings and WRDs were predicted to flow to the Valkeajoki. However, in the Phase 2 design tailings will be deposited in the Rautuvaara TMF within the Niesajoki catchment and WRDs have been located outside of the groundwater catchment of the Valkeajoki. Hence, no seepage from the mine site area is predicted to enter the Valkeajoki.

Surface water runoff from WRDs close to the Äkäsjoki/Valkeajoki topographical divide will be captured and will not flow into the Valkeajoki.

Hence, in Phase 2 there are no predicted impacts on Valkeajoki water quality during operations of the Hannukainen mine.

Post-closure: Impact of seepage from waste dumps on stream water quality

No seepage from areas impacted by mining is predicted to enter the Valkeajoki during operations or closure. There are WRDs located within the surface water catchment of the Valkeajoki (Table 9-16). Hence, there is the potential for some surface runoff from the WRDs to flow to the Valkeajoki. However, following reclamation of the WRDs any surface runoff will flow over the surface cap of the dumps and is not expected to interact with waste rock. Water interacting with waste rock will seep through the dump into the groundwater system and flow to the north-east away from the Valkeajoki.

Hence, in Phase 2 there are no predicted impacts on Valkeajoki water quality during closure of the Hannukainen mine.

9.4 Niesajoki River

Construction Phase: Impact of Construction of new dams and diversion structures within Niesa Basin

Construction of the Rautuvaara TMF will require excavation of new stream diversion channels and construction of other site infrastructure.

In addition, there will be the construction of the pipeline from the South Pond to the Muonionjoki River. This pipeline will pass through undeveloped forests and will cross multiple watercourses (tributary streams to the Niesajoki as well as minor drainage channels, see Figure 9-5) as well as wetland areas. Impacts will be confined to the Niesajoki catchment, with the most significant construction activities associated with the Rautuvaara TMF.

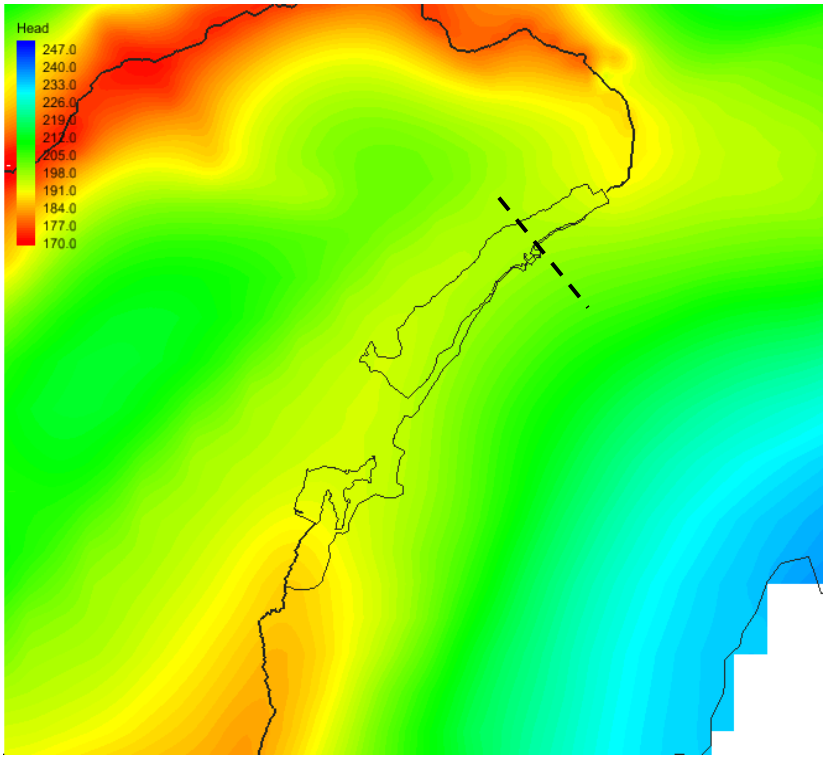
It is not possible to quantify these impacts as they will depend on a number of factors such as the timing of works and how the works are managed. However, if unmitigated there is the potential for releases of suspended solids to the streams as a result of earthworks and general construction activity. There is also a risk of spills of oil and fuels from machinery during the construction works.

On the basis that construction works are undertaken adhering to best practise, with effective sediment control and environmental management plans, it is anticipated that impacts on water quality in the Niesajoki River can be minimised and will not be significant.

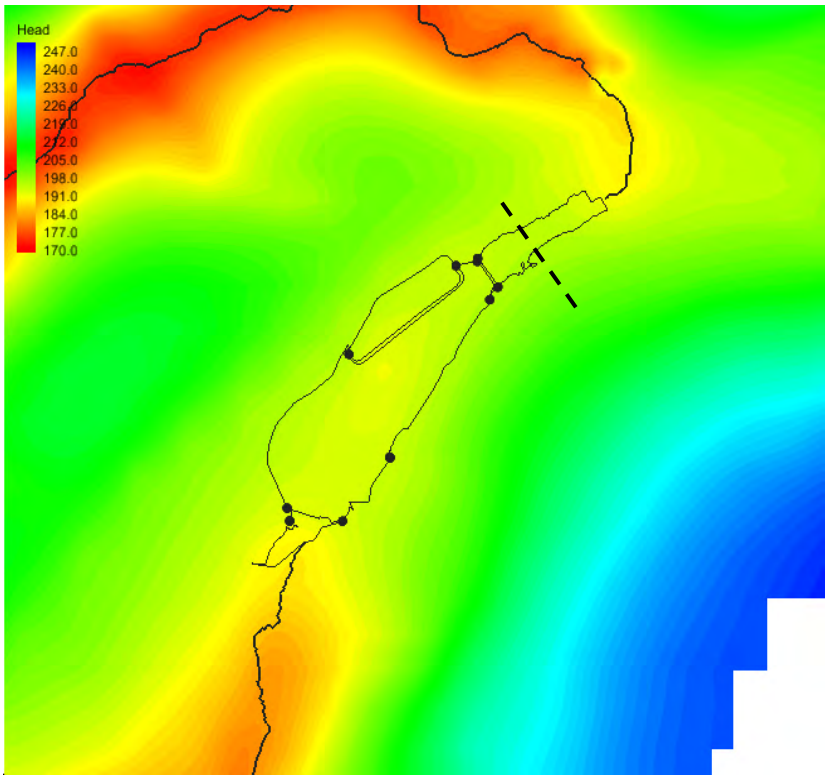
Operational Phase: Groundwater flow pathways

Groundwater is the principle pathway for the migration of potential contamination from the TMF to the local surface water features. It is therefore important to understand the movement of groundwater within the Niesa Basin under both current conditions and following the planned expansion of the TMF.

The groundwater surface was predicted using numerical groundwater modelling, as described in Section 8.1.1. The results of this modelling is summarised below in Figure 9-4. A full description of the groundwater flow regime is provided in Appendix I.



(a)



(b)

Figure 9-4: Predicted Piezometric Surface for (a) Current and (b) LOM Conditions in Average Climatic Conditions

It can be seen that:

- Generally, groundwater within the current and proposed TMF flows in a broadly southerly direction towards the Niesajoki River valley. The general, or regional, groundwater divide (highlighted by a black dashed line) is located within the North Pond, and defines the divide between groundwater that ultimately flows north to the Kylmäoja Stream or south to the Niesajoki River providing baseflow to these rivers;
- There are some localised groundwater dynamics within the area of both the current and proposed TMF facilities although ultimately the majority of the tailings seepage migrates southwards;
- Under current conditions the model predicts a groundwater divide at the northern crest of the existing tailings pile which is consistent with groundwater contours interpreted from field data. Seepage water derived from both the Acid Pond and the North Pond is diluted by ambient groundwater migrating southward towards the Niesajoki River; and
- At LOM seepage from the southern toe of the tailings pile will migrate south to the South Pond and groundwater immediately north of the tailings crest moves northward. Groundwater modelling indicates that seepage in the northern portion of the LIMS tailings generally remains within the tailings, moving east or west rather than north or south. Seepage beneath the High-S cell all flows east to the LIMS tailings. The 'regional' scale groundwater divide is located beneath the North Pond and ultimately all seepage from beneath the LIMS and High-S tailings combines with seepage from the North Pond and moving south towards the South Pond and Niesajoki River.

A full description of the groundwater regime, including particle tracking, is included in Appendix I.

The predicted water balances of the North Pond and South Pond under current conditions and at LOM are summarised below in Table 9-19 and Table 9-20 respectively and predicted seepage from the ponds is summarised in Table 9-21. Full details are provided in Appendix I.

Table 9-19: Calculated Water Balance for Current Conditions at Rautuvaara

Parameter	June current conditions				Winter current conditions				Average annual current conditions			
	North Pond		South Pond		North Pond		South Pond		North Pond		South Pond	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Precipitation (m^3/d)	1,536.6		386.7		0.0		0.0		1,914.2		481.8	
Evaporation (m^3/d)		2,773.7		698.1		390.7		98.3		2,461.1		619.5
Runoff (m^3/d)	235.0		165.0		0.0		0.0		25.0		40.0	
Groundwater (m^3/d)	1,002.2	0.1	147.2	0.8	391.9	1.2	98.5	0.2	523.8	1.9	98.2	0.6
Surface water (m^3/d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	2,774.0	2,774.0	699.0	699.0	392.0	392.0	99.0	99.0	2,463.0	2,463.0	620.0	620.0
Stage (masl)	190.5		189.8		191.7		188.5		191.8		189.8	
Volume (m^3)	19,757,000		4,794,000		21,316,000		4,402,700		21,426,000		4,776,500	
Surface area (m^2)	1,302,200		327,750		1,302,200		327,750		1,302,200		327,750	
Precipitation (%)	55.4		55.3		0.0		0.0		77.7		77.7	
Evaporation (%)		100.0		99.9		99.7		99.8		99.9		99.9
Runoff (%)	8.5		23.6		0.0		0.0		1.0		6.5	
Groundwater (%)	36.1	0.0	21.1	0.1	100.0	0.3	100.0	0.2	21.3	0.1	15.8	0.1
Surface water (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9-20: Predicted Water Balance for LOM Conditions at Rautuvaara

Parameter	June LOM conditions				Winter LOM conditions				Average annual LOM conditions			
	North Pond		South Pond		North Pond		South Pond		North Pond		South Pond	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Precipitation (m^3/d)	619.0		247.0		0.0		0.0		771.1		307.7	
Evaporation (m^3/d)		1117.3		445.9		157.4		62.8		991.5		395.7
Runoff (m^3/d)	95.0		180.0		0.0		0.0		0.0		80.0	
Groundwater (m^3/d)	403.4	0.0	35.3	16.4	157.5	0.1	63.0	0.2	250.3	1.9	21.5	13.6
Surface water (m^3/d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	0.0	0.0
Total	1117.0	1117.0	462.0	462.0	157.0	157.0	63.0	63.0	1021.0	1023.0	409.0	409.0
Stage (masl)	190.5		190.0		191.3		186.3		190.6		190.0	
Volume (m^3)	7,872,800		3,426,800		8,290,600		2,665,600		7,887,500		3,432,300	
Surface area (m^2)	524,580		209,340		524,580		209,340		524,580		209,340	
Precipitation (%)	55.4		53.4		0.0		0.0		75.5		75.2	
Evaporation (%)		100.0		96.4		99.9		99.7		96.9		96.7
Runoff (%)	8.5		38.9		0.0		0.0		0.0		19.5	
Groundwater (%)	36.1	0.0	7.6	3.6	100.0	0.1	100.0	0.3	24.5	0.2	5.3	3.3
Surface water (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0

Table 9-21: Predicted Dam Seepage

	Current conditions			LOM conditions		
	Summer	Winter	Average	Summer	Winter	Average
Seepage north from North Pond(m^3/d)	85	90	89	99	99	94
Seepage south from South Pond (m^3/d)	79	84	84	77	60	76

Operational Phase: Impact of Development of Rautuvaara TMF on Surface Water Quantity

An initial scoping exercise identifying potential impacts of the development on surface water quantity was undertaken and further developed during the baseline assessment. All identified potential impacts were presented in Table 4-3.

The key potential impacts of the operation of the Rautuvaara facilities on surface water quantity in the Niesajoki River are:

- Changes in flows in the Niesajoki as a result of changes to the layout of the Niesa Basin, including construction of new dams and diversion channels;
- Changes to local flow pathways and burial of streams and some wetland areas as a result of expansion of facilities; and
- Change to flow rates as a result of seepage from the south clarification pond (South Pond) into Niesajoki River.

The Niesa Basin sits in the headwaters of the Niesajoki River. At present, surface water runoff flows out of the basin with limited control due to the presence of a spillway on the South Pond and a breach in the diversion channel to the west of the South Pond. Baseline catchments and flow pathways associated with the Niesa Basin were outlined in Section 6.3.4.

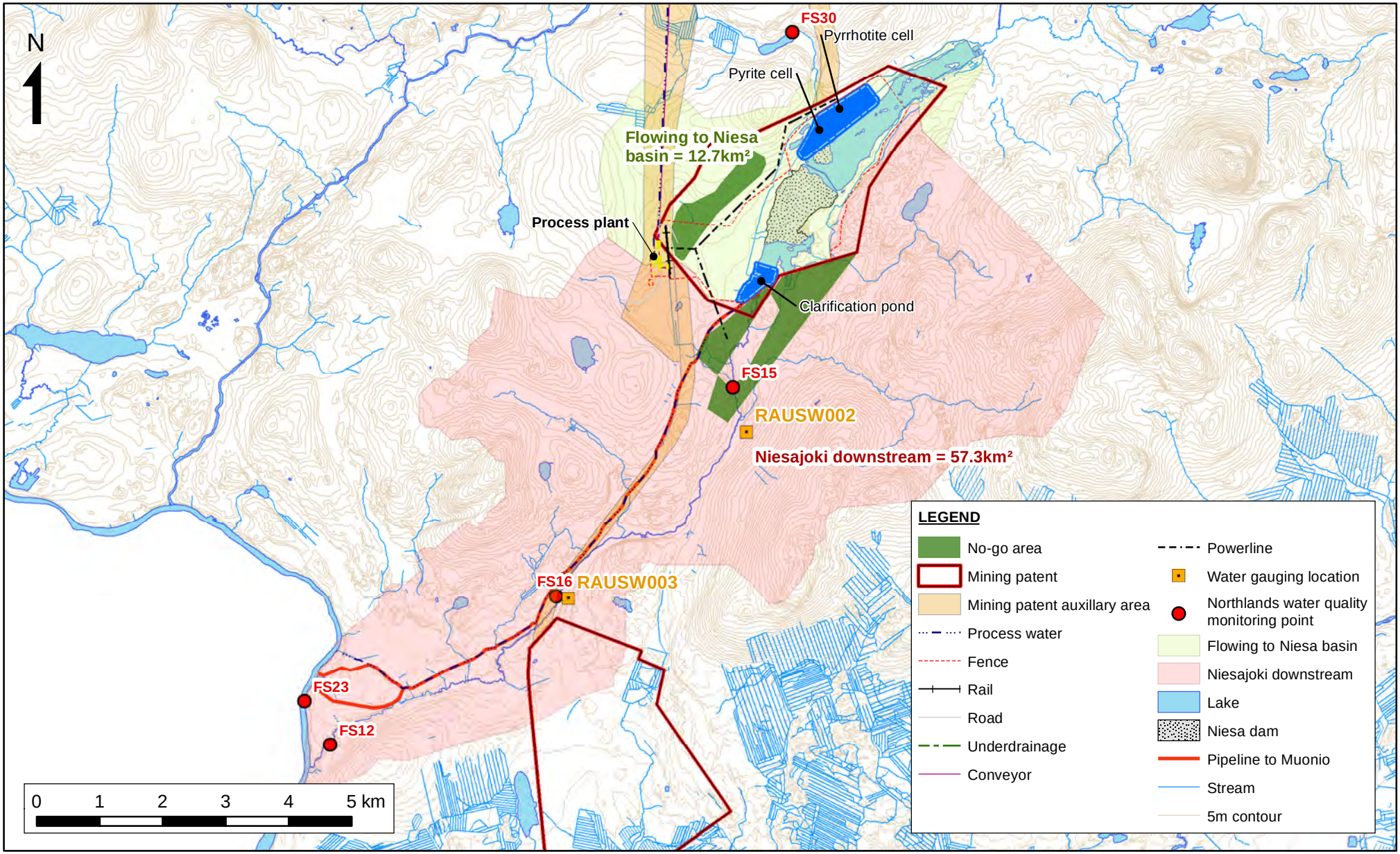
Once the Niesa Basin has been developed as part of the Rautuvaara TMF option, there will be a number of changes to the hydrology of the Niesa Basin, namely:

- There will be no uncontrolled releases of surface water from the Rautuvaara TMF, with excess, treated surface runoff stored in the South Pond before being piped to the Muonionjoki. This is the base case option considered in the Pöyry (2012a) water balance;
- A bund or channel will be constructed to the south of the Rautuvaara TMF (parallel to the channel linking the North Pond and South Pond) to divert natural runoff from high ground to the south of the basin away from the storage area. This will include the Sivakkaoja catchment which will flow directly into the headwaters of the Niesajoki River;
- A diversion channel is likely to be constructed to the north of the Rautuvaara TMF; however such a feature is not shown on current Version 5 drawings. As a result, this assessment considers scenarios where the northern catchment is diverted to the Niesajoki River (most likely scenario) and where it is allowed to flow into the South Pond. An existing diversion channel (north-eastern diversion channel shown in Figure 6-9) will be submerged under tailings and no longer active; and
- The footprint of the Rautuvaara TMF will be larger than that of the old tailings facility within the Niesa Basin.

Figure 9-5 and Figure 9-6 illustrate the post-development catchment of Niesajoki River and Niesa Basin respectively.

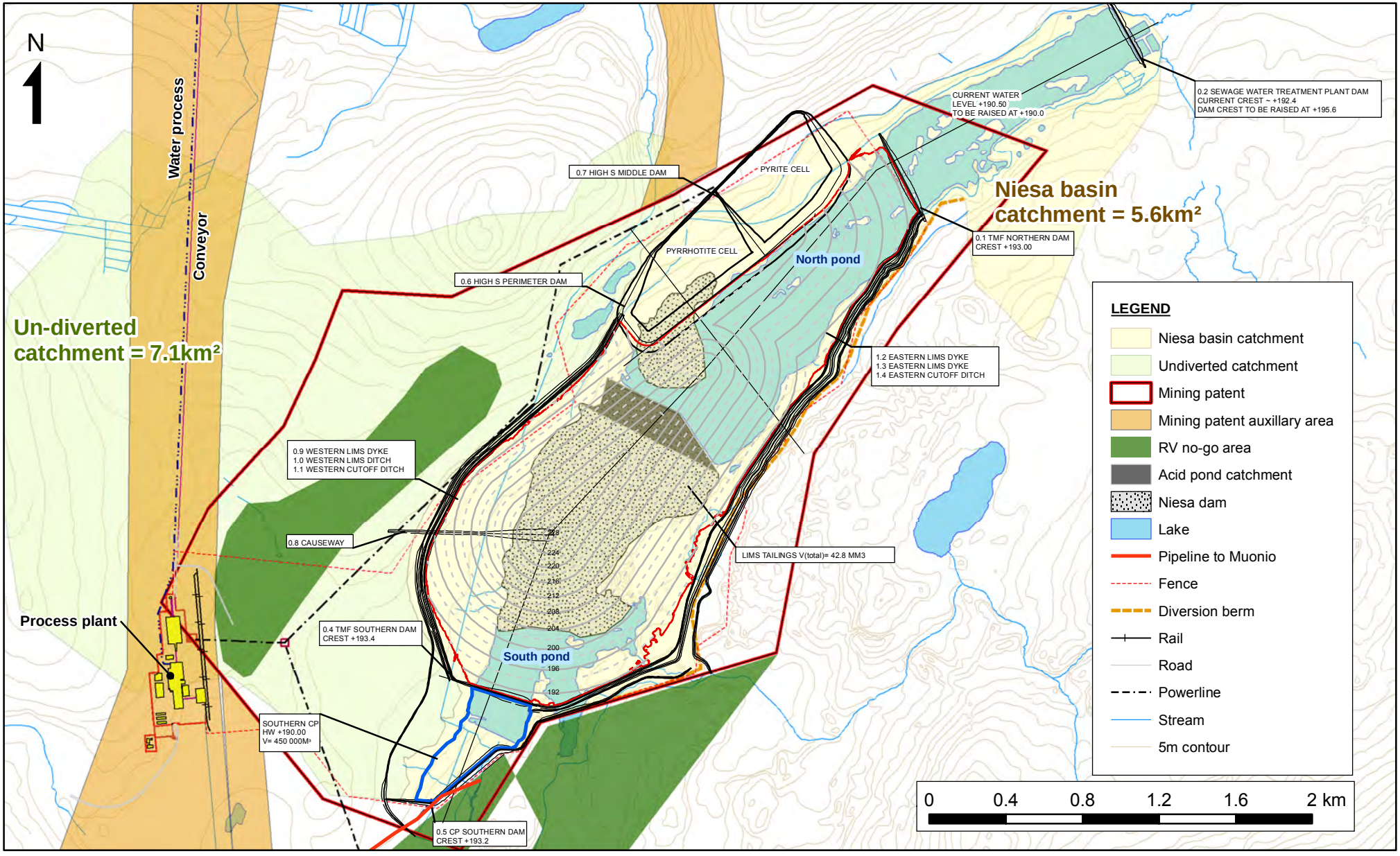
Assuming no diversion of runoff from the north of the Rautuvaara TMF a catchment of around 12.7 km^2 is estimated to flow to the Rautuvaara TMF (Figure 9-5). This compares to a catchment of around 14.8 km^2 flowing to the Niesa Basin at present. If the catchment to the north of the Rautuvaara TMF (Figure 9-6) is diverted around the South Pond to the Niesajoki

River the catchment flowing to the Rautuvaara TMF will be 5.6 km^2.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Post-development Catchments of Niesajoki River	Figure 9.5

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JANUARY 2013	U4790	HANNUKAINEN HIA PHASE 2	
srk consulting		Post-Development Catchments of Niesa Basin	Figure 9-6

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Although the changes to catchment areas post-development may not be large compared to the total catchment area of the Niesajoki River (70 km^2), there is the potential for changes to the flow rates in the stream. At present, runoff flowing to, and precipitation landing on, the Niesa Basin is able to flow freely (with attenuation in the North and South Ponds and losses due to evaporation) to the Niesajoki River.

Post-development surface flows from the catchment, exposed tailings dam and excess water from the North Pond will flow into the South Pond, which will also receive treated water from the Hannukainen mine site and treated runoff from the High-S tailings in the Rautuvaara TMF. Water will be retained within the South Pond before it is pumped by way of a pipeline to the Muonionjoki River. The only water entering the Niesajoki River from the Rautuvaara TMF will be through seepage from the facility.

Groundwater modelling work outlined in Section 8.1.1 indicated that seepage rates from the Niesa Basin to the Niesajoki River would likely decrease following the development of the Rautuvaara TMF. However, changes to seepage rates will be minor compared to changes in surface water flows in the river. Predicted pre- and post-development seepage rates are shown in Table 9-22. Post-development seepage rates are predicted to be <0.1 L/s less than pre-development rates.

Table 9-22: Changes in seepage rates to the Niesajoki from the Niesa Basin (under average climatic conditions)

	Average daily seepage rate (m^3/d)	Average seepage rate (L/s)
Current	83.7	0.97
Post-development	76.5	0.89
Difference	-7.2	-0.08

Post-development change in flows within the Niesajoki River will result from the storage of water from the catchment surrounding the Rautuvaara TMF. Water from these catchments will eventually be pumped to the Muonionjoki, bypassing the Niesajoki River. In broad terms the catchment area of the Niesajoki River will be decreased by 12.7 km^2 if the natural catchment to the north-east of the Rautuvaara TMF is allowed to discharge to the South Pond, or by 5.6 km^2 if this catchment area is diverted to the Niesajoki River.

As outlined in the baseline assessment (Section 6.3.4), observed stream flows in the Niesajoki River suggest higher runoff coefficients for catchments in the Niesa Basin compared to the lower reaches of the river. Based on the water balance work presented in Section 6.3.4 the potential impact of the development of Rautuvaara TMF on average monthly flows and low flows at locations along the Niesajoki River are outlined in Table 9-23.

The results indicate the potential for significant decreases in flow within the upper reaches of the Niesajoki River. Just downstream of the Rautuvaara TMF flows may tend to zero during winter months (December to April), with very small volumes of surface runoff supporting groundwater fed baseflow in the streams.

At the mouth of the river the impacts of development on flows will be minimal. The impact of the decrease in flows on water levels, channel wetted perimeter and cross-section area near the mouth of the river (gauging station RAUSW003) was calculated based on the channel cross-section and the rating curve at the gauged site. A photograph of the site is shown in Photo 9-4, with a cross-section profile in Figure 9-7.



Photo 9-4: Gauging site RAUSW003 downstream of a road bridge

Table 9-24 summarises the impact of flows on water level, wetted perimeter and cross-section area. The results indicate minimal effects on these flow parameters.

Table 9-23: Predicted change in stream flows within Niesajoki River

Baseline average flows (L/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Downstream Ponds	37	28	27	56	585	196	102	104	118	144	89	53	
Niesa Mid-Point (FS 15)	105	79	77	161	1280	590	302	287	296	341	256	152	
Niesa near Mouth (FS16)	168	126	124	257	2040	941	482	457	472	543	408	242	
Niesa at Mouth (FS12)	196	147	144	300	2386	1101	563	534	552	636	477	283	
Post-development flows - larger Niesa catchment (L/s)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**[a]Percentage Change**
Downstream Ponds	5	4	4	8	84	28	15	15	17	21	13	8	-86%
Niesa Mid-Point (FS 15)	69	52	51	106	840	388	198	188	194	224	168	100	-34%
Niesa near Mouth (FS16)	132	99	97	202	1601	739	378	359	370	426	320	190	-22%
Niesa at Mouth (FS12)	160	120	118	245	1947	898	460	436	450	519	389	231	-18%
Post-development flows - smaller Niesa catchment (L/s)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**[a]Percentage Change**
Downstream Ponds	23	17	17	35	364	122	64	65	73	89	55	33	-38%
Niesa Mid-Point (FS 15)	89	67	66	137	1086	501	256	243	251	289	217	129	-15%
Niesa near Mouth (FS16)	152	114	112	233	1847	852	436	414	427	492	369	219	-9%
Niesa at Mouth (FS12)	181	135	133	276	2193	1011	518	491	507	584	438	260	-8%

a Percentage change in monthly and annual flows

Table 9-24: Predicted impact of decreased catchment on channel section for the Niesajoki

Flow Condition	Baseline				Change in parameters at LOM			
	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2	Flow m^3/s	Water level m	Wetted perimeter m	Cross-section area m^2
Average July	0.57	9.6	6.0	1.6	-0.046	-0.016	-0.080	-0.093
Average Winter	0.26	9.5	5.5	1.0	-0.021	-0.020	-0.35	-0.076

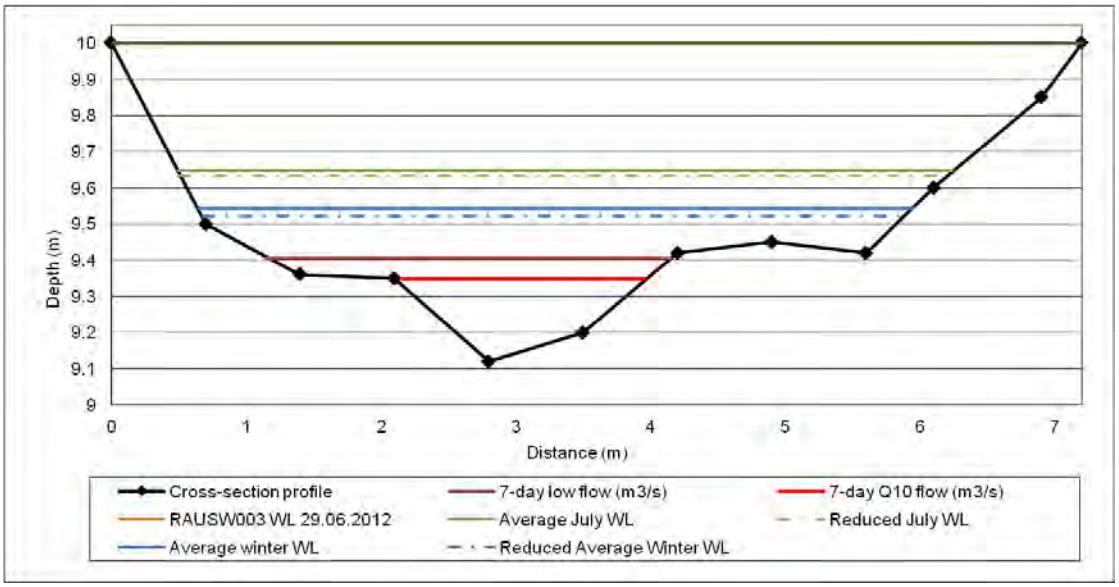


Figure 9-7: Cross-section of Niesajoki at river gauging point RAUSW003, showing water levels at time of survey, predicted water levels under low flow conditions and predicted change in July and average winter water levels

Operational Phase: Impact of Development of Rautuvaara TMF on Surface Water Quality

An initial scoping exercise identifying potential impacts of the development on surface water quantity was undertaken and further developed during the baseline assessment. All identified potential impacts were presented in Table 4-3.

The key potential impacts of the operation of the Rautuvaara TMF on surface water quality in the Niesajoki River are:

- Releases of sediment or disturbance of existing tailings during construction of Rautuvaara TMF;
- Seepage from North and South Ponds into the Niesajoki River via groundwater migration as described previously in the section 'Operational Phase: Groundwater flow pathways'; and
- Uncontrolled releases of tailings solids or water from the South Pond into the Niesajoki River.

At present, the Niesa Basin is a source of poor quality water for the Niesajoki River. The baseline assessment in Section 6.3.4 estimated that for some parameters close to 100% of the total loadings at the mouth of the Niesajoki River are sourced from the existing TMF. During operations of the proposed Rautuvaara TMF, there will be a marked decrease in flows from the Niesa Basin area to the Niesajoki River, as excess water accumulating in the South Pond will be piped to the Muonionjoki, as outlined above. During operations the only mechanism by which water from the Rautuvaara TMF will entering the Niesajoki River will be seepage from the North and South Ponds that enters the groundwater and subsequently reports to the river as baseflow, as described above in the section 'Operational Phase: Groundwater flow pathways'.

Though seepage from the TMF will enter the river via a groundwater pathway the volume of baseflow will be significantly less than the reduction of surface water flows from the Rautuvaara TMF to the Niesajoki River. The net reduction of flow should result in a marked improvement in the quality of water in the Niesajoki.

Predictions of water quality at the mouth of the Niesajoki River during operations are provided in Table 9-25, based on a methodology described in Section 8.1.3. The results are for Year 19 (i.e. LOM). The impact on water quality in other years of the mine life is very similar and as there is an overall improvement in water quality in the Niesajoki, results for other years are not included.

The results clearly show marked improvements in water quality within the Niesajoki River for all parameters apart from cadmium (all flow conditions) and mercury (average and winter flow conditions). Given the extremely low concentrations of cadmium in the baseline data it is likely that this result is affected by uncertainties within the geochemical model calculations and would not be a significant issue during operations. Predicted concentrations of cadmium are below the parameter's AV in any case. Baseline mercury concentrations are also very low and predicted increases in winter months due to seepage from the South Pond are not predicted to exceed TVs.

Under normal operations of the Rautuvaara TMF there should be no surface water releases from the South Pond to the Niesajoki River. However, there remains a risk of uncontrolled releases in the case of overtopping or failure of the dam impounding the South Pond. Water balance calculations for the South Pond are being undertaken by Pöyry and at present there is no information on design standards for the clarification ponds or details on the potential for overtopping of the South Pond (e.g. above which return period storm overtopping could occur).

Hence, at this stage there is no information with which to undertake a detailed analysis of the downstream effects of overtopping. However, the impoundment dam will be a managed structure and it is assumed that the dam will be designed and maintained to minimise the risk of uncontrolled releases to the Niesajoki River. If such a release were to occur it would have a detrimental effect on water quality within the river.

The extent and duration of the impact would depend on the nature of the over-spill. For example, if it resulted from an overtopping of the South Pond following heavy rainfall the impacts would be expected to be short-term (i.e. duration of the high flow event) and ameliorated by the dilution of South Pond water by rainfall. In contrast, if the over-spill were caused by a failure of the South Pond impoundment structure, there would be a risk of release of poor quality water and contaminated sediments. The duration of impacts caused by a failure might be expected to be longer term, controlled by the time taken to repair the dam and the time required to remove contaminated sediment. However, the most likely spill would occur following heavy rainfall and would not be expected to cause a failure in the impoundment structure.

Table 9-25: Predicted change of water quality at mouth of Niesajoki River at LOM

Parameter	Unit	WQO – FS12		Baseline concentration	Post-development concentration			Percentage change %		
		TV	AV		June	Average	Winter	June	Average	Winter
Key parameters										
Nitrate	mg/L	0.15	20	0.053	0.028	0.046	0.057	-46	-12	7.5
Chloride	mg/L	2.0	150	1.2	0.12	0.12	0.12	-90	-90	-90
Sulphate	mg/L	39	80	25	2.8	3.0	3.1	-89	-88	-88
Iron	mg/L	0.81	1.9	0.63	0.32	0.32	0.32	-50	-50	-50
Aluminium	mg/L	0.067	0.10	0.039	0.019	0.019	0.019	-50	-50	-50
Arsenic	mg/L	0.00045	0.0050	0.00028	0.00014	0.00014	0.00014	-50	-50	-50
Cadmium	mg/L	0.0000028	0.000080	0.0000025	0.0000035	0.0000053	0.0000062	41	110	150
Cobalt	mg/L	0.00042	0.0040	0.00020	0.00013	0.00015	0.00017	-35	-23	-16
Chromium III	mg/L	0.00039	0.0010	0.00035	0.00018	0.00019	0.00020	-47	-45	-44
Copper	mg/L	0.0021	0.0050	0.0014	0.00038	0.00038	0.00041	-73	-73	-71
Mercury	mg/L	0.0000022	0.000050	0.0000010	0.00000082	0.0000011	0.0000012	-18	7.3	21
Manganese	mg/L	0.038	0.70	0.032	0.0034	0.0035	0.0035	-90	-89	-89
Molybdenum	mg/L	0.00020	1.0	0.00015	0.000082	0.000089	0.000097	-44	-39	-33
Nickel	mg/L	0.0024	0.020	0.0020	0.00025	0.00029	0.00032	-87	-85	-84
Lead	mg/L	0.000061	0.0072	0.000030	0.000016	0.000016	0.000016	-48	-47	-46
Uranium	mg/L	0.00023	0.015	0.00019	0.000031	0.000041	0.000047	-84	-79	-76
Zinc	mg/L	0.0022	0.030	0.0013	0.00069	0.00073	0.00079	-46	-43	-38

Parameter	Unit	WQO – FS12		Baseline concentration	Post-development concentration			Percentage change %		
		TV	AV		June	Average	Winter	June	Average	Winter
Other Parameters										
Phosphate	mg/L	0.0070	0.027	0.0040	0.0020	0.0021	0.0021	-49	-49	-47
Calcium	mg/L	16	33	9.8	1.1	1.1	1.2	-89	-88	-88
Potassium	mg/L	1.8	2.9	1.3	0.16	0.17	0.18	-88	-87	-86
Magnesium	mg/L	5.3	9.1	3.1	0.32	0.32	0.33	-90	-90	-89
Sodium	mg/L	3.4	5.8	2.4	0.26	0.27	0.29	-89	-88	-88
Silicon	mg/L	6.1	12	5.4	2.7	2.7	2.7	-50	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0018	0.0018	0.0019	-75	-75	-75
Strontium	mg/L	0.041	0.070	0.028	0.0028	0.0028	0.0028	-90	-90	-90
Antimony	mg/L	0.000014	0.000029	0.0000050	0.0000027	0.0000039	0.0000046	-46	-23	-8.0

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Post-Closure Phase: Impact of Closure of Rautuvaara TMF on Surface Water Quantity

At the end of operations at the Rautuvaara TMF flow pathways and water management at the facility will depend on the quality of water within the South Pond and whether this water would be able to be discharged to the Niesajoki River without treatment. In turn this will depend on the volume of excess water from the Hannukainen mine that might need to be treated post-closure as well as the volume of water from the High-S tailings at Rautuvaara that may also need to be treated. If the treatment plant and Muonionjoki pipeline is still in operation in the early years of post-closure then flows within the Niesajoki River would be expected to be similar to those during operations.

Once the water in the South Pond is considered of good enough quality for it to be discharged to the Niesajoki River without treatment, water in the South Pond would be allowed to overspill freely into the river. At that time flow rates in the Niesajoki River would be expected to return close to present day conditions. Due to the presence of the Niesa Basin and the diversion of the headwaters of the Kylmäoja Stream, flows in the Niesajoki River would not return to natural conditions (i.e., prior to mining activities in the area).

Post-Closure Phase: Impact of Closure of Rautuvaara TMF on Surface Water Quality

As outlined in Section 7.1.4, at the end of operations at the Rautuvaara TMF flow pathways and water management at the Rautuvaara TMF will depend on the quality of water within the South Pond and whether this water would be able to be discharged to the Niesajoki River without treatment. Facilities will be covered upon closure however seepage from the TMF will still enter the rivers via groundwater baseflow.

If the treatment plant and Muonionjoki pipeline are still in operation in the early years post-closure water quality within the Niesajoki River would be expected to be similar to those during operations. Once the water quality in the South Pond is considered of good enough quality for it to be discharged to the Niesajoki without treatment, water in the South Pond would be allowed to overspill freely into the river.

Dilution calculations were undertaken to predict water quality at the mouth of the Niesajoki River for the closure period for two main scenarios based on geochemical modelling work described in Section 8.1.3:

Scenario 1: Predictions for the scenario where the Muonionjoki pipeline is in operation during closure and as a result the only water entering the Niesajoki River from the Rautuvaara TMF is through seepage. This is a similar situation to that seen during operations; however, loadings from seepage are different from those predicted during operations as the geochemical model considers the impact of reclamation work within the Rautuvaara TMF, specifically related to the control of runoff from High-S tailings; and

Scenario 2: Predictions for the scenario where the Muonionjoki pipeline has been de-commissioned and all excess water from the Rautuvaara TMF (excess surface water and seepage water) are allowed to discharge into the Niesajoki River. Details of the sources of loadings to the Rautuvaara TMF and geochemical modelling work undertaken for this scenario are outlined in detail in Section 8.1.3.

In both scenarios it is assumed that there is no treatment of water from the Rautuvaara TMF and no source of loadings from the Hannukainen mine.

For each scenario three runs were undertaken which consider different reclamation options for the High-S tailings:

- Worst case that assumes 100% of High-S tailings are available to contribute to loadings in the TMF;
- Medium case that assumes 50% of High-S tailings are encapsulated at closure; and
- Best case that assumes 0% of High-S tailings are available to contribute to loadings in the TMF.

Predicted water quality at the mouth of the Niesajoki River for the six model runs are provided in Table 9-26 to Table 9-31.

The results for Scenario 1 indicate poorer quality water within the Southern Pond during closure when compared to operations. Concentrations of cadmium, mercury, molybdenum, uranium and zinc are higher than baseline for all three model runs (0 – 100% of High-S tailings contributing to loadings), with concentrations of copper exceeding baseline conditions for scenarios with 50% and 100% of High-S tailings contributing to loadings. The calculations predict that copper concentrations have the potential to exceed AVs for scenarios with 50% and 100% of High-S tailings contributing to loadings (Table 9-27 and Table 9-28).

The results for Scenario 2 predict significant increases in a number of key and other parameters. Predictions of cadmium, cobalt, copper, mercury, uranium and zinc are predicted to exceed AVs at the mouth of the Niesajoki. It should be noted that this scenario assumes that all excess water from the Rautuvaara TMF is discharged from the facility into the Niesajoki, without treatment. The results would imply that additional treatment or discharge of waters to Muonionjoki would need to continue into closure until water quality in the facility was better than predicted in this assessment, before the outfall to the Muonionjoki is removed.

Table 9-26: Scenario 1; Predicted change of water quality at the mouth of the Niesajoki River at closure; 0% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 1; Seepage to Niesajoki only; 0% High-S tailings able to contribute to loadings								
Key parameters								
Nitrite	mg/L							
Nitrate	mg/L	0.15	20	0.053	0.0054	0.0056	-90	-89
Chloride	mg/L	2	150	1.19	0.12	0.12	-90	-90
Sulphate	mg/L	39	80	25.3	2.9	3.8	-88	-85
Iron	mg/L	0.81	1.9	0.63	0.32	0.32	-50	-50
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.019	-50	-50
Arsenic	mg/L	0.00045	0.005	0.00028	0.00014	0.00014	-50	-48
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	2.2E-06	4.2E-06	-14	69
Cobalt	mg/L	0.0004	0.004	0.0002	0.00012	0.00017	-38	-14
Chromium III	mg/L	0.00039	0.001	0.00035	0.00017	0.00017	-50	-50
Copper	mg/L	0.0021	0.005	0.0014	0.00036	0.00039	-75	-72
Mercury	mg/L	2.2E-06	0.00005	0.000001	1.3E-06	3.4E-06	34	240
Manganese	mg/L	0.04	0.7	0.032	0.0039	0.0055	-88	-83
Molybdenum	mg/L	0.000201	1	0.000146	0.00012	0.00024	-15	65
Nickel	mg/L	0.00244	0.02	0.00198	0.00024	0.00032	-88	-84
Lead	mg/L	0.000061	0.0072	0.00003	0.000015	0.000015	-50	-49
Uranium	mg/L	0.000227	0.015	0.000191	0.0008	0.0026	320	1300
Zinc	mg/L	0.0022	0.03	0.00127	0.0011	0.0021	-14	69
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.0027	0.0048	-33	20
TOC	mg/L	10.8	24	6.6	3.3	3.3	-50	-50
Calcium	mg/L	16	33	9.8	1.3	1.9	-87	-81
Potassium	mg/L	1.8	2.9	1.34	0.25	0.5	-82	-63
Magnesium	mg/L	5.3	9	3.08	0.34	0.42	-89	-86
Sodium	mg/L	3.4	5.8	2.36	0.26	0.31	-89	-87
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0019	0.0019	-75	-75
Strontium	mg/L	0.041	0.07	0.0278	0.0036	0.0055	-87	-80
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-75

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-27: Scenario 1; Predicted change of water quality at the mouth of the Niesajoki River at closure; 50% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 1; Seepage to Niesajoki only; 50% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.15	20	0.053	0.0054	0.0056	-90	-89
Chloride	mg/L	2	150	1.19	0.12	0.12	-90	-90
Sulphate	mg/L	39	80	25.3	2.9	3.8	-88	-85
Iron	mg/L	0.81	1.9	0.63	0.32	0.32	-50	-50
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.019	-50	-50
Arsenic	mg/L	0.00045	0.005	0.00028	0.00014	0.00015	-50	-45
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	2.6E-06	5.7E-06	4.2	130
Cobalt	mg/L	0.0004	0.004	0.0002	0.00016	0.00031	-17	57
Chromium III	mg/L	0.00039	0.001	0.00035	0.00017	0.00017	-50	-50
Copper	mg/L	0.0021	0.005	0.00142	0.0017	0.0056	22	290
Mercury	mg/L	2.2E-06	0.00005	0.000001	1.8E-06	4.9E-06	83	390
Manganese	mg/L	0.04	0.7	0.032	0.0039	0.0055	-88	-83
Molybdenum	mg/L	0.000201	1	0.000146	0.00012	0.00024	-15	67
Nickel	mg/L	0.00244	0.02	0.00198	0.00028	0.00045	-86	-77
Lead	mg/L	0.000061	0.0072	0.00003	0.000016	0.000018	-48	-42
Uranium	mg/L	0.000227	0.015	0.000191	0.0008	0.0026	320	1300
Zinc	mg/L	0.0022	0.03	0.00127	0.0011	0.0022	-12	74
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.003	0.01	-26	150
TOC	mg/L	10.8	24	6.6	3.3	3.3	-50	-50
Calcium	mg/L	16	33	9.8	1.3	1.9	-87	-81
Potassium	mg/L	1.8	2.9	1.34	0.25	0.5	-82	-63
Magnesium	mg/L	5.3	9	3.08	0.34	0.42	-89	-86
Sodium	mg/L	3.4	5.8	2.36	0.26	0.31	-89	-87
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0019	0.0019	-75	-75
Strontium	mg/L	0.041	0.07	0.0278	0.0036	0.0055	-87	-80
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-75

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-28: Scenario 1; Predicted change of water quality at the mouth of the Niesajoki River at closure; 100% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 1; Seepage to Niesajoki only; 100% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.15	20	0.053	0.0054	0.0056	-90	-89
Chloride	mg/L	2	150	1.19	0.12	0.12	-90	-90
Sulphate	mg/L	39	80	25.3	2.9	3.9	-88	-85
Iron	mg/L	0.81	1.9	0.63	0.32	0.32	-50	-50
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.019	-50	-50
Arsenic	mg/L	0.00045	0.005	0.00028	0.00014	0.00015	-48	-44
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	3.1E-06	7.1E-06	22	190
Cobalt	mg/L	0.0004	0.004	0.0002	0.00021	0.00045	5	130
Chromium	mg/L	0.00039	0.001	0.00035	0.00017	0.00017	-50	-50
Copper	mg/L	0.0021	0.005	0.00142	0.0036	0.013	160	820
Mercury	mg/L	2.2E-06	0.00005	0.000001	2.3E-06	6.3E-06	130	530
Manganese	mg/L	0.04	0.7	0.032	0.004	0.0055	-88	-83
Molybdenum	mg/L	0.000201	1	0.00015	0.00013	0.00024	-14	67
Nickel	mg/L	0.00244	0.02	0.002	0.00032	0.00058	-84	-71
Lead	mg/L	0.000061	0.0072	0.00003	0.000016	0.000018	-47	-40
Uranium	mg/L	0.000227	0.015	0.00019	0.0008	0.0026	320	1300
Zinc	mg/L	0.0022	0.03	0.0013	0.0011	0.0022	-11	77
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.0043	0.014	8.6	250
TOC	mg/L	10.8	24	6.6	3.3	3.3	-50	-50
Calcium	mg/L	16	33	9.8	1.3	1.9	-87	-81
Potassium	mg/L	1.8	2.9	1.34	0.25	0.5	-82	-63
Magnesium	mg/L	5.3	9	3.08	0.34	0.42	-89	-86
Sodium	mg/L	3.4	5.8	2.36	0.26	0.31	-89	-87
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0019	0.0019	-75	-75
Strontium	mg/L	0.041	0.07	0.0278	0.0036	0.0055	-87	-80
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-75

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-29: Scenario 2; Predicted change of water quality at the mouth of the Niesajoki River at closure; 0% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 2; TMF overflow and seepage to Niesajoki; 0% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.15	20	0.053	0.0096	0.016	-82	-69
Chloride	mg/L	2	150	1.2	0.21	0.27	-82	-77
Sulphate	mg/L	39	79.7	25	16	43	-38	71
Iron	mg/L	0.81	1.87	0.63	0.31	0.29	-51	-54
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.018	-51	-53
Arsenic	mg/L	0.00045	0.005	0.00028	0.00014	0.00027	-48	-3.7
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	0.000031	0.000098	1200	3800
Cobalt	mg/L	0.00042	0.004	0.0002	0.00084	0.0024	330	1100
Chromium III	mg/L	0.00039	0.001	0.00035	0.00017	0.00016	-51	-54
Copper	mg/L	0.0021	0.005	0.0014	0.00054	0.0015	-62	6
Mercury	mg/L	2.2E-06	0.00005	0.000001	0.000028	0.000095	2700	9400
Manganese	mg/L	0.038	0.7	0.032	0.027	0.075	-17	130
Molybdenum	mg/L	0.0002	1	0.00015	0.0018	0.0056	1100	3700
Nickel	mg/L	0.0024	0.02	0.002	0.0015	0.0042	-23	110
Lead	mg/L	0.000061	0.0072	0.00003	0.000016	0.000019	-47	-36
Uranium	mg/L	0.00023	0.015	0.00019	0.026	0.084	13000	44000
Zinc	mg/L	0.0022	0.03	0.0013	0.016	0.05	1100	3800
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.024	0.093	510	2200
TOC	mg/L	11	24	6.6	3.2	3	-51	-54
Calcium	mg/L	16	33	9.8	10	30	3.4	210
Potassium	mg/L	1.8	2.9	1.3	3.9	12	190	800
Magnesium	mg/L	5.3	9.1	3.1	1.5	3.9	-53	26
Sodium	mg/L	3.4	5.8	2.4	1.1	2.7	-55	15
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0021	0.0023	-71	-69
Strontium	mg/L	0.041	0.069	0.028	0.031	0.093	12	230
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-74

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-30: Scenario 2; Predicted change of water quality at the mouth of the Niesajoki River at closure; 50% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 2; TMF overflow and seepage to Niesajoki; 50% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.15	20	0.053	0.0095	0.016	-82	-69
Chloride	mg/L	2	150	1.2	0.21	0.27	-82	-77
Sulphate	mg/L	39	79.7	25	16	44	-37	76
Iron	mg/L	0.81	1.87	0.63	0.31	0.29	-51	-54
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.018	-51	-53
Arsenic	mg/L	0.00045	0.005	0.00028	0.00017	0.00056	-40	100
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	0.000046	0.00015	1700	5700
Cobalt	mg/L	0.00042	0.004	0.0002	0.0023	0.0069	1100	3400
Chromium III	mg/L	0.00039	0.001	0.00035	0.00018	0.00017	-49	-52
Copper	mg/L	0.0021	0.005	0.0014	0.046	0.17	3100	12000
Mercury	mg/L	2.2E-06	0.00005	0.000001	0.000045	0.00014	4400	14000
Manganese	mg/L	0.038	0.7	0.032	0.027	0.077	-17	140
Molybdenum	mg/L	0.0002	1	0.00015	0.0018	0.0056	1100	3800
Nickel	mg/L	0.0024	0.02	0.002	0.0028	0.0084	43	330
Lead	mg/L	0.000061	0.0072	0.00003	0.000038	0.000092	25	200
Uranium	mg/L	0.00023	0.015	0.00019	0.026	0.084	13000	44000
Zinc	mg/L	0.0022	0.03	0.0013	0.016	0.052	1200	4000
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.034	0.27	750	6600
TOC	mg/L	11	24	6.6	3.2	3	-51	-54
Calcium	mg/L	16	33	9.8	10	30	3.7	210
Potassium	mg/L	1.8	2.9	1.3	3.9	12	190	800
Magnesium	mg/L	5.3	9.1	3.1	1.5	3.9	-53	26
Sodium	mg/L	3.4	5.8	2.4	1.1	2.7	-55	15
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0021	0.0023	-71	-69
Strontium	mg/L	0.041	0.069	0.028	0.031	0.092	11	230
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-74

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-31: Scenario 2; Predicted change of water quality at the mouth of the Niesajoki River at closure; 100% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS12		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Scenario 2; TMF overflow and seepage to Niesajoki; 100% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.15	20	0.053	0.0095	0.016	-82	-69
Chloride	mg/L	2	150	1.2	0.21	0.27	-82	-77
Sulphate	mg/L	39	79.7	25	16	46	-36	80
Iron	mg/L	0.81	1.87	0.63	0.31	0.35	-51	-44
Aluminium	mg/L	0.067	0.1	0.039	0.019	0.02	-51	-49
Arsenic	mg/L	0.00045	0.005	0.00028	0.00028	0.00064	-1	130
Cadmium	mg/L	2.8E-06	0.00008	2.5E-06	0.000061	0.00019	2300	7600
Cobalt	mg/L	0.00042	0.004	0.0002	0.0037	0.012	1800	5800
Chromium	mg/L	0.00039	0.001	0.00035	0.00018	0.00017	-49	-50
Copper	mg/L	0.0021	0.005	0.0014	0.11	0.41	7600	29000
Mercury	mg/L	2.2E-06	0.00005	0.000001	0.000059	0.00019	5800	19000
Manganese	mg/L	0.038	0.7	0.032	0.027	0.077	-16	140
Molybdenum	mg/L	0.0002	1	0.00015	0.0018	0.0057	1100	3800
Nickel	mg/L	0.0024	0.02	0.002	0.0041	0.013	110	540
Lead	mg/L	0.000061	0.0072	0.00003	0.000044	0.00012	46	280
Uranium	mg/L	0.00023	0.015	0.00019	0.026	0.084	13000	44000
Zinc	mg/L	0.0022	0.03	0.0013	0.017	0.053	1200	4100
Other parameters								
Phosphate	mg/L	0.007	0.027	0.004	0.08	0.39	1900	9700
TOC	mg/L	11	24	6.6	3.2	3	-51	-54
Calcium	mg/L	16	33	9.8	10	30	4.2	210
Potassium	mg/L	1.8	2.9	1.3	3.9	12	190	800
Magnesium	mg/L	5.3	9.1	3.1	1.5	3.9	-53	27
Sodium	mg/L	3.4	5.8	2.4	1.1	2.7	-55	15
Silicon	mg/L	6.1	12	5.4	2.7	2.7	-50	-50
Barium	mg/L	0.0077	0.013	0.0074	0.0021	0.0023	-72	-69
Strontium	mg/L	0.041	0.069	0.028	0.031	0.092	11	230
Antimony	mg/L	0.000014	0.000029	0.000005	1.3E-06	1.3E-06	-75	-74

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs

9.5 Kylmäoja Stream

Construction Phase; Impact of Construction of Rautuvaara TMF

Construction activities related to the pre-development of the Rautuvaara TMF are likely to include the reconstruction of the water impoundment dam at the north end of the North Pond of the existing Niesa Basin (northern retaining dam). In addition, there will be the construction of new drainage channels to the north and south of the North Pond of the Rautuvaara TMF.

It is not possible to quantify these effects as impacts will depend on a number of factors such as the timing of works and how the works are managed. However, if unmitigated there is the potential for releases of suspended solids to the streams as a result of earthworks. There is also a risk of spills of oil and fuels from machinery during the construction works.

On the basis that construction works are undertaken adhering to best practise with effective sediment control and environmental management plans it is anticipated that impacts on water quality in the Kylmäoja Stream can be minimised and will not be significant.

Operations Phase: Impact of Development of Rautuvaara TMF on Surface Water Quantity

An initial scoping exercise identifying potential impacts of the development on surface water quantity was undertaken and further developed during the baseline assessment. All identified potential impacts were presented in Table 4-3.

The key potential impacts of the operation of the Rautuvaara facilities on surface water quantity in Kylmäoja Stream are:

- Changes in flows in Kylmäoja Stream as a result of changes to the layout of the Niesa Basin, including construction of new dams and diversion channels; and
- Change to flow rates as a result of seepage from the North Pond into Kylmäoja Stream.

At present, there are no releases of surface water from the Niesa Basin into the Kylmäoja Stream and this will continue to be the case post-development. There are no proposed changes to the catchment flowing to the Kylmäoja Stream; it is likely that the impoundment dam in the north of the facility will be replaced and raised but the location will remain the same and therefore the modifications of the dam should not alter the current hydrological regime.

The proposed expansion of the facility is not predicted to impact the small catchments to the north and east of the Niesa Basin that flow to the Kylmäoja Stream (shown in Figure 9-6). Hence, there will be no changes in flow in the Kylmäoja Stream due to changes in surface water catchments or flow pathways as a result of the Rautuvaara TMF development.

Groundwater modelling of the Niesa Basin has produced predictions of seepage rates from the basin to the Kylmäoja Stream for the pre- and post-development situation. Predicted pre- and post-development seepage rates to Kylmäoja Stream from the Niesa Basin are outlined in Table 9-32. Based on average conditions, the change in flow rates will be negligible, less than 0.1 L/s. Calculations for post-development seepage rates in winter months are slightly higher than the annual average, but the difference from current conditions would be expected to be the same. To put these changes in context the winter flow rate at the mouth of the Kylmäoja is around 80 L/s in March (lowest of year) and around 300 L/s in August (lowest in summer months), based on Table 6-32.

The results indicate a small increase in seepage to the Kylmäoja Stream from the Rautuvaara TMF, but at an insignificant rate.

Table 9-32: Changes in seepage rates to the Kylmäoja Stream (assuming average climatic conditions)

	Average daily seepage rate (m^3/d)	Average seepage rate (L/s)
Current	88.8	1.03
Post-development	94.0	1.09
Difference	+5.2	+0.06

Operational Phase: Impact of Development of Rautuvaara TMF on Surface Water Quality

An initial scoping exercise identifying potential impacts of the development on surface water quantity was undertaken and further developed during the baseline assessment. All identified potential impacts were presented in Table 4-3.

The key potential impacts of the operation of the Rautuvaara facilities on surface water quality in Kylmäoja Stream are:

- Releases of sediment or disturbance of existing tailings during construction of Rautuvaara TMF facilities;
- Seepage from the North Pond into Kylmäoja Stream; and
- Uncontrolled releases of tailings solids or untreated water from clarification ponds into Kylmäoja Stream.

Under normal operations all surface water released from the Rautuvaara TMF will piped to the Muonionjoki River. As a result, there are expected to be no surface water discharges from the tailings facility to the Kylmäoja Stream. However, there is the potential for seepage of water from the North Pond into the Kylmäoja Stream, with seepage water entering the stream close to the northern retaining dam.

Seepage rates from the tailings facility to the Kylmäoja Stream were calculated using the groundwater model of the Niesa Basin area (Section 8.1.1), with flow rates summarised in Table 9-32. Predictions of loadings of key water quality parameters are summarised in Table 9-33 with methods discussed in more detail in Section 8.1.3. It is unclear at this stage whether seepage from the pond will be captured through seepage control wells, so the assessment takes the conservative assumption that all seepage is able to report to Kylmäoja Stream.

A series of simple dilution calculations were undertaken to assess the impact of seepage on median baseline water quality at the mouth of the Kylmäoja Stream, based on baseline water quality and flow rates at water quality sampling station FS03. Results are provided in Table 9-33.

The results show negligible changes (<10%) in all water quality parameters, with no concentrations predicted to exceed TVs or AVs. For all parameters apart from sodium and potassium under spring flow conditions the changes in concentrations post-development compared to baseline conditions are predicted to be <1%. This is not unexpected given the small change in flows from the facility to Kylmäoja compared to baseline conditions.

The results presented in Table 9-33 are for LOM, i.e. end of mine operations. The impact on water quality in other years of the mine life is very similar and as there is an overall improvement in water quality in the Niesajoki, results for other years are not included.

As noted above, there should be no surface water releases from the Rautuvaara TMF to Kylmäoja Stream. However, there remains a risk of uncontrolled releases in the case of overtopping or failure of the northern retaining dam.

Water balance calculations for the Niesa Basin are being undertaken by Pöyry and at present there is no information on design standard for the clarification ponds or details on the potential for overtopping of the pond (e.g., above which return period storm overtopping could occur). Hence, at this stage there is no information with which to undertake a detailed analysis of the downstream effects of overtopping.

However, the impoundment dam will be a managed structure and it is assumed that the dam will be designed and maintained to minimise the risk of uncontrolled releases to the Kylmäoja Stream.

Post-closure Phase: Impact of Closure of Rautuvaara TMF on Surface Water Quantity

Seepage rates from the North Pond to the Kylmäoja Stream will depend on the post-closure water level in the pond. However, given the low seepage rates predicted during operations and the likelihood that water levels in the pond will be maintained close to those during operations, there are expected to be no significant impacts on water quantity in the Kylmäoja Stream during closure of the Rautuvaara TMF.

Post-closure Phase: Impact of Closure of Rautuvaara TMF on Surface Water Quality

The northern retaining dam will be maintained post closure and following the end of operations at the Rautavaara facility it is assumed that the main outflow from the facility will be to the south into Niesajoki River or Muonionjoki River. No surface water outflows are predicted to the Kylmäoja Stream and any impacts of the Rautuvaara TMF on water quality in the Kylmäoja Stream will be due to seepage from the North Pond.

Seepage rates post-closure were calculated based on groundwater modelling (Section 8.1.1) and a geo-chemical model (Section 8.1.3) was used to make predictions of the quality of water in the North Pond during closure.

Three closure options are considered, varying depending on the effectiveness of encapsulation of High-S tailings during closure:

- Worst case that assumes 100% of High-S tailings are available to contribute to loadings in the TMF;
- Medium case that assumes 50% of High-S tailings are encapsulated at closure; and
- Best case that assumes 0% of High-S tailings are available to contribute to loadings in the TMF.

Results for the three model runs are provided in Table 9-34 to Table 9-36.

The results show negligible changes (<10%) in all key water quality parameters for all three modelled scenarios, with no concentrations predicted to exceed TVs or AVs. Most parameters change around 1% or less from baseline conditions. The only parameters which is predicted to exceed baseline conditions by >10% is potassium (not a key parameter) in spring under the worst case scenario with 100% of High-S tailings contributing loadings to the TMF. In this case the predicted concentration is still below the TV.

The results indicate that changes to the existing Rautuvaara TMF are not expected to significantly impact the water quality in the Kylmäoja Stream.

Table 9-33: Predicted changes in water quality in the Kylmäoja stream at its mouth (water quality sampling station FS03) due to seepage from the Rautuvaara TMF during operations

Parameter	Unit	[a]WQO – FS03		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
Key parameters								
Nitrate	mg/L	0.077	20	0.013	0.013	0.013	0.1	0.5
Chloride	mg/L	1	150	0.79	0.8	0.79	0.6	-0.05
Sulphate	mg/L	6.8	65	4.4	4.4	4.3	0.74	-0.039
Iron	mg/L	0.59	2.6	0.44	0.44	0.44	-0.28	-0.048
Aluminium	mg/L	0.049	0.1	0.022	0.022	0.022	-0.02	-0.05
Arsenic	mg/L	0.0001	0.005	0.000061	0.000061	0.000061	-0.02	-0.06
Cadmium	mg/L	0.000003	0.00008	2.5E-06	2.5E-06	2.5E-06	-0.04	-0.13
Cobalt	mg/L	0.00031	0.004	0.00019	0.00019	0.00019	-0.027	-0.072
Chromium	mg/L	0.00034	0.001	0.00027	0.00027	0.00027	-0.02	-0.05
Copper	mg/L	0.00052	0.005	0.00042	0.00042	0.00042	-0.02	-0.03
Mercury	mg/L	1.4E-06	0.00005	0.000001	0.000001	0.000001	-0.026	-0.066
Manganese	mg/L	0.032	0.7	0.024	0.024	0.024	-0.027	-0.074
Molybdenum	mg/L	0.00024	1	0.00019	0.00019	0.00019	0	0.1
Nickel	mg/L	0.00069	0.02	0.00048	0.00048	0.00048	0	0
Lead	mg/L	0.000057	0.0072	0.000039	0.000039	0.000039	-0.03	-0.07
Uranium	mg/L	0.000091	0.015	0.000065	0.000065	0.000065	0	0.1
Zinc	mg/L	0.0016	0.03	0.00034	0.00034	0.00034	-0.02	-0.06
Other parameters								
Phosphate	mg/L	0.01	0.026	0.008	0.008	0.008	0	0
TOC	mg/L	8.1	16	4.7	4.4	4.3	0.74	-0.04
Calcium	mg/L	5.8	17	4.4	4.3	4.4	-0.25	-0.05
Potassium	mg/L	0.88	2.1	0.64	0.66	0.64	3.9	-0.03
Magnesium	mg/L	1.5	4.3	1.2	1.2	1.2	-0.77	-0.05
Sodium	mg/L	2.3	8.1	2	2	2	2.1	-0.04
Silicon	mg/L	6.6	12	5	5	5	0.06	-0.05
Barium	mg/L	0.014	0.022	0.012	0.012	0.012	-0.02	-0.05
Strontium	mg/L	0.02	0.035	0.017	0.017	0.017	-0.02	-0.05
Antimony	mg/L	0.000014	0.000024	0.000011	0.00001	0.00001	-0.02	-0.02

a TVs (TV) and AVs (AV) for Äkäsjoki River are used for Kylmäoja Stream as no WQOs have been developed for the Kylmäoja.
b 50% or more of the baseline data is below detection limit.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-34: Predicted change of water quality at mouth of the Kylmäoja River at closure; 0% of High-S tailings able to contribute to loadings

Parameter	Unit	[a]WQO – FS03		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
TMF seepage to Kylmäoja; 0% High-S tailings able to contribute to loadings								
Key parameters								
Nitrite	mg/L							
Nitrate	mg/L	0.077	20	0.013	0.013	0.013	1.6	1.6
Chloride	mg/L	1	150	0.79	0.79	0.79	-0.4	-0.4
Sulphate	mg/L	6.8	65	4.4	4.4	4.3	1.2	-1.2
Iron	mg/L	0.59	2.6	0.44	0.44	0.44	0	0
Aluminium	mg/L	0.049	0.1	0.022	0.022	0.022	0	0
Arsenic	mg/L	0.0001	0.005	0.000061	0.000061	0.000061	-0.16	-0.16
Cadmium	mg/L	0.000003	0.00008	2.5E-06	2.5E-06	2.5E-06	0	0
Cobalt	mg/L	0.00031	0.004	0.00019	0.00019	0.00019	-1	-1
Chromium	mg/L	0.00034	0.001	0.00027	0.00027	0.00027	-1.5	-1.5
Copper	mg/L	0.00052	0.005	0.00042	0.00042	0.00042	0.48	0.48
Mercury	mg/L	1.4E-06	0.00005	0.000001	0.000001	0.000001	0	0
Manganese	mg/L	0.032	0.7	0.024	0.024	0.024	-1.6	-1.6
Molybdenum	mg/L	0.00024	1	0.00019	0.00019	0.00019	1.1	1.1
Nickel	mg/L	0.00069	0.02	0.00048	0.00048	0.00048	-0.21	-0.21
Lead	mg/L	0.000057	0.0072	0.000039	0.000039	0.000039	0	0
Uranium	mg/L	0.000091	0.015	0.000065	0.000065	0.000065	-0.58	-0.58
Zinc	mg/L	0.0016	0.03	0.00034	0.00034	0.00034	-0.15	-0.15
Other parameters								
Phosphate	mg/L	0.01	0.026	0.008	0.008	0.008	-0.5	-0.5
TOC	mg/L	8.1	16	4.7	4.7	4.7	-0.84	-0.84
Calcium	mg/L	5.8	17	4.4	4.4	4.4	0.92	0.92
Potassium	mg/L	0.88	2.1	0.64	0.64	0.64	0.16	0.16
Magnesium	mg/L	1.5	4.3	1.2	1.2	1.2	0.84	0.84
Sodium	mg/L	2.3	8.1	2	2	2	2	2
Silicon	mg/L	6.6	12	5	5	5	-0.2	-0.2
Barium	mg/L	0.014	0.022	0.012	0.012	0.012	2.6	2.6
Strontium	mg/L	0.02	0.035	0.017	0.017	0.017	-0.58	-0.58
Antimony	mg/L	0.000014	0.000024	0.000011	0.00001	0.00001	-4.8	-4.8

a TVs (TV) and AVs (AV) for Äkäsjoki River are used for Kylmäoja Stream as no WQOs have been developed for the Kylmäoja.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the baseline data is below detection limit.

Table 9-35: Predicted change of water quality at mouth of the Kylmäoja River at closure; 50% of High-S tailings able to contribute to loadings

Parameter	Unit	[a]WQO – FS03		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
TMF seepage to Kylmäoja; 50% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.077	20	0.013	0.013	0.013	1.6	1.6
Chloride	mg/L	1	150	0.79	0.8	0.79	0.88	-0.38
Sulphate	mg/L	6.8	65	4.4	4.7	4.3	8	-1.2
Iron	mg/L	0.59	2.6	0.44	0.44	0.44	0	0
Aluminium	mg/L	0.049	0.1	0.022	0.022	0.022	0	0
Arsenic	mg/L	0.0001	0.005	0.000061	0.000061	0.000061	-0.16	-0.16
Cadmium	mg/L	0.000003	0.00008	2.5E-06	2.5E-06	2.5E-06	0	0
Cobalt	mg/L	0.00031	0.004	0.00019	0.00019	0.00019	-1	-1
Chromium	mg/L	0.00034	0.001	0.00027	0.00027	0.00027	-1.5	-1.5
Copper	mg/L	0.00052	0.005	0.00042	0.00042	0.00042	0.48	0.48
Mercury	mg/L	1.4E-06	0.00005	0.000001	0.000001	0.000001	0	0
Manganese	mg/L	0.032	0.7	0.024	0.024	0.024	-1.6	-1.6
Molybdenum	mg/L	0.00024	1	0.00019	0.00019	0.00019	1.1	1.1
Nickel	mg/L	0.00069	0.02	0.00048	0.00048	0.00048	-0.21	-0.21
Lead	mg/L	0.000057	0.0072	0.000039	0.000039	0.000039	0	0
Uranium	mg/L	0.000091	0.015	0.000065	0.00034	0.00034	-0.58	-0.58
Zinc	mg/L	0.0016	0.03	0.00034	0.000066	0.00007	1.4	7.5
Other parameters								
Phosphate	mg/L	0.01	0.026	0.008	0.008	0.008	-0.5	-0.5
TOC	mg/L	8.1	16	4.7	4.7	4.7	-0.84	-0.84
Calcium	mg/L	5.8	17	4.4	4.7	4.4	7.8	0.9
Potassium	mg/L	0.88	2.1	0.64	0.81	0.64	27	0.16
Magnesium	mg/L	1.5	4.3	1.2	1.2	1.2	0.84	0.84
Sodium	mg/L	2.3	8.1	2	2	2	2	2
Silicon	mg/L	6.6	12	5	5	5	-0.2	-0.2
Barium	mg/L	0.014	0.022	0.012	0.012	0.012	2.6	2.6
Strontium	mg/L	0.02	0.035	0.017	0.017	0.017	-0.58	-0.58
Antimony	mg/L	0.000014	0.000024	0.000011	0.00001	0.00001	-4.8	-4.8

a TVs (TV) and AVs (AV) for Äkäsjoki River are used for Kylmäoja Stream as no WQOs have been developed for the Kylmäoja.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the baseline data is below detection limit.

Table 9-36: Predicted change of water quality at mouth of the Kylmäoja River at closure; 100% of High-S tailings able to contribute to loadings

Parameter	Unit	[a]WQO – FS03		Baseline	Post-development concentration		Percentage change %	
		TV	AV	concentration	June	Winter	June	Winter
TMF seepage to Kylmäoja; 100% High-S tailings able to contribute to loadings								
Key parameters								
Nitrate	mg/L	0.077	20	0.013	0.013	0.013	1.6	1.6
Chloride	mg/L	1	150	0.79	0.8	0.79	0.88	-0.38
Sulphate	mg/L	6.8	65	4.4	4.7	4.3	8	-1.2
Iron	mg/L	0.59	2.6	0.44	0.44	0.44	0	0
Aluminium	mg/L	0.049	0.1	0.022	0.022	0.022	0	0
Arsenic	mg/L	0.0001	0.005	0.000061	0.000061	0.000061	-0.16	-0.16
Cadmium	mg/L	0.000003	0.00008	2.5E-06	2.5E-06	2.5E-06	0	0
Cobalt	mg/L	0.00031	0.004	0.00019	0.00019	0.00019	-1	-1
Chromium	mg/L	0.00034	0.001	0.00027	0.00027	0.00027	-1.5	-1.5
Copper	mg/L	0.00052	0.005	0.00042	0.00042	0.00042	0.48	0.48
Mercury	mg/L	1.4E-06	0.00005	0.000001	0.000001	0.000001	0	0
Manganese	mg/L	0.032	0.7	0.024	0.024	0.024	-1.6	-1.6
Molybdenum	mg/L	0.00024	1	0.00019	0.00019	0.00019	1.1	1.1
Nickel	mg/L	0.00069	0.02	0.00048	0.00048	0.00048	-0.21	-0.21
Lead	mg/L	0.000057	0.0072	0.000039	0.000039	0.000039	0	0
Uranium	mg/L	0.000091	0.015	0.000065	0.00034	0.00034	-0.58	-0.58
Zinc	mg/L	0.0016	0.03	0.00034	0.000066	0.00007	1.4	7.5
Other parameters								
Phosphate	mg/L	0.01	0.026	0.008	0.008	0.008	-0.5	-0.5
TOC	mg/L	8.1	16	4.7	4.7	4.7	-0.84	-0.84
Calcium	mg/L	5.8	17	4.4	4.7	4.4	7.8	0.92
Potassium	mg/L	0.88	2.1	0.64	0.81	0.64	27	0.16
Magnesium	mg/L	1.5	4.3	1.2	1.2	1.2	0.84	0.84
Sodium	mg/L	2.3	8.1	2	2	2	2	2
Silicon	mg/L	6.6	12	5	5	5	-0.2	-0.2
Barium	mg/L	0.014	0.022	0.012	0.012	0.012	2.6	2.6
Strontium	mg/L	0.02	0.035	0.017	0.017	0.017	-0.58	-0.58
Antimony	mg/L	0.000014	0.000024	0.000011	0.00001	0.00001	-4.8	-4.8

a TVs (TV) and AVs (AV) for Äkäsjoki River are used for Kylmäoja Stream as no WQOs have been developed for the Kylmäoja.
Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.
b 50% or more of the baseline data is below detection limit.

9.6 Muonionjoki River

An initial scoping exercise identifying potential impacts of the development on surface water quantity was undertaken and further developed during the baseline assessment. All identified potential impacts were presented in Table 4-3.

Operations Phase: Impact of Development of Rautuvaara TMF, including discharge of water to Muonionjoki on Surface Water Quantity

Changes to flows in the Niesajoki, Kylmäoja and Äkäsjoki Rivers have the potential to affect flows in the Muonionjoki. However, most of the changes to flows within the study area relate to diversions of water from one catchment to another (e.g. pumping of water from the mine site in the Äkäsjoki catchment to the Niesa Basin or pumping of water from the Rautuvaara TMF direct to the Muonionjoki), with all catchments tributaries of the Muonionjoki. Hence although there may be changes in timing of flows due to storage at the mine site or Rautuvaara TMF there will be negligible net effect on flows to the Muonionjoki.

The proposed pipeline from the Rautuvaara TMF to the Muonionjoki River will be around 600 mm in diameter, with outfall rates shown in Table 9-37, based on water balance results from Pöyry (2012c). The results in Table 9-37 illustrate that the treatment plant effluent will comprise less than 1% of the total flow in the river, even in winter months. Flow rates from the Rautuvaara TMF to the Muonionjoki River will increase through the life of the mine, reaching a peak at the end of mine life, when discharges will reach around 0.65% of the river flows.

The Muonionjoki (14,500 km^2 catchment) is a very large river in comparison to the Niesajoki (70 km^2 catchment) and Kylmäoja stream (39 km^2 catchment) and small changes in flows resulting from storage, pumping of water and seepage from the Rautuvaara facilities will have a negligible (<1%) impact on flow rates in the Muonionjoki.

Table 9-37: Comparison of average monthly flows in the Muonionjoki River with predicted outfall discharge rates from Pöyry (2012a)

	Monthly average flows in the Muonionjoki (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Flow	42.1	37.5	34.9	53.6	467	483	226	172	169	139	77	52
Year	**Outfall discharge (m^3/s)**											
1	0.019	0.026	0.022	0.024	0.010	0.007	0.001	0.005	0.020	0.096	0.086	0.083
2	0.076	0.045	0.057	0.060	0.099	0.030	0.028	0.050	0.055	0.051	0.023	0.020
3	0.040	0.046	0.058	0.061	0.146	0.039	0.038	0.059	0.063	0.060	0.024	0.021
4	0.056	0.062	0.074	0.077	0.161	0.055	0.054	0.075	0.079	0.076	0.040	0.037
5	0.056	0.061	0.073	0.077	0.196	0.063	0.064	0.086	0.087	0.083	0.041	0.037
6	0.080	0.087	0.117	0.082	0.295	0.110	0.113	0.243	0.209	0.135	0.105	0.099
7	0.086	0.051	0.066	0.068	0.295	0.114	0.118	0.247	0.214	0.140	0.110	0.104
8	0.090	0.055	0.070	0.073	0.325	0.127	0.134	0.263	0.226	0.151	0.116	0.109
9	0.094	0.059	0.073	0.076	0.333	0.132	0.140	0.269	0.231	0.156	0.120	0.112
10	0.098	0.063	0.078	0.081	0.338	0.137	0.145	0.274	0.236	0.160	0.124	0.117
11	0.104	0.069	0.083	0.086	0.282	0.146	0.195	0.248	0.284	0.207	0.131	0.122
12	0.115	0.080	0.094	0.098	0.299	0.174	0.219	0.270	0.301	0.217	0.143	0.134
13	0.136	0.100	0.115	0.118	0.319	0.194	0.239	0.291	0.321	0.238	0.163	0.154
14	0.146	0.110	0.124	0.128	0.333	0.205	0.251	0.302	0.333	0.249	0.174	0.164
15	0.164	0.169	0.142	0.107	0.388	0.185	0.269	0.320	0.312	0.304	0.191	0.182
16	0.182	0.188	0.161	0.126	0.407	0.203	0.287	0.339	0.330	0.322	0.210	0.200
17	0.193	0.199	0.171	0.136	0.422	0.215	0.300	0.351	0.342	0.334	0.221	0.211
18	0.211	0.217	0.189	0.154	0.477	0.233	0.318	0.332	0.322	0.278	0.239	0.304
19	0.274	0.242	0.215	0.180	0.436	0.249	0.334	0.348	0.338	0.294	0.265	0.143

Year	Outfall discharge as percentage of Muonionjoki River flow (%)											
1	0.044	0.07	0.064	0.044	0.0022	0.0015	0.00052	0.0027	0.012	0.069	0.11	0.16
2	0.18	0.12	0.16	0.11	0.021	0.0063	0.012	0.029	0.032	0.037	0.030	0.039
3	0.096	0.12	0.17	0.11	0.031	0.0081	0.017	0.035	0.038	0.043	0.032	0.041
4	0.13	0.16	0.21	0.14	0.035	0.011	0.024	0.044	0.047	0.055	0.052	0.072
5	0.13	0.16	0.21	0.14	0.042	0.013	0.028	0.05	0.051	0.059	0.053	0.071
6	0.19	0.23	0.33	0.15	0.063	0.023	0.050	0.14	0.12	0.097	0.14	0.19
7	0.20	0.14	0.19	0.13	0.063	0.024	0.052	0.14	0.13	0.10	0.14	0.20
8	0.21	0.15	0.20	0.14	0.070	0.026	0.059	0.15	0.13	0.11	0.15	0.21
9	0.22	0.16	0.21	0.14	0.071	0.027	0.062	0.16	0.14	0.11	0.16	0.22
10	0.23	0.17	0.22	0.15	0.072	0.028	0.064	0.16	0.14	0.12	0.16	0.22
11	0.25	0.18	0.24	0.16	0.060	0.03	0.086	0.14	0.17	0.15	0.17	0.23
12	0.27	0.21	0.27	0.18	0.064	0.036	0.097	0.16	0.18	0.16	0.19	0.26
13	0.32	0.27	0.33	0.22	0.068	0.040	0.11	0.17	0.19	0.17	0.21	0.30
14	0.35	0.29	0.36	0.24	0.071	0.043	0.11	0.18	0.20	0.18	0.23	0.32
15	0.39	0.45	0.41	0.20	0.083	0.038	0.12	0.19	0.18	0.22	0.25	0.35
16	0.43	0.50	0.46	0.23	0.087	0.042	0.13	0.20	0.20	0.23	0.27	0.39
17	0.46	0.53	0.49	0.25	0.090	0.045	0.13	0.20	0.20	0.24	0.29	0.41
18	0.50	0.58	0.54	0.29	0.100	0.048	0.14	0.19	0.19	0.20	0.31	0.58
19	0.65	0.65	0.62	0.34	0.093	0.052	0.15	0.20	0.20	0.21	0.34	0.27

Operations Phase: Impact of Development of Rautuvaara TMF, including discharge of water to Muonionjoki on Surface Water Quality

Description

The key potential impact of the development of the Rautuvaara TMF on water quality in the Muonionjoki River relates to the discharge of treated mine water into the Muonionjoki by way of an outfall.

It is proposed that water in the South Pond of the Rautuvaara TMF will be discharged to the Muonionjoki River by way of a pipeline, Figure 9-5. The water accumulating in the South Pond will comprise treated excess water from the Hannukainen mine site, treated runoff from the High-S tailings in the Rautuvaara TMF and excess runoff on the Rautuvaara TMF.

Table 9-37 compares the predicted flow rates from the Rautuvaara TMF (0.001 – 0.50 m^3/s) to the average monthly flows in Muonionjoki River (35 – 480 m^3/s), to give an indication of the level of dilution available within the larger river.

There will be other potential impacts on the Muonionjoki due to seepage from the Rautuvaara TMF and potential improvements to the water quality in the Muonionjoki due to the predicted improvement in water quality with the Niesajoki River, as outlined in Section 9.1. In addition, changes to the water quality in the Äkäsjoki River due to mining activities at Hannukainen also have the potential to impact water quality in the Muonionjoki.

However, results presented in Section 9.5 indicate that post-development seepage loadings to the Kylmäoja will be not be significantly different from current conditions and therefore will have negligible impact on the quality of the Muonionjoki. Impacts on the Äkäsjoki outlined in the Section 9.1 are also considered to be minor. Hence, this assessment focuses on the two main changes to water quality in the Muonionjoki:

- The improvement to the Niesajoki River water quality due to changes at the Rautuvaara TMF, outlined in Section 9.1; and
- The impact of piped water from the South Pond to Muonionjoki River.

In terms of loadings, the dominant impact on the Muonionjoki River will come from the piped water discharged to the Muonionjoki River.

Predictions of water quality in the Muonionjoki are made at three locations:

1. At the **outfall** where the effluent undergoes initial dilution. This is modelled using a Box Model approach;
2. Close to the outfall where the effluent has formed a **plume**, but has not fully mixed across the river. This is modelled using a 2D model; and
3. At a distance from the outfall when the effluent has **fully mixed** with the river flows. This is modelled using a standard conservative dilution modelling approach.

Details of the methods used to predict water quality in the Muonionjoki are provided in Section 8.1.3.

Results are presented for two flow conditions representing conditions of high river flow (spring (May/June)) and low river flow (average winter conditions). Results are also provided for three periods during the lifetime of the mine; Years 5, 10 and 18 of operations (where Year 1 is the time at which production, and therefore tailings deposition, commences). Discharge rates from the Rautuvaara TMF to the Muonionjoki increase over time; with highest flow rates predicted for Year 18, near end of mine life. These are consistent with the periods of time considered in the geochemical modelling work, Section 8.1.3.

Prediction of Water Quality: Outfall

Table 9-38 compares the effluent quality for the water discharged to the Muonionjoki with WQOs for key parameters at station FS23. The results indicate that the effluent itself prior to entering the Muonionjoki will exceed AVs of many parameters. However, it is notable that the water quality in the effluent discharged to the Muonionjoki is predicted to improve over the life of the mine. However, in contrast the flow rate for effluent is predicted to increase over time.

As a result, there are two competing factors with respect to the discharge to Muonionjoki; the improving concentrations of effluent over time versus the increasing flow rate requiring to be discharged to the river.

Initial dilution calculations are typically undertaken as initial screening stage calculations to assess if there is a risk of effluent producing water quality related issues within a water body. They are conservative calculations that consider dilution within a small water volume close to the outfall. If these calculations indicate no issues with respect to water quality further, more detailed calculations are not normally required. However, if the initial dilution calculations suggest exceedances of water quality limits, then more detailed work, such as plume modelling, would be required.

Results for initial dilution calculations at the outfall are not presented in this report as predictions for a number of parameters clearly indicated the potential for exceedances of TVs or AVs close to the outfall. Given these results, a plume model or full mixing approach is more appropriate to assess the impact of discharges from the outfall on water quality in the Muonionjoki.

Table 9-38: Comparison of Predicted Outfall Quality against WQOs for the Muonionjoki River FS23[a]

Parameter	Unit	Year 5 [a]				Year 10 [a]				Year 18 [a]			
		TVS		AVS		TVS		AVS		TVS		AVS	
		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key Parameters													
Nitrate	mg/L	Above	Above	Below	Below	Above	Above	Below	Below	Above	Above	Below	Below
Chloride	mg/L	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below
Sulphate	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Iron	mg/L	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below
Aluminium	mg/L	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below
Arsenic	mg/L	Above	Below	Below	Below	Above	Below	Below	Below	Above	Below	Below	Below
Cadmium	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Below
Cobalt	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Chromium	mg/L	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Copper	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Mercury	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Manganese	mg/L	Above	Above	Below	Below	Above	Above	Below	Below	Above	Above	Below	Below
Molybdenum	mg/L	Above	Above	Below	Below	Above	Above	Below	Below	Above	Above	Below	Below
Nickel	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Lead	mg/L	Above	Above	Below	Below	Above	Above	Below	Below	Above	Above	Below	Below
Uranium	mg/L	Above	Above	Above	Below	Above	Above	Above	Below	Above	Above	Above	Below
Zinc	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above

Parameter	Unit	Year 5 [a]				Year 10 [a]				Year 18 [a]			
		TVS		AVS		TVS		AVS		TVS		AVS	
		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters													
Parameter	Unit	May/June	Average Winter	May/June	Average Winter	May/June	Average Winter	May/June	Average Winter	May/June	Average Winter	May/June	Average Winter
Phosphate	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Below	Above
TOC	mg/L	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below
Calcium	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Potassium	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Magnesium	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Sodium	mg/L	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Silicon	mg/L	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below	Below
Barium	mg/L	Below	Above	Below	Above	Below	Above	Below	Above	Below	Below	Below	Below
Strontium	mg/L	Below	Above	Below	Below	Below	Above	Below	Below	Below	Below	Below	Below
Antimony	mg/L	Below	Above	Above	Above	Below	Above	Above	Above	Below	Above	Above	Above

[a] *Absolute values for parameter concentrations are provided in Table 9-53*

Prediction of Water Quality: Plume model

Description

The dispersion of effluent from the outfall in the Muonionjoki River up to 500 m downstream of the outfall was modelled using a two-dimensional advection dispersion model (Telemac2D). The model set-up and detailed methodology is provided in Section 8.1.2.

Model scenarios were considered for spring (May/June) and average winter flow conditions, and for pumping rates for Years 5, 10 and 18 of the mine life. The modelled scenarios are summarised in Table 9-39, with river flow conditions equal to average monthly flows based on Table 6-37.

Given the number of parameters to be considered, a simplified modelling approach is considered at this stage to provide an indication of the amount of dilution available in the Muonionjoki River. The model runs consider the discharge of 1 mg/L of a conservative tracer into the river at a rate shown in Table 9-39. Background concentrations in the river are set at 0 mg/L; hence, the concentration predictions in Figure 9-8 to Figure 9-10 provide an illustration of the dilution rate within the river, i.e. a value of 0.4 in Figure 9-8 to Figure 9-10 indicates that the concentration in the river at that location is 40% of the initial effluent concentration.

Assessment of Impacts without Mitigation

Table 9-40 provides the approximate distance downstream of the outfall by which each parameter is predicted to meet the TV or AV in the Muonionjoki.

The effluent plumes for Years 5, 10 and 15 are seen to be very similar despite the difference in discharge rates in each of the years. This indicates that dispersal is controlled by the flow conditions within the river and by the modelled dispersal coefficient and representation of turbulence in the model, rather than by the effluent discharge rate. This is not unexpected given the relative difference in the effluent discharge rate and the river flow conditions. The plumes are seen to be restricted to one side of the river under both winter and spring conditions, with full mixing across the river not predicted until 1 - 2 km downstream.

The results indicate that in Year 5 of operations the concentrations of a number of parameters would be expected to exceed AVs, with fewer exceedances in spring and more in winter, within a dilution zone of at least 500 m downstream of the outfall. By Year 18, with lower concentrations of most parameters in the effluent cobalt and copper concentrations are predicted to exceed AVs at least 500 m from the outfall; nickel within around 250 m and zinc within 40 m. All other parameters would meet AVs in close proximity to the outfall (<10 m). TVs of many parameters are predicted to be exceeded at least 500 m from the outfall.

Assessment of Impacts with Mitigation

It should be noted that the modelling work presented here is highly conservative and assumes the discharge of effluent at a single point into the river. There are numerous engineering solutions to aid dilution close to an outfall. For example, discharge through multiple diffusers can broaden an effluent plume, resulting in enhanced mixing across the river channel.

In addition, the modelling work should be considered indicative only as it based on limited data describing flow conditions in the river, i.e., a single flow survey.

More work will be required to better define the model parameters. However, it is likely that even with improved modelling and multiple diffusers that a dilution zone will be required downstream of the outfalls within which WQOs will not be met. Hence, discussions with regulators are advised in tandem with work looking at optimising water management within the mine site (e.g., storing water during winter months to decrease winter discharge rates to river) and optimisation of the water treatment process focussing on key parameters of concern.

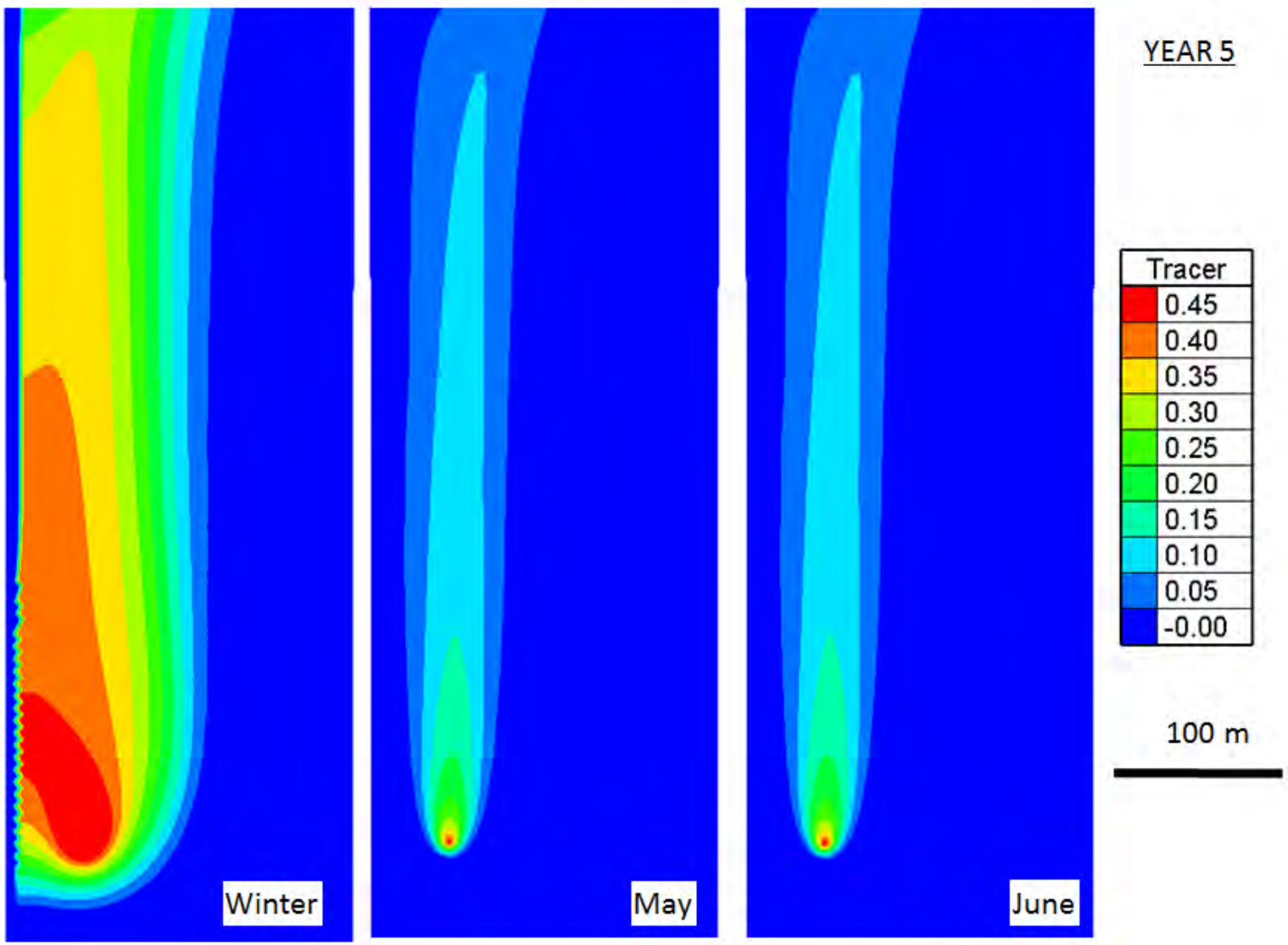


Figure 9-8: Plume model predictions for Year 5

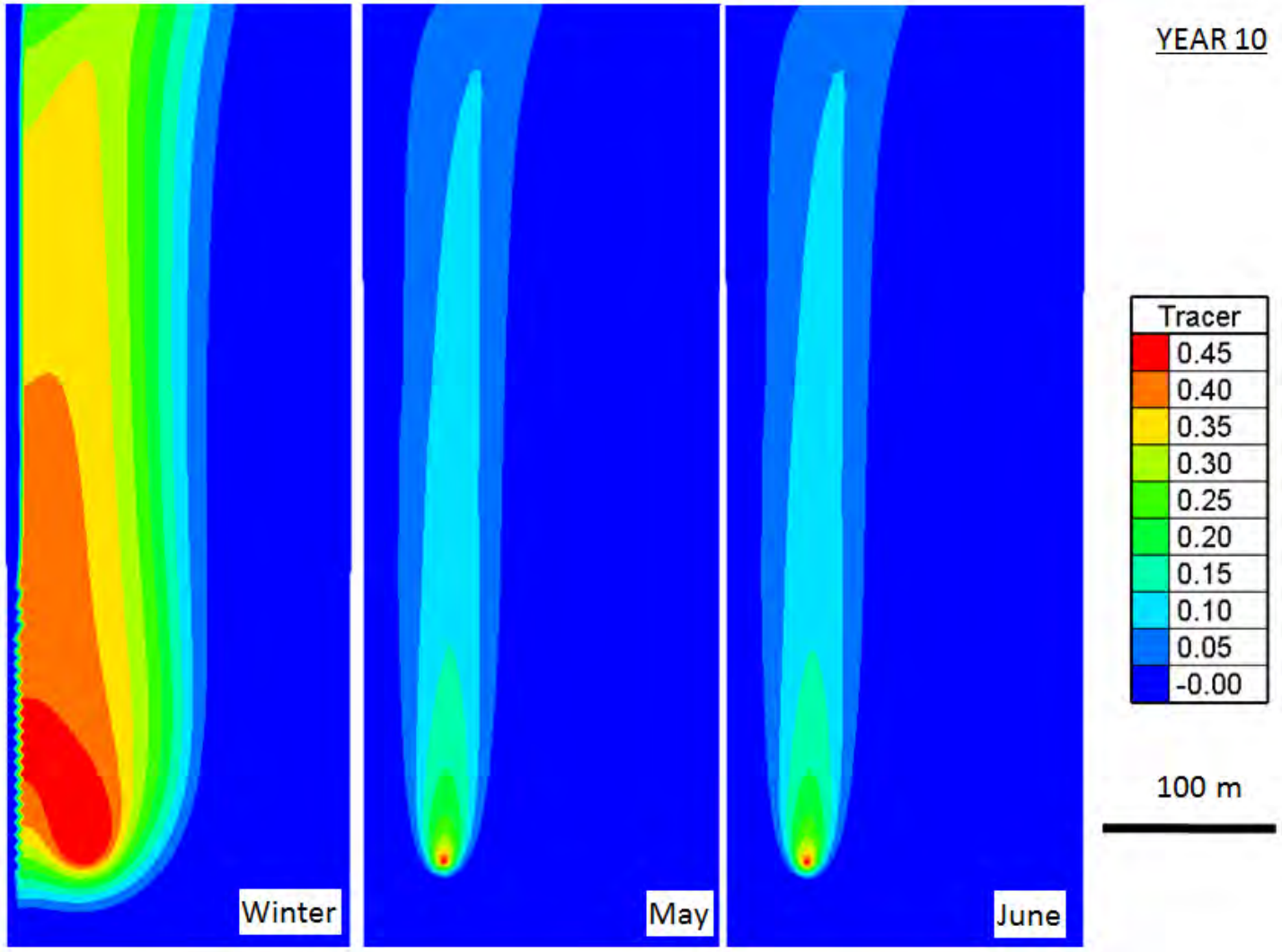


Figure 9-9: Plume model predictions for Year 10

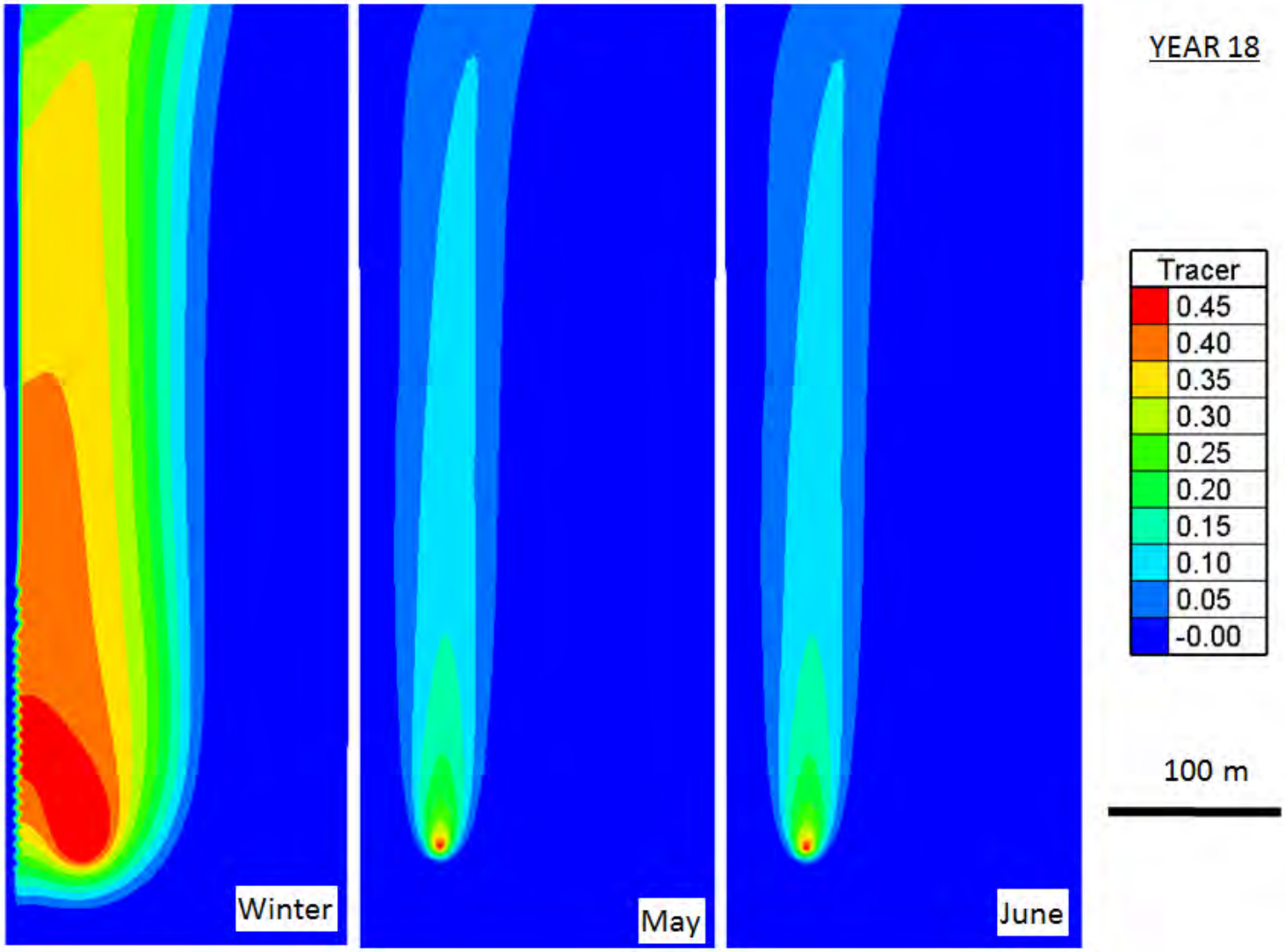


Figure 9-10: Plume model predictions for Year 18

Table 9-39: Scenarios for plume model

Scenario	Flows (m^3/s)		Water Depth (m)	Description
	Outfall	Muonionjoki		
Scenario 1	0.06	50	1.4	Year 5; Average Winter Flows
Scenario 2	0.20	470	3.4	Year 5; May Flows
Scenario 3	0.06	480	3.5	Year 5; June Flows
Scenario 4	0.09	50	1.4	Year 10; Average Winter Flows
Scenario 5	0.35	470	3.4	Year 10; May Flows
Scenario 6	0.22	480	3.5	Year 10; June Flows
Scenario 7	0.22	50	1.4	Year 18; Average Winter Flows
Scenario 8	0.49	470	3.4	Year 18; May Flows
Scenario 9	0.23	480	3.5	Year 18; June Flows

Table 9-40: Approximate distance from outfall where TV and AV will be met

Parameter	Unit	Year 5				Year 10				Year 18			
		TVS		AVS		TVS		AVS		TVS		AVS	
		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters – Distance from Outfall that TV or AV will be met													
Nitrate	mg/L	400m	>500m	*Discharge below AV*	*Discharge below AV*	150m	>500m	*Discharge below AV*	*Discharge below AV*	60m	>500m	*Discharge below AV*	*Discharge below AV*
Chloride	mg/L	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Sulphate	mg/L	500m	>500m	40m	500m	500m	>500m	450m	450m	500m	>500m	100m	10m
Iron	mg/L	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Aluminium	mg/L	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Arsenic	mg/L	40m	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	150m	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	60m	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Cadmium	mg/L	>500m	>500m	500m	<10m	>500m	>500m	>500m	<10m	>500m	>500m	500m	*Discharge below AV*
Cobalt	mg/L	>500m	>500m	120m	>500m	500m	>500m	120m	>500m	>500m	>500m	100m	>500m
Chromium	mg/L	500m	*Discharge below TV*	500m	*Discharge below AV*	500m	*Discharge below TV*	>500m	*Discharge below AV*	500m	*Discharge below TV*	500m	*Discharge below AV*
Copper	mg/L	500m	>500m	450m	>500m	500m	>500m	500m	>500m	500m	>500m	400m	>500m
Mercury	mg/L	500m	>500m	450m	<10m	>500m	>500m	500m	<10m	500m	>500m	400m	10m
Manganese	mg/L	60m	>500m	*Discharge below AV*	*Discharge below AV*	50m	>500m	*Discharge below AV*	*Discharge below AV*	60m	>500m	*Discharge below AV*	*Discharge below AV*
Molybdenum	mg/L	500m	>500m	*Discharge below AV*	*Discharge below AV*	500m	>500m	*Discharge below AV*	*Discharge below AV*	60m	>500m	*Discharge below AV*	*Discharge below AV*
Nickel	mg/L	500m	>500m	10m	500m	>500m	>500m	60m	500m	>500m	>500m	60m	250m
Lead	mg/L	400m	500m	*Discharge below AV*	*Discharge below AV*	500m	500m	*Discharge below AV*	*Discharge below AV*	400m	>500m	*Discharge below AV*	*Discharge below AV*
Uranium	mg/L	>500m	>500m	<10m	*Discharge below AV*	>500m	>500m	<10m	*Discharge below AV*	>500m	>500m	<10m	*Discharge below AV*
Zinc	mg/L	500m	>500m	<10m	>500m	500m	>500m	<10m	>500m	400m	>500m	10m	40m

Parameter	Unit	Year 5				Year 10				Year 18			
		TVS		AVS		TVS		AVS		TVS		AVS	
		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters – Distance from Outfall that TV or AV will be met													
Phosphate	mg/L	150m	>500m	<10m	>500m		>500m	<10m	>500m	50m	>500m	*Discharge below AV*	500m
TOC	mg/L	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Calcium	mg/L	60m	>500m	10m	>500m	100m	>500m	10m	>500m	120m	>500m	<10m	450m
Potassium	mg/L	500m	>500m	500m	>500m	>500m	>500m	500m	>500m	>500m	>500m	500m	>500m
Magnesium	mg/L	150m	>500m	50m	500m	450m	>500m	100m	500m	450m	>500m	50m	250m
Sodium	mg/L	450m	>500m	150m	>500m	500m	>500m	450m	>500m	500m	>500m	400m	450m
Sulphur	mg/L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Silicon	mg/L	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Barium	mg/L	*Discharge below TV*	<10m	*Discharge below AV*	<10m	*Discharge below TV*	<10m	*Discharge below AV*	<10m	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Strontium	mg/L	*Discharge below TV*	<10m	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	<10m	*Discharge below AV*	*Discharge below AV*	*Discharge below TV*	*Discharge below TV*	*Discharge below AV*	*Discharge below AV*
Antimony	mg/L	*Discharge below TV*	>500m	500m	>500m	*Discharge below TV*	>500m	500m	>500m	*Discharge below TV*	>500m	500m	500m

Prediction of Water Quality: Fully mixed model

Description

Given the size of the Muonionjoki River, extrapolation of the plume modelling results (described above) would suggest that effluent from the outfall might be expected to be fully mixed across the river by a couple of kilometres downstream of the outfall. Therefore, dilution calculations have been undertaken to estimate the concentration of parameters once the effluent plume is fully mixed with the river water. Calculations are based on the methodology outlined in Section 8.1.3.

Assessment of Impacts without Mitigation

Predictions of the concentrations in the Muonionjoki River downstream of the outfall once the effluent plume has mixed fully with the river are outlined in Table 9-41, Table 9-42 and Table 9-43 for Year 5, 10 and 18 of operations respectively. Discharge rates from the mine site to the Muonionjoki River increase through the lifetime of the mine; however, concentrations of most parameters in the effluent decrease over time, although for most parameters overall loadings (flow rate times concentration) are higher in Year 18 than in Year 5.

In Year 5 calculations predict that no concentrations would exceed AVs. However, TVs are predicted to be exceeded for cobalt and molybdenum and nickel during average winter conditions. Uranium concentrations are predicted to exceed TVs during spring and winter conditions. It is noted that concentrations of nitrate (winter months) only are predicted to be more than 50% above baseline conditions.

By Year 18 calculations predict that no concentrations would exceed AVs. However, TVs are predicted to be exceeded for uranium (spring and winter), cadmium (spring conditions only) and cobalt, chromium, molybdenum and nickel (winter conditions only). Concentrations of nitrate, cobalt and nickel (winter only) are predicted to exceed baseline by 50% or more.

It is noted that in all calculations no parameters are predicted to exceed AVs and that baseline water quality in the Muonionjoki is very good, such that even relatively small loadings from the mine result in relatively large increases over baseline conditions. A review of the water quality predictions also highlighted that no post-development concentrations for key parameters in the Muonionjoki were predicted to exceed a third of the AV.

In addition for some parameters below detection limit samples in the baseline data set results in TV values that are close to the median baseline concentrations, e.g. molybdenum and cadmium. For these parameters even a relatively small increase in concentrations over baseline could result in an exceedance of TVs.

Assessment of Impacts with Mitigation

Although no parameter is predicted to exceed AVs, the presence of concentrations in excess of baseline conditions may be a source of concern for regulators. As a result, a review of the site water management plan and existing treatment options are recommended. The assessment is based on predicted discharge rates provided by Poyry (2012c). Hence, there is the potential for refinement of the water management at the mine site.

If water was able to be stored on site during winter months to be discharged to the Muonionjoki River during spring there would be the potential to control winter flow rates to the Muonionjoki River and to limit impacts on the river. Further modelling work will be required that combines the mine water balance with the modelling of impact in Muonionjoki River in order to optimise on-site storage and discharge.

It should also be noted that the assessment also focuses on impacts during average flow conditions. At present there is no information on discharge rates to the Muonionjoki River or water quality of the effluent during periods with lower than average flow (e.g., 1 in 10 dry year). Under these conditions there would be less dilution within the Muonionjoki River than during average flow conditions. However, it would be expected that the discharge rate from the mine site to the Muonionjoki River would be correspondingly lower under these conditions.

Post-Closure Phase: Impact of Development of Rautuvaara TMF, including discharge of water to Muonionjoki on Surface Water Quality

Description

At the end of operations at the Rautuvaara TMF the current closure plan has excess water from the TMF flowing into Niesajoki River. An alternative water management option, if the runoff from the TMF is shown to have an unacceptably negative impact on Niesajoki River, would be to continue to discharge the excess water from the TMF to the Muonionjoki River by way of the pipeline. Whichever option is used, the effect on the Muonionjoki River would likely be similar as the loadings from the TMF would end up in the Muonionjoki either through the outfall or from Niesajoki River. At closure there will be no further loadings from the Hannukainen mine reaching the Rautuvaara TMF and exposed tailings on the shore of the TMF will undergo reclamation and will be covered.

Three closure options are considered, varying depending on the effectiveness of encapsulation of High-S tailings during closure:

- Worst case that assumes 100% of High-S tailings are available to contribute to loadings in the TMF;
- Medium case that assumes 50% of High-S tailings are encapsulated at closure; and
- Best case that assumes 0% of High-S tailings are available to contribute to loadings in the TMF.

Results for three model runs assessing the impact of loadings from the Rautuvaara TMF on water quality in the Muonionjoki are provided in Table 9-44 to Table 9-46, based on calculations assuming that the outfall has fully mixed with the Muonionjoki River. No additional treatment of runoff or seepage from the High-S tailings is considered in the calculations.

Plume modelling simulations have not been undertaken for the closure scenarios.

Assessment of Impacts without Mitigation

Considering the worst case scenario results (Table 9-46) the calculations indicate that, without effective encapsulation of the High-S tailings, concentrations of copper, molybdenum and uranium in the Muonionjoki River are predicted to exceed TVs under spring and winter flow conditions. Concentrations of cobalt, copper, mercury and uranium are predicted to exceed baseline median concentrations by >50%.

Assessment of Impacts with Mitigation

If the High-S tailings can be effectively encapsulated then copper concentrations in the seepage and runoff from the Rautuvaara TMF will be substantially lower, with copper predictions for the best case scenario (Table 9-44) lower than the TVs. However, even with the encapsulation of the High-S tailings, calculations predict that molybdenum and uranium concentrations would exceed TVs. Concentrations of uranium only are predicted to exceed baseline median concentrations by >50% under the best case scenario. Uranium and molybdenum loadings are sourced from the LIMS tailings within the Rautuvaara TMF.

It should be noted that baseline molybdenum values in the Muonionjoki River have a number of below detection limit samples, so that the TV for this parameter is very close to the median baseline concentration. Hence, for the best case scenario (Table 9-44) the post-closure concentrations are only 8 – 12 % above baseline, although a TV exceedance is predicted. The AV for molybdenum is more than 3 orders of magnitude above the TV; hence, even with a change from baseline conditions molybdenum concentrations are well below AVs. For uranium, post-development concentrations are predicted to be significantly higher than baseline (300 – 500%); however, the resultant concentrations are still 1 to 1.5 times below AVs.

Table 9-41: Predicted changes in water quality in the Muonionjoki downstream of the outfall during operations, Year 5 (based on data from water quality sampling station FS23)

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters								
Nitrate	mg/L	0.070	20	0.0051	0.0052	0.0089	1.6	73
Chloride	mg/L	0.91	150	0.79	0.78	0.78	-0.33	-0.74
Sulphate	mg/L	3.8	65	2.57	2.6	2.7	0.7	4.6
Iron	mg/L	0.54	1.9	0.40	0.40	0.40	-0.21	-0.53
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.24	-0.58
Arsenic	mg/L	0.000073	0.005	0.000058	0.000058	0.000057	-0.46	-1.3
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000032	0.0000026	26	4.4
Cobalt	mg/L	0.000097	0.004	0.000031	0.000037	0.00010	21	230
Chromium	mg/L	0.00033	0.001	0.00024	0.00024	0.00023	2.6	-0.49
Copper	mg/L	0.00046	0.005	0.00037	0.00039	0.00041	3.8	11
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000014	0.0000013	14	5.2
Manganese	mg/L	0.018	0.7	0.0067	0.0067	0.0069	-0.61	3.1
Molybdenum	mg/L	0.00025	1	0.00024	0.00024	0.00026	1.3	8.7
Nickel	mg/L	0.00032	0.02	0.00025	0.00026	0.00032	4	28
Lead	mg/L	0.00006	0.0072	0.000040	0.000040	0.000040	0.31	0.74
Uranium	mg/L	0.00009	0.015	0.000085	0.000091	0.00010	6.5	19
Zinc	mg/L	0.0017	0.03	0.00096	0.00097	0.0012	1.3	24

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0030	0.0032	0.12	5.1
TOC	mg/L	6.9	13	5.1	n/a	n/a	n/a	n/a
Calcium	mg/L	4.6	8.9	3.5	3.4	3.5	-0.41	0.0062
Potassium	mg/L	0.81	1.9	0.63	0.63	0.64	0.85	2.3
Magnesium	mg/L	1.2	2.4	0.9	0.90	0.90	-0.46	-0.44
Sodium	mg/L	1.9	3.4	1.4	1.4	1.4	0.15	0.69
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.22	-0.52
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.20	0.22
Strontium	mg/L	0.022	0.043	0.016	0.015	0.015	-0.39	-0.75
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000057	0.0000062	13	23

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-42: Predicted changes in water quality in the Muonionjoki downstream of the outfall during operations, Year 10 (based on data from water quality sampling station FS23)

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters								
Nitrate	mg/L	0.070	20	0.0051	0.0052	0.01	1.8	97
Chloride	mg/L	0.91	150	0.79	0.78	0.78	-0.36	-0.74
Sulphate	mg/L	3.8	65	2.57	2.8	2.8	9	9.6
Iron	mg/L	0.54	1.9	0.40	0.4	0.4	-0.23	-0.6
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.26	-0.64
Arsenic	mg/L	0.000073	0.005	0.000058	0.000058	0.000057	-0.23	-1.3
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000061	0.0000027	140	7.1
Cobalt	mg/L	0.000097	0.004	0.000031	0.00004	0.00015	31	390
Chromium	mg/L	0.00033	0.001	0.00024	0.00025	0.00023	6.5	-0.56
Copper	mg/L	0.00046	0.005	0.00037	0.00041	0.00044	9.8	20
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000017	0.0000013	38	9.1
Manganese	mg/L	0.018	0.7	0.0067	0.0067	0.0071	-0.51	6.4
Molybdenum	mg/L	0.00025	1	0.00024	0.00025	0.00027	3.6	11
Nickel	mg/L	0.00032	0.02	0.00025	0.00029	0.00037	17	49
Lead	mg/L	0.00006	0.0072	0.000040	0.000041	0.00004	1.7	1.3
Uranium	mg/L	0.00009	0.015	0.000085	0.000098	0.00011	15	30
Zinc	mg/L	0.0017	0.03	0.00096	0.00097	0.0013	1.8	35

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0030	0.0032	0.13	7.1
TOC	mg/L	6.9	13	5.1	n/a	n/a	n/a	n/a
Calcium	mg/L	4.6	8.9	3.5	3.5	3.5	-0.27	0.78
Potassium	mg/L	0.81	1.9	0.63	0.66	0.65	3.3	3.9
Magnesium	mg/L	1.2	2.4	0.9	0.9	0.9	-0.047	0.13
Sodium	mg/L	1.9	3.4	1.4	1.4	1.4	1.2	1.4
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.24	-0.58
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.22	-0.17
Strontium	mg/L	0.022	0.043	0.016	0.015	0.015	-0.41	-0.72
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000069	0.0000067	38	34

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-43: Predicted changes in water quality in the Muonionjoki downstream of the outfall during operations, Year 18 (based on data from water quality sampling station FS23)

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Key parameters								
Nitrate	mg/L	0.070	20	0.0051	0.00529	0.0117	2.98	128
Chloride	mg/L	0.91	150	0.79	0.784	0.779	-0.379	-0.958
Sulphate	mg/L	3.8	65	2.57	2.9	3	11	16
Iron	mg/L	0.54	1.9	0.40	0.4	0.4	-0.26	-0.85
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.28	-0.86
Arsenic	mg/L	0.000073	0.005	0.000058	0.000058	0.000057	-0.2	-1.6
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000068	0.0000028	170	13
Cobalt	mg/L	0.000097	0.004	0.000031	0.000047	0.00026	53	760
Chromium	mg/L	0.00033	0.001	0.00024	0.00025	0.00023	7.7	-0.8
Copper	mg/L	0.00046	0.005	0.00037	0.00042	0.00053	14	43
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000017	0.0000016	46	31
Manganese	mg/L	0.018	0.7	0.0067	0.0067	0.0076	-0.17	13
Molybdenum	mg/L	0.00025	1	0.00024	0.00025	0.00028	4.4	16
Nickel	mg/L	0.00032	0.02	0.00025	0.00031	0.00046	22	85
Lead	mg/L	0.00006	0.0072	0.000040	0.000041	0.000041	2	2.2
Uranium	mg/L	0.00009	0.015	0.000085	0.0001	0.00012	18	46
Zinc	mg/L	0.0017	0.03	0.00096	0.00098	0.0014	2	45

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0030	0.0033	0.19	9.0
TOC	mg/L	6.9	13	5.1	n/a	n/a	n/a	n/a
Calcium	mg/L	4.6	8.9	3.5	3.5	3.5	-0.19	1.6
Potassium	mg/L	0.81	1.9	0.63	0.65	0.67	4.1	6.3
Magnesium	mg/L	1.2	2.4	0.9	0.9	0.91	0.1	0.94
Sodium	mg/L	1.9	3.4	1.4	1.4	1.4	1.5	2.9
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.27	-0.82
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.24	-0.31
Strontium	mg/L	0.022	0.043	0.016	0.015	0.015	-0.43	-0.91
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000073	0.0000078	46	56

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-44: Predicted change of water quality in the Muonionjoki downstream of the outfall at closure; 0% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Discharge to Muonionjoki; 0% High-S tailings able to contribute to loadings								
Key Parameters								
Nitrate	mg/L	0.070	20	0.0051	0.0050	0.0050	-1.3	-4.0
Chloride	mg/L	0.91	150	0.79	0.79	0.78	-0.2	-0.8
Sulphate	mg/L	3.8	65	2.57	2.7	2.4	3.9	-5.0
Iron	mg/L	0.54	1.9	0.40	0.40	0.40	-0.2	-0.5
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.3	-0.5
Arsenic	mg/L	0.000073	0.005	0.000058	0.000060	0.000060	-0.5	-0.1
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000029	0.0000030	14	20
Cobalt	mg/L	0.000097	0.004	0.000031	0.000039	0.000042	29	37
Chromium	mg/L	0.00033	0.001	0.00024	0.00023	0.0002	-0.2	-0.5
Copper	mg/L	0.00046	0.005	0.00037	0.00037	0.00037	-0.1	0.0007
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000020	0.0000020	28	40
Manganese	mg/L	0.018	0.7	0.0067	0.0070	0.00690	3.1	3.1
Molybdenum	mg/L	0.00025	1	0.00024	0.00026	0.00027	8.4	12
Nickel	mg/L	0.00032	0.02	0.00025	0.00026	0.00026	4.6	4.3
Lead	mg/L	0.00006	0.0072	0.000040	0.000040	0.000040	-0.091	-0.18
Uranium	mg/L	0.00009	0.015	0.000085	0.00040	0.00052	360	510
Zinc	mg/L	0.0017	0.03	0.00096	0.0011	0.0012	19	26

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other Parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0033	0.0035	8.8	15
TOC	mg/L	6.9	13	5.1	5.1	5.1	-0.2	-0.4
Calcium	mg/L	4.6	8.9	3.5	3.5	3.4	2.5	-1.5
Potassium	mg/L	0.81	1.9	0.63	0.67	0.62	6.7	-1.1
Magnesium	mg/L	1.2	2.4	0.9	0.91	0.88	0.7	-1.8
Sodium	mg/L	1.9	3.4	1.4	1.4	1.4	0.3	-0.9
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.2	-0.5
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.2	-0.5
Strontium	mg/L	0.022	0.043	0.016	0.016	0.016	1.8	2.1
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000050	0.0000050	-0.2	-0.5

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-45: Predicted change of water quality in the Muonionjoki downstream of the outfall at closure; 50% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Discharge to Muonionjoki; 50% High-S tailings able to contribute to loadings								
Key Parameters								
Nitrate	mg/L	0.070	20	0.0051	0.0050	0.0050	-1.3	-4.0
Chloride	mg/L	0.91	150	0.79	0.79	0.78	-0.2	-0.7
Sulphate	mg/L	3.8	65	2.57	2.7	2.7	4.0	3.5
Iron	mg/L	0.54	1.9	0.40	0.40	0.40	-0.2	-0.5
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.3	-0.5
Arsenic	mg/L	0.000073	0.005	0.000058	0.000060	0.000060	0.001	2.5
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000030	0.0000032	21	30
Cobalt	mg/L	0.000097	0.004	0.000031	0.00010	0.00010	84	110
Chromium	mg/L	0.00033	0.001	0.00024	0.00023	0.00023	-0.2	-0.4
Copper	mg/L	0.00046	0.005	0.00037	0.00092	0.0013	150.0	240
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000020	0.0000020	44.0	61
Manganese	mg/L	0.018	0.7	0.0067	0.0070	0.0070	3.1	3.2
Molybdenum	mg/L	0.00025	1	0.00024	0.00026	0.00027	8.5	12
Nickel	mg/L	0.00032	0.02	0.00025	0.00028	0.00028	11	13
Lead	mg/L	0.00006	0.0072	0.000040	0.000040	0.000040	0.6	0.8
Uranium	mg/L	0.00009	0.015	0.000085	0.00040	0.00052	360	510
Zinc	mg/L	0.0017	0.03	0.00096	0.0011	0.0012	20	27

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other Parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0034	0.0044	13	45
TOC	mg/L	6.9	13	5.1	5.1	5.1	-0.2	-0.4
Calcium	mg/L	4.6	8.9	3.5	3.5	3.6	2.5	2.9
Potassium	mg/L	0.81	1.9	0.63	0.67	0.68	6.6	8.8
Magnesium	mg/L	1.2	2.4	0.9	0.91	0.90	0.7	0.3
Sodium	mg/L	1.9	3.4	1.4	1.40	1.40	0.30	0.030
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.2	-0.5
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.2	-0.5
Strontium	mg/L	0.022	0.043	0.016	0.0160	0.0160	1.8	2.0
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000050	0.0000050	-0.2	-0.5

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

Table 9-46: Predicted change of water quality in the Muonionjoki downstream of the outfall at closure; 100% of High-S tailings able to contribute to loadings

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Discharge to Muonionjoki; 100% High-S tailings able to contribute to loadings								
Key Parameters								
Nitrite	mg/L	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nitrate	mg/L	0.070	20	0.0051	0.0050	0.0050	-1.3	-4.0
Chloride	mg/L	0.91	150	0.79	0.79	0.78	-0.2	-0.7
Sulphate	mg/L	3.8	65	2.57	2.7	2.70	4.2	3.7
Iron	mg/L	0.54	1.9	0.40	0.40	0.40	-0.2	-0.4
Aluminium	mg/L	0.057	0.1	0.021	0.021	0.021	-0.3	-0.5
Arsenic	mg/L	0.000073	0.005	0.000058	0.000060	0.000060	2.3	3.2
Cadmium	mg/L	0.0000066	0.00008	0.0000025	0.0000032	0.0000035	29	40.0
Cobalt	mg/L	0.000097	0.004	0.000031	0.00010	0.000089	140	190.0
Chromium	mg/L	0.00033	0.001	0.00024	0.00023	0.00020	-0.2	-0.4
Copper	mg/L	0.00046	0.005	0.00037	0.0017	0.0025	350	570
Mercury	mg/L	0.0000039	0.00005	0.0000012	0.0000020	0.0000020	59	81
Manganese	mg/L	0.018	0.7	0.0067	0.0070	0.0069	3.2	3.2
Molybdenum	mg/L	0.00025	1	0.00024	0.00026	0.00027	8.6	12
Nickel	mg/L	0.00032	0.02	0.00025	0.00029	0.00031	17	22
Lead	mg/L	0.00006	0.0072	0.000040	0.000040	0.000040	0.8	1.1
Uranium	mg/L	0.00009	0.015	0.000085	0.00040	0.00052	360	510
Zinc	mg/L	0.0017	0.03	0.00096	0.0011	0.0012	20	28

Parameter	Unit	WQO – FS23		Baseline concentration	Post-development concentration		Percentage change %	
		TV	AV		Spring (May/June)	Average Winter	Spring (May/June)	Average Winter
Other Parameters								
Phosphate	mg/L	0.0051	0.017	0.003	0.0039	0.0050	31	67
TOC	mg/L	6.9	13	5.1	5.1	5.1	-0.2	-0.4
Calcium	mg/L	4.6	8.9	3.5	3.5	3.6	2.5	2.9
Potassium	mg/L	0.81	1.9	0.63	0.67	0.68	6.6	8.8
Magnesium	mg/L	1.2	2.4	0.9	0.91	0.90	0.8	0.3
Sodium	mg/L	1.9	3.4	1.4	1.40	1.40	0.3	0.0
Sulphur	mg/L	1.6	2.7	1.1	n/a	n/a	n/a	n/a
Silicon	mg/L	5.4	10	3.2	3.2	3.2	-0.2	-0.5
Barium	mg/L	0.0096	0.015	0.0069	0.0068	0.0068	-0.2	-0.5
Strontium	mg/L	0.022	0.043	0.016	0.0160	0.0160	1.8	2.1
Antimony	mg/L	0.000012	0.00015	0.000005	0.0000050	0.0000050	-0.2	-0.5

Note; Values shaded green are in excess of TVs. Values shaded orange are in excess of AVs.

9.7 Pit Lakes

Post-closure: Pit lake recovery

Upon closure the open pits will be artificially flooded to form pit lakes as described in Section 7.1.1. The time required to fully flood the Hannukainen and Kuervitikko pits is 13 – 81 years and 4 – 18 years respectively. The rate depends on the volume of water abstracted from rivers, the CP and diverted to the pit as surface water runoff. A full description of these inputs is provided in Appendix K and summarised below:

- Precipitation on, and evaporation from, pit lake surface: The model predicts the change in pit lake area over time as it fills, based on relationships relating lake area with pit lake volume.
- Groundwater inflows and outflows: Groundwater inflows to Hannukainen and Kuervitikko pits have been predicted by groundwater modelling. The pits will be net sinks for groundwater and groundwater inflow rates to the pit lakes will decrease as they fill.
- Surface water runoff over pit walls: The pit wall area exposed above the pit lake water level varies over time as the pit lake fills. Pit wall areas are calculated as the difference between the total pit area and the pit lake area. Over time the pit wall area will become steadily smaller as the pit lake expands and submerges the pit walls.
- Runoff from catchments surrounding the pit lakes: At closure runoff from the WRDs and upstream catchments will be directed towards the pit lakes.
- Abstraction from Rivers: For practical and environmental reasons the Base Case assumes that there is no pumping during winter (November to April). The pumping rate during open water months (May to October) is set at 550 L/s which is around 3% of May (Spring thaw) flows in the river and 10% of mid-summer flows.
- Overspill from pit lakes: Hannukainen pit lake will overspill towards Äkäsjoki River once the pit lake water level has reached 185.5 masl. Kuervitikko pit lake will overspill towards Kuerjoki River once the pit lake water level has reached 234.3 masl.

The artificial flooding scenarios are summarised in Table 9-47.

More detail on the modelling of pit lake recovery, including all model inputs, is provided in Appendix K.

Table 9-47: Predicted rate of pit lake recovery: artificial flooding scenarios

Model Run	Comment	Years to fill pit lake	Result compared to Base Case
Hannukainen			
Base Case	**Parameters as per Table 8 in Appendix K**	**14**	
Sensitivity1	1 in 20 wet year rainfall in every year. Wet year runoff from WRDs.	14	Higher rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by pumped inflows.
Sensitivity 2	1 in 20 dry year rainfall in every year. Dry year runoff from WRDs.	15	Lower rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by pumped inflows.
Sensitivity 3	Zero Pumped Inflow	81	As pumped inflows dominate the Base Case water balance for Hannukainen pit, if there are no pumped inflows to the pit lake the time to fill will increase to 82 years.
Sensitivity 4	Pumped Inflow Halved	24	Halving pumped inflows increases the time to fill to 25 years.
Sensitivity 5	Groundwater Inflow Halved	15	Groundwater inflows are a small component of the Base Case water balance so that halving inflows does not have a significant impact on time to fill.
Sensitivity 6	Groundwater Inflow Doubled	13	Groundwater inflows are a small component of the Base Case water balance so that doubling inflows does not have a significant impact on time to fill.
Sensitivity 7	Kuervitikko pit filled before Hannukainen pit	18	Infilling Kuervitikko pit lake prior to filling Hannukainen is predicted to delay infilling of Hannukainen by around 4 years from the Base Case.
Kuervitikko			
Base Case	**Parameters as per Table 8 in Appendix K**	**17**	
Sensitivity1	1 in 20 wet year rainfall in every year. Wet year runoff from WRDs.	16	Higher rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by groundwater inflows during initial period when there are no pumped inflows to Kuervitikko.
Sensitivity 2	1 in 20 dry year rainfall in every year. Dry year runoff from WRDs.	17	Lower rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by groundwater inflows during initial period when there are no pumped inflows to Kuervitikko.
Sensitivity 3	Zero Pumped Inflow	18	Pumped inflows have limited impact on infilling rate as pit lake is substantially filled before pumping commences (i.e. after Hannukainen has been filled). Kuervitikko is able to fill in 19 years from groundwater inflows alone.
Sensitivity 4	Pumped Inflow Halved	18	Halving pumped inflows has limited impact on time to fill for reasons outlined above.
Sensitivity 5	Groundwater Inflow Halved	18	The impact of reducing groundwater inflows is compensated by pumped inflows filling the pit in years 16 to 19.
Sensitivity 6	Groundwater Inflow Doubled	10	Groundwater inflows are a key inflow to Kuervitikko pit lake and increasing groundwater flows reduces the time for the pit lake to fill.
Sensitivity 7	Kuervitikko pit filled before Hannukainen pit	4	If Kuervitikko is filled before Hannukainen the pit could be filled in substantially less time than under Base Case conditions.

At both Hannukainen and Kuervitikko the pit lake water level is predicted to rise to a level equal to pit-perimeter topography (185.5 masl and 234.3 masl respectively) and so the pit lakes overtop. Table 9-48 presents the predicted steady state over-topping volumes for different climatic and runoff scenarios described in Table 9-47.

Table 9-48: Modelled pit lake over-topping volumes

Climate conditions and WRD runoff	Steady state over-topping volume to river (m^3/d)	
	Hannukainen (to Äkäsjoki River)	Kuervitikko (to Kuerjoki River)
Average, no WRD runoff	2,930	[a]1,890
Wet, no WRD runoff	4,160	[a]3,000
Dry, no WRD runoff	164	[a]1,450
Average, WRD runoff	3,390	1,890
Wet, WRD runoff	4,660	3,000
Dry, WRD runoff	1,950	1,450

[a] *Model does not predict surface runoff to Kuervitikko.*

Water level recovery in each sub-pit or sump (described in Section 7.1.1) will initially occur independently of the neighbouring sub-pits within each pit. Only once water levels reach the elevation of the crest between sub-pits do the waters mix and single pit lakes form at both Hannukainen and Kuervitikko.

Post closure: Water quality

Description

Water quality predictions for the Hannukainen and Kuervitikko pit lakes have been undertaken based on the pit lake numerical hydrogeological model presented in Appendix I. Full details of the pit lake water quality prediction methodology and results is given in Appendix J.

In order to simplify the model each of the sub-pits within the Hannukainen and Kuervitikko main pits have been treated as one unit (i.e. one water quality prediction has been made for each pit). Predictions are made for two scenarios;

- Initial overflow from pit lake: This scenario considers water quality in the pit lake at the point when the pit lakes become full and water overflows. The results assume that river water has been used to assist in pit lake infilling and the river water acts to dilute inflow contribution from pit walls and runoff from the WRDs. Pumped river water accounts for a lower percentage of the total inflow volume of the Kuervitikko pit lake than the Hannukainen pit lake, with most of the water infilling the Kuervitikko pit lake coming from precipitation on the pit surface and groundwater (see Appendix K). It should be noted that the predictions assume that the pit lake is fully mixed.
- Steady state: This scenario considers water quality in the pit lake assuming steady state inflows from each of the key sources to the lake. It is assumed that over time the effect of initial conditions on water quality in the pit lakes (i.e., the contribution of river water pumped to the pit lake to speed up infilling) will diminish and water quality in the pit lake will be reflected by the relative contributions from natural runoff, pit wall runoff, groundwater inflows, direct precipitation and seepage from the WRDs.

In addition, two pit lake water quality predictions are provided, one assuming that seepage from PAF WRDs are consistent with data from Humidity Cell Testing (HCT) and the second assuming that seepage from the PAF waste rock materials are consistent with data from Net Acid Generation testing (NAG data). Although it is common practice to use HCT data for calculating seepage water quality from sulphide waste rock, it is the opinion of SRK that the Hannukainen HCT tests have not fully matured and therefore are not representative of long term leachate generation from materials within the PAF dumps. Therefore, it is suggested that predictions based on HCT data might under-predict actual WRD runoff quality. In this instance, in order that the range of potential chemistries can be predicted, SRK has also use NAG data (which uses an aggressive hydrogen peroxide leach) to predict an upper boundary leach data. Therefore, two scenarios are presented; one with NAG data potentially over-predicting actual WRD seepage quality and one with HCT data likely under-predicting WRD seepage quality. Hence, water quality predictions based on these two model inputs are considered in the subsequent tables to provide bounds for likely river water quality; the actual WRD runoff quality is expected to lie somewhere between these two data sets.

Water quality predictions for initial spill conditions in the Hannukainen and Kuervitikko pit lakes are shown Table 9-49 and Table 9-51 respectively, and for steady state conditions in Table 9-50 and Table 9-52. Analysis has been made against the respective AV for the receiving watercourse for each respective pit lake. TV are not considered as these are specific to the receiving water course only and do not represent potential for negative impacts in the future pit lakes. The impacts to the receiving water courses are discussed in more detail in Sections 9.1 and 9.2. Water quality impacts for key parameters in the pit lakes are discussed below.

Hannukainen Pit Lake: No mitigation

There is potential for exceedences of the AVs derived from sample site FS09 (sited on the Äkäsjoki River) during initial overtopping for key parameters i.e. iron, aluminium, cadmium, chromium, cobalt, copper and nickel. Water quality predictions made using HCT data show exceedences for only cadmium and chromium. Exceedences of cadmium and chromium have been shown to be potentially related to detection limits available in testwork in the case of cadmium and due to enhanced release of chromium in NAG tests.

Concentrations in the Hannukainen pit lake under steady state conditions are predicted to be of a lower quality than the water quality of the initial over-topping water. This is due to the greater proportion of seepage received from the PAF WRD to the pit lake and the absence of continued inflow of river water with good water quality.

Based on HCT predictions, concentrations of the key parameters sulphate, aluminium, cadmium, chromium, cobalt, mercury, manganese, nickel, zinc and uranium are predicted to exceed the FS09 AVs. Additional exceedences of lead, arsenic and iron are predicted for the NAG seepage models. pH conditions are predicted to be weakly to mildly acidic based on the HCT and NAG data, ranging from 6.1 to 3.5.

Hannukainen Pit Lake: With Mitigation

Addition of limestone to the PAF dumps is predicted to significantly reduce the load to the pit lakes and reduce concentrations of iron, aluminium, cobalt, copper, and nickel during initial overtopping, however, concentrations are still predicted to exceed the FS09 AVs based on initial NAG data.

Addition of limestone to the PAF WRDs is predicted to cause a marked improvement to the Hannukainen pit lake water quality under steady state conditions. Concentrations of iron, aluminium, arsenic, manganese and lead are predicted to be reduced to levels below the FS09 AVs, whilst significant reduction in concentrations of cobalt, nickel, copper, nickel, lead and zinc are predicted.

Calculations indicate that approximately 13 Mt of limestone is required to neutralise the PAF WRDs.

Kuervitikko Pit Lake: No Mitigation

Water quality of the Kuervitikko pit lake has been compared to AVs determined for sample site FS40 (sited on Kuerjoki River). Under initial overtopping conditions water quality of the Kuervitikko pit lake shows exceedences for cadmium, chromium and mercury in the HCT prediction, and additional exceedences of sulphate, iron, aluminium, cobalt, copper, nickel and zinc in the NAG prediction.

No exceedences of FS40 AVs for key parameters are predicted for the Kuervitikko pit lake under steady state conditions for all predicted scenarios.

Kuervitikko Pit Lake: With Mitigation

Addition of lime to neutralise the initial pit overtopping significantly improves water quality of the Kuervitikko pit lake by reducing concentrations of iron, aluminium, chromium, copper, mercury and zinc below FS40 AVs. Additional reduction in concentrations of sulphate, cadmium, and nickel is predicted in the case of limestone addition at source.

Table 9-49: Predicted water quality for initial overtopping water from the Hannukainen pit lake

Parameter	Unit	AV - FS09	HCT*	NAG*	NAG - $CaCO_3$ added to WRD
Key Parameters					
Nitrate	mg/L	20	0.487	0.488	0.488
Chloride	mg/L	150	2.27	1.74	1.73
Sulphate	mg/L	65	31	41.6	37.1
Iron	mg/L	0.975	0.295	2.98	0.489
Aluminium	mg/L	0.1	0.0109	0.206	0.115
Arsenic	mg/L	0.005	0.000612	0.00051	0.000508
Cadmium	mg/L	0.00008	0.000124	0.000114	0.000095
Cobalt	mg/L	0.004	0.00129	0.0187	0.00453
Chromium	mg/L	0.001	0.00404	0.0035	0.00347
Copper	mg/L	0.005	0.00213	0.162	0.0116
Mercury	mg/L	0.00005	0.0000438	3.32E-05	0.0000298
Manganese	mg/L	0.7	0.0974	0.0826	0.0503
Molybdenum	mg/L	1	0.00287	0.00139	0.00137
Nickel	mg/L	0.02	0.00353	0.0213	0.00349
Lead	mg/L	0.0072	0.000417	0.000549	0.00042
Zinc	mg/L	0.03	0.00873	0.0136	0.00678
Uranium	mg/L	0.015	0.00594	0.00496	0.00495
Other Parameters					
pH	s.u.	6.5	6.08	4.57	5.18
Phosphate	mg/L	0.01926	0.0533	0.0531	0.052
Calcium	mg/L	6.542	15.7	11.4	11.6
Potassium	mg/L	0.888	5.47	3.21	3.43
Magnesium	mg/L	1.808	2.71	2.83	2.7
Sodium	mg/L	2.794	5.46	4.72	4.71
Silicon	mg/L	9.62	2.39	2.91	2.92
Barium	mg/L	0.01792	0.0129	0.012	0.012
Strontium	mg/L	0.03014	0.0679	0.0493	0.0493
Antimony	mg/L	0.00002802	0.00311	0.000182	0.000182
Additional Parameters					
Alkalinity	mg/L		5.15	-1.59	0.344
Fluorine	mg/L		0.0481	0.123	0.0525
Silver	mg/L		0.000619	0.000176	0.000169
Boron	mg/L		0.0133	0.0121	0.0121
Lithium	mg/L		0.025	0.00426	0.00425
Selenium	mg/L		0.000541	0.000761	0.000262
Tin	mg/L		0.000112	0.000172	0.000172
Thallium	mg/L		0.00626	0.000186	0.000186
Vanadium	mg/L		0.0125	0.00947	0.00893

Note; Values shaded orange are in excess of AVs.
**HCT = Based on humidity cell test analysis, NAG = Based on net-acid generation test analysis*

Table 9-50: Predicted water quality for initial overtopping water from the Kuervitikko pit lake

Parameter	Unit	AV - FS40	HCT*	NAG*	NAG - Lime added to pit lake	NAG - $CaCO_3$ added to WRD
Key Parameters						
Nitrate	mg/L	20	0.207	0.199	0.199	0.199
Chloride	mg/L	150	3.93	2.37	2.36	2.36
Sulphate	mg/L	65	30.8	76.6	76.3	57.3
Iron	mg/L	0.72	0.364	11.3	0.223	0.727
Aluminium	mg/L	0.1	0.074	0.61	0.0027	0.23
Arsenic	mg/L	0.005	0.00106	0.000622	0.000000257	0.000616
Cadmium	mg/L	0.00008	0.000178	0.000142	0.000136	0.0000604
Cobalt	mg/L	0.004	0.00367	0.071	0.0696	0.0132
Chromium	mg/L	0.001	0.00792	0.00603	0.000000566	0.00587
Copper	mg/L	0.005	0.00297	0.653	0.0165	0.0212
Mercury	mg/L	0.00005	0.000084	5.72E-05	0.0000397	0.0000429
Manganese	mg/L	0.7	0.256	0.198	0.196	0.0755
Molybdenum	mg/L	1	0.0079	0.00237	0.002	0.00228
Nickel	mg/L	0.02	0.0111	0.0837	0.0783	0.0071
Lead	mg/L	0.0072	0.000249	0.000804	0.00000425	0.0002
Zinc	mg/L	0.03	0.0158	0.0359	0.0288	0.00718
Uranium	mg/L	0.015	0.00646	0.00906	0.00905	0.00901
Other Parameters						
pH	s.u.	6.5	5.66	3.86	7	4.44
Phosphate	mg/L	0.017	0.116	0.118	0.00282	0.114
Calcium	mg/L	4.8	25.4	12.1	36.7	12.6
Potassium	mg/L	0.82	16.4	8.17	8.17	9.08
Magnesium	mg/L	1.4	4.29	5.24	5.23	4.7
Sodium	mg/L	2.5	10.7	8.74	8.73	8.72
Silicon	mg/L	10	2.93	4.06	4.05	4.06
Barium	mg/L	0.01	0.0119	0.00973	0.00973	0.00973
Strontium	mg/L	0.03	0.114	0.0478	0.0478	0.0476
Antimony	mg/L	0.000014	0.012	0.000394	0.000394	0.000393
Additional Parameters						
Alkalinity	mg/L		1.9	-9.34	43.7	-2.27
Fluorine	mg/L		0.102	0.409	0.409	0.116
Silver	mg/L		0.00198	0.00039	0.00039	0.000361
Boron	mg/L		0.0305	0.0273	0.0273	0.0272
Lithium	mg/L		0.0722	0.0117	0.0117	0.0117
Selenium	mg/L		0.00179	0.0027	0.000375	0.000499
Tin	mg/L		0.000206	0.00038	0.00038	0.000379
Thallium	mg/L		0.0189	0.00044	0.00044	0.000439
Vanadium	mg/L		0.0301	0.0186	0.0000799	0.0162

Note; Values shaded orange are in excess of AVs.
**HCT = Based on humidity cell test analysis, NAG = Based on net-acid generation test analysis*

Table 9-51: Predicted water quality for Steady State Overtopping from the Hannukainen pit lake

Parameter	Unit	AV - FS09	HCT*	NAG*	NAG - $CaCO_3$ added to WRD
Key Parameters					
Nitrate	mg/L	20	3.12	3.29	3.24
Chloride	mg/L	150	77.5	37.3	36.3
Sulphate	mg/L	65	264	1880	878
Iron	mg/L	0.975	0.409	180	0.332
Aluminium	mg/L	0.1	0.102	65.6	0.0445
Arsenic	mg/L	0.005	0.00361	0.00818	0.00344
Cadmium	mg/L	0.00008	0.00179	0.00321	0.000959
Cobalt	mg/L	0.004	0.068	1.86	0.11
Chromium	mg/L	0.001	0.0808	0.131	0.0767
Copper	mg/L	0.005	0.0114	18.8	0.0103
Mercury	mg/L	0.00005	0.00212	0.00113	0.000754
Manganese	mg/L	0.7	5.27	4.71	0.405
Molybdenum	mg/L	1	0.0419	0.0479	0.0341
Nickel	mg/L	0.02	0.0497	2.15	0.0292
Lead	mg/L	0.0072	0.00134	0.0466	0.00104
Zinc	mg/L	0.03	0.0703	0.85	0.0633
Uranium	mg/L	0.015	0.321	0.278	0.271
Other Parameters					
pH	s.u.	6.5	6.06	3.47	6.31
Phosphate	mg/L	0.01926	0.391	2.28	0.468
Calcium	mg/L	6.542	396	88.6	91.9
Potassium	mg/L	0.888	435	247	230
Magnesium	mg/L	1.808	84.6	106	34.1
Sodium	mg/L	2.794	175	112	107
Silicon	mg/L	9.62	5.46	5.45	5.52
Barium	mg/L	0.01792	0.0167	0.00235	0.00304
Strontium	mg/L	0.03014	2.74	0.661	0.722
Antimony	mg/L	2.8E-05	0.243	0.00733	0.00997
Additional Parameters					
Alkalinity	mg/L		6	-54.7	9.95
Fluorine	mg/L		0.779	9.94	1.06
Silver	mg/L		0.0516	0.00972	0.00796
Boron	mg/L		0.803	0.724	0.694
Lithium	mg/L		2.2	0.304	0.284
Selenium	mg/L		0.00483	0.0892	0.00498
Tin	mg/L		0.00435	0.01	0.00979
Thallium	mg/L		0.577	0.0116	0.0111
Vanadium	mg/L		0.24	0.304	0.24

Note; Values shaded orange are in excess of AVs.
**HCT = Based on humidity cell test analysis, NAG = Based on net-acid generation test analysis*

Table 9-52: Predicted water quality for Steady State Overtopping from the Kuervitikko pit lake

Parameter	Unit	AV - FS40	HCT*	NAG*	NAG - $CaCO_3$ added to WRD
Key Parameters					
Nitrate	mg/L	20	0.0911	0.0911	0.0911
Chloride	mg/L	150	2.06	2.06	2.06
Sulphate	mg/L	65	3.71	3.71	3.71
Iron	mg/L	0.72	0.23	0.23	0.23
Aluminium	mg/L	0.1	0.00598	0.00597	0.00598
Arsenic	mg/L	0.005	0.000737	0.000737	0.000737
Cadmium	mg/L	0.00008	1.56E-05	1.56E-05	0.0000156
Cobalt	mg/L	0.004	0.000207	0.000207	0.000207
Chromium	mg/L	0.001	0.000455	0.000455	0.000455
Copper	mg/L	0.005	0.000897	0.000895	0.000897
Mercury	mg/L	0.00005			
Manganese	mg/L	0.7	0.0397	0.0397	0.0397
Molybdenum	mg/L	1	0.00175	0.00175	0.00175
Nickel	mg/L	0.02	0.000764	0.000763	0.000764
Lead	mg/L	0.0072	0.00013	0.00013	0.00013
Zinc	mg/L	0.03	0.00345	0.00345	0.00345
Uranium	mg/L	0.015	0.000148	0.000148	0.000148
Other Parameters					
pH	s.u.	6.5	6.27	6.27	6.27
Phosphate	mg/L	0.017	0.0827	0.0828	0.0827
Calcium	mg/L	4.8	3.93	3.93	3.93
Potassium	mg/L	0.82	0.973	0.974	0.973
Magnesium	mg/L	1.4	1.56	1.56	1.56
Sodium	mg/L	2.5	6.86	6.85	6.86
Silicon	mg/L	10	2.06	2.06	2.06
Barium	mg/L	0.01	0.00582	0.00582	0.00582
Strontium	mg/L	0.03	0.0191	0.0191	0.0191
Antimony	mg/L	0.000014			
Additional Parameters					
Alkalinity	mg/L		7.86	7.87	7.86

Note; Values shaded orange are in excess of AVs.
**HCT = Based on humidity cell test analysis, NAG = Based on net-acid generation test analysis*

The development of the closure plan for the Hannukainen and Kuervitikko pit lakes is on-going. Artificial flooding has been investigated during the Phase 2 study and a conservative approach has been taken to pit lake water quality prediction, which assumes that the lakes will be fully mixed.

However, due to the large depth of the Hannukainen and Kuervitikko pits relative to pit lake area (11.4 and 12.3% respectively[10]) it is highly likely that both pit lakes will be meromictic and will not experience complete seasonal turnover. This is characteristic of the existing pit lakes at Hannukainen which show strong stratification and in which no turnover was recorded. Therefore, the next phase of geochemical prediction could consider the effect of chemical stratification.

[10] *Relative depth* $= 50 z_m \sqrt{\pi} / \sqrt{A_0}$ *where* A_o *is the final pit lake area and* z_m *is the pit lake depth (Doyle and Runnels (1997))*

9.8 Rautuvaara Clarification Ponds

Operational and Post Closure Phase: Impact of tailings deposition on water quality

The water quality of the two clarification ponds at the Rautuvaara tailings site (North Pond and South Pond) during LOM and following closure of the Hannukainen mine site have been predicted using the methodology described in Section 8.1.3. The predicted water quality in the South Ponds are given in Table 9-53 and Table 9-54 and the predicted water quality with the North pond are given in Table 9-55 and Table 9-56 for winter and spring (May/June) scenarios respectively.

LOM model predictions have been made for Year 5, 10 and 18 (Year 19 being end of mine life (EOML)) scenarios. Post closure predictions are based on the High-S tailings facility liner integrity (Figure 7-2). It is planned that the High-S tailings will be underlined with a low permeability HDPE liner and, following closure, will be capped with a low permeability low-density polyethylene (LDPE) cover. Therefore it is expected that seepage from the High-S tailings facility will effectively be eliminated.

However, it is indicated in the tailings characterisation report (Erikson, 2012) that, over the long term, the integrity of the liner material will degrade resulting in some seepage from the High-S material being released to the Niesajoki Catchment. As the extent to which the liner system will degrade cannot be fully quantified, a series of models were run taking into account variation in seepage load post closure from 0%, 10%, 50% and 100% from the potential load predicted in Erikson (2012). During LOM, it is expected that the integrity of the containment system will result in zero untreated discharge from the High-S tailings.

The predicted water quality in the South Pond is given in Table 9-53 and Table 9-54. It is evident that concentrations of the following elements are predicted to exceed the AV for FS23 (sited on the Muonionjoki just upstream of the confluence with the Niesajoki) in both the winter and spring scenarios:

Current conditions: sulphate, arsenic, cadmium, cobalt and chromium

End of Mine Life: sulphate, cadmium, cobalt, copper, mercury, nickel and zinc

Post closure: sulphate, cadmium, cobalt, copper, mercury, manganese, nickel, uranium and zinc

It should be noted that predicted exceedences of cadmium and mercury are potential artefacts of detection limit issues in the models.

As shown in the tailings characterisation report (Erikson, 2012) the load from the LIMS tailings is predicted to increase post closure due to drain-down (leading to the upper portion of the tailings pile becoming unsaturated) and a greater mass of unsaturated tailings being exposed to weathering. This is predicted to result in concentrations of key elements increasing significantly. In particular, uranium and molybdenum (both principally sourced from the LIMS tailings) are predicted to show a 10 fold concentration increase following post closure as compared to EOML conditions. However, only uranium is predicted to exceed the FS23 AV. The effect of liner degradation of the High-S tailings facility post closure results in a clear increase in concentrations of cobalt, copper and nickel within the South Pond.

The model results show that, as expected, emplacement of the Hannukainen LIMS and High-S tailings at the Rautuvaara site will result in an increase in the majority of key parameters in respect to current conditions and is predicted to be the case at all modelled stages of mine development (Years 5, 10 and 18 and post closure). Exceptions to the general increase in concentrations of key parameters are arsenic and lead resulting from saturation of the historic tailings (key source of arsenic and lead release) and therefore a reduced weathering rate from this material.

It should be noted that concentrations of aluminium and iron are predicted to be lower in the LOM and post closure scenarios than in the current ponds but is a likely to be a response to equilibration with respect to iron oxide and aluminium oxide minerals in the models. It is expected that actual concentrations of iron and aluminium are likely to be closer to the current pond water quality due to binding with organic acids (note: organic acid binding cannot be accounted for in the current model).

Pore water from the tailings will seep into the underlying groundwater system and migrate southwards along regional groundwater path, described previously in Section 9.4. It is likely that significant natural attenuation of copper and other key elements released from the High-S tailings will occur along the groundwater flow path. This is likely to be significantly enhanced when the seepage contacts peat material that may underline the High-S cell which is known to have a high capacity to attenuate metals such as copper, cobalt, nickel and uranium. This has been demonstrated in attenuation testing undertaken by SRK (SRK, 2012c) and in analysis of peat material receiving seepage from the current tailings facility has been shown to be enriched in elements discharged from the tailings indicating attenuation is taking place (Närhi et al, 2012). The effect of attenuation of source term concentrations other than mineral equilibration is outside the scope of the current HIA predictions and therefore the water quality predicted here may be seen as conservative in this respect.

Predicted water quality within the North Pond during LOM and post closure conditions are shown in Table 9-55 for winter conditions and Table 9-56 for spring conditions respectively. In the case of the North Pond, comparison is not made to guidelines and has been based on comparison to current conditions.

A general improvement to the water quality within the North Pond is predicted during LOM operation, this is due to the changes in localized groundwater flow regime, described in Section 9.4, which predict that seepage from the existing WRD and TMF will migrate southwards during LOM rather than towards the North Pond. It is conservatively predicted that 10% of the LIMs tailings load and 30% of the High-S tailings loads will migrate to the North Pond therefore, post closure concentrations within the pond are predicted to decrease in comparison to EOML and current water quality. As with the South Pond water quality, concentrations of elements sulphate, cobalt, copper, nickel and zinc are predicted to increase with increasing High-S tailings load release.

Table 9-53: Average predicted water quality in the South Pond during winter conditions

Parameter	Unit	AV - FS23	South Pond - Winter Conditions							
			Current Mean	Operational Mining			Post Closure			
				Year 5	Year 10	18 Years	No High S	10% High S	50% High S	100% High S
Key Parameters										
pH	S.U.		7.15	6.92	6.9	6.91	6.35	6.26	5.93	5.36
Nitrate	mg/l	20	0.332	3.447	2.778	1.556	0.13	0.13	0.13	0.13
Chloride	mg/l	150	1.65	0.575	0.682	0.347	1.88	1.88	1.88	1.88
Sulphate	mg/l	65	90.6	208	197	123	469	472	482	494
Iron	mg/l	1.9	0.842	0.00376	0.00399	0.00374	0.0113	0.0147	0.0417	0.772
Aluminium	mg/l	0.1	0.0236	0.0027	0.00275	0.0027	0.00505	0.00491	0.00569	0.022
Arsenic	mg/l	0.005	0.00521	4.44E-05	3.47E-05	1.65E-05	0.00161	0.00196	0.005	0.00582
Cadmium^	mg/l	0.00008	0.000254	9.78E-05	9.96E-05	7.76E-05	0.00111	0.00121	0.00165	0.0022
Cobalt	mg/l	0.004	0.00578	0.0607	0.0631	0.0528	0.0263	0.0368	0.0784	0.131
Chromium	mg/l	0.001	0.00117	1.93E-05	1.76E-05	1.67E-05	2.28E-06	0.0000159	0.0000749	0.000168
Copper	mg/l	0.005	0.00361	0.04	0.042	0.0381	0.0135	0.247	1.957	4.726
Mercury^	mg/l	0.00005	0.0000342	5.76E-05	6.08E-05	8.65E-05	0.00108	0.0012	0.00163	0.00217
Manganese	mg/l	0.7	0.281	0.32	0.315	0.234	0.829	0.83	0.841	0.847
Molybdenum	mg/l	1	0.000489	0.0184	0.015	0.00918	0.0629	0.063	0.0637	0.0639
Nickel	mg/l	0.02	0.0133	0.0693	0.0704	0.0508	0.0461	0.0559	0.0945	0.143
Lead	mg/l	0.0072	0.00115	0.000363	0.000363	0.000253	0.0000648	0.000344	0.000897	0.00116
Uranium	mg/l	0.015	0.00125	0.0148	0.0143	0.00928	0.958	0.957	0.957	0.957
Zinc	mg/l	0.03	0.00897	0.198	0.182	0.0994	0.564	0.573	0.587	0.602
Other Parameters										
Phosphate	mg/l	0.017	0.0263	0.144	0.121	0.0665	1.038	1.207	3.04	4.46
Calcium	mg/l	8.9	29.2	43.3	42.1	26.4	334	334	336	337
Potassium	mg/l	1.9	2.85	18.4	16.9	11	137	138	137	137
Magnesium	mg/l	2.4	12.3	9.99	9.24	6.12	41.3	41.3	41.3	41.5
Sodium	mg/l	3.4	4.43	19.3	17.6	13	28.6	28.5	28.5	28.6
Silicon	mg/l	10	3.72	0.887	0.794	0.41	2.89	2.89	2.89	2.88
Barium	mg/l	0.015	0.0151	0.019	0.0162	0.00854	0.0071	0.00707	0.00695	0.00682
Strontium	mg/l	0.043	0.0416	0.0287	0.0257	0.0131	1.029	1.025	1.025	1.028
Antimony	mg/l	0.00015	0.000891	0.00102	0.000924	0.000644	1.61E-06	1.61E-06	1.61E-06	0.0000016
Additional Parameters										
Alkalinity	mg/L as HCO_3		45.87	28.7	27.4	27.4	9.12	7.38	3.82	1.13
Fluoride	mg/l			0.00861	0.0077	0.00388	0.0285	0.0285	0.0285	0.0285
Silver*	mg/l			9.72E-08	8.69E-08	4.38E-08	3.22E-07	3.21E-07	3.21E-07	3.21E-07
Selenium*	mg/l			2.79E-06	2.50E-06	1.26E-06	8.39E-06	8.61E-06	9.16E-06	9.29E-06
Thorium*	mg/l						5.54E-05	5.54E-05	5.54E-05	5.54E-05
Thallium*	mg/l			5.48E-07	4.91E-07	2.47E-07	1.81E-06	1.81E-06	1.81E-06	1.81E-06

* Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only
^ Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent

Table 9-54: Average predicted water quality in the South Pond during summer conditions

Parameter	Unit	AV - FS23	South Pond - Summer Conditions							
			Current Mean	Operational Mining			Post Closure			
				Year 5	Year 10	18 Years	No High S	10% High S	50% High S	100% High S
Key Parameters										
pH	S.U.		7.15	6.85	6.83	6.84	6.59	6.5	6.2	5.88
Nitrate	mg/l	20	0.332	0.713	0.407	0.357	0.165	0.164	0.164	0.164
Chloride	mg/l	150	1.65	0.212	0.13	0.111	3.54	3.54	3.54	3.54
Sulphate	mg/l	65	90.6	263	571	461	490	492	501	511
Iron	mg/l	1.9	0.842	0.00327	0.00398	0.00364	0.00137	0.00169	0.00348	0.00855
Aluminium	mg/l	0.1	0.0236	0.0019	0.00197	0.00193	0.000784	0.000828	0.00129	0.00163
Arsenic	mg/l	0.005	0.00521	0.00026	0.00044	0.00033	0.000303	0.000255	0.00113	0.00521
Cadmium^	mg/l	0.00008	0.000254	0.00242	0.00719	0.00571	0.00112	0.00124	0.00167	0.00222
Cobalt	mg/l	0.004	0.00578	0.025	0.0194	0.0219	0.0279	0.0384	0.0807	0.133
Chromium	mg/l	0.001	0.00117	0.0242	0.0316	0.025	8.28E-06	0.0000516	0.000248	0.000366
Copper	mg/l	0.005	0.00361	0.0618	0.0782	0.0724	0.00716	0.159	1.697	4.052
Mercury^	mg/l	0.00005	0.0000342	0.00063	0.00091	0.00073	0.00104	0.00118	0.00164	0.00219
Manganese	mg/l	0.7	0.281	0.103	0.0731	0.0813	0.876	0.879	0.885	0.896
Molybdenum	mg/l	1	0.000489	0.0126	0.0177	0.0145	0.0631	0.0631	0.0638	0.0646
Nickel	mg/l	0.02	0.0133	0.0526	0.0927	0.0781	0.0496	0.0599	0.0986	0.147
Lead	mg/l	0.0072	0.00115	0.00063	0.00144	0.00116	0.0000442	0.000242	0.000864	0.0011
Uranium	mg/l	0.015	0.00125	0.0219	0.0257	0.0211	0.965	0.964	0.964	0.965
Zinc	mg/l	0.03	0.00897	0.0528	0.0383	0.033	0.557	0.572	0.588	0.603
Other Parameters										
Phosphate	mg/l	0.017	0.0263	0.0332	0.0201	0.0169	0.836	0.874	1.197	2.889
Calcium	mg/l	8.9	29.2	25.8	25.3	22	340	340	341	343
Potassium	mg/l	1.9	2.85	30.5	47.7	38.8	140	140	139	139
Magnesium	mg/l	2.4	12.3	9.16	12.9	10.7	42.9	43	43	43.2
Sodium	mg/l	3.4	4.43	27.1	43.9	36.3	30.7	30.8	30.8	30.7
Silicon	mg/l	10	3.72	0.216	0.135	0.112	3.56	3.56	3.56	3.55
Barium	mg/l	0.015	0.0151	0.00423	0.00254	0.0021	0.0118	0.0117	0.0115	0.0114
Strontium	mg/l	0.043	0.0416	0.00688	0.00431	0.00349	1.054	1.051	1.051	1.053
Antimony	mg/l	0.00015	0.000891	0.00244	0.00385	0.0031	1.61E-06	1.61E-06	1.61E-06	0.0000016
Additional Parameters										
Alkalinity	mg/L as HCO_3		45.87	23.4	22.8	23.3	12.6	10.4	5.54	2.99
Fluoride	mg/l			0.00177	0.00111	0.00088	0.0285	0.0285	0.0285	0.0285
Silver	mg/l			2.00E-08	1.25E-08	9.92E-09	3.22E-07	3.21E-07	3.21E-07	3.21E-07
Selenium	mg/l			5.72E-07	3.58E-07	2.84E-07	7.17E-06	7.34E-06	8.45E-06	9.14E-06
Thorium	mg/l						5.54E-05	5.54E-05	5.54E-05	5.54E-05
Thallium	mg/l			1.13E-07	7.05E-08	5.60E-08	1.81E-06	1.81E-06	1.81E-06	1.81E-06

* Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only
^ Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent

Table 9-55: Average predicted water quality in the North Pond during winter conditions

Parameter	Unit	North Pond - Winter Conditions							
		Current Mean	Operational Mining			Post Closure			
			Year 5	Year 10	18 Years	No High S	10% High S	50% High S	100% High S
Key Parameters									
pH	S.U.	6.89	7.16	7.11	7.68	7.11	7.07	6.99	6.88
Nitrate	mg/l	1.181	5.09	1.91	8.37	0.203	0.203	0.203	0.203
Chloride	mg/l	4.44	1.82	1.82	1.08	1.17	1.18	1.17	1.17
Sulphate	mg/l	131	50.1	47.2	160	271	272	278	286
Iron	mg/l	0.616	0.00167	0.00191	0.000496	0.00218	0.00243	0.00309	0.00465
Aluminium	mg/l	0.0257	0.0023	0.00236	0.00228	0.00242	0.00247	0.00259	0.00284
Arsenic	mg/l	0.000889	0.0000488	0.0000733	7.49E-05	0.0000335	0.0000127	0.000011	0.0000141
Cadmium^	mg/l	0.00029	0.0000151	0.0000129	2.77E-05	0.000675	0.000759	0.00103	0.00137
Cobalt	mg/l	0.0111	0.00576	0.00296	0.00434	0.00645	0.0131	0.0394	0.0722
Chromium	mg/l	0.000941	3.13E-06	7.18E-06	1.41E-05	2.82E-07	2.09E-06	1.59E-06	0.00000168
Copper	mg/l	0.00519	0.0187	0.0204	0.0117	0.00064	0.027	0.0336	0.0492
Mercury^	mg/l	0.0000451	3.21E-06	1.07E-06	1.84E-05	0.000688	0.000756	0.00103	0.00137
Manganese	mg/l	1.003	0.196	0.195	0.151	0.401	0.404	0.408	0.414
Molybdenum	mg/l	0.0000516	0.00117	0.000784	0.0332	0.0398	0.0395	0.0393	0.0393
Nickel	mg/l	0.00963	0.00728	0.0046	0.0103	0.0132	0.0197	0.0437	0.0738
Lead	mg/l	0.00128	0.000145	0.000278	0.000255	0.00000897	0.0000566	0.00004	0.0000385
Uranium	mg/l	0.000176	0.000196	0.000175	0.00916	0.606	0.605	0.605	0.605
Zinc	mg/l	0.0137	0.00791	0.00713	0.0089	0.0157	0.0192	0.0263	0.0355
Other Parameters									
Phosphate	mg/l	0.0278	0.271	0.29	0.378	0.255	0.327	0.436	0.51
Calcium	mg/l	35.9	17.5	17.2	29.4	206	206	206	206
Potassium	mg/l	4.33	2.82	2.52	19.2	87.6	87.6	87.6	87.4
Magnesium	mg/l	15.9	6.03	5.95	10.3	25	25	25	25.2
Sodium	mg/l	6.82	10	9.79	25.7	21	21	20.9	20.9
Silicon	mg/l	2.28	4.52	4.52	2.67	2.9	2.89	2.89	2.9
Barium	mg/l	0.015	0.0352	0.0349	0.0369	0.00942	0.00937	0.00915	0.00889
Strontium	mg/l	0.0847	0.0832	0.0832	0.0492	0.645	0.645	0.645	0.644
Antimony	mg/l	0.000873	0.0000321	0.0000107	0.00113				
Additional Parameters									
Alkalinity	mg/L as HCO_3	20.92	49	43.5	168	47.3	43.4	36.5	28.2

^ Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent

Table 9-56: Average predicted water quality in the North Pond during summer conditions

Parameter	Unit	North Pond - Summer Conditions							
		Current Mean	Operational Mining			Post Closure			
			Year 5	Year 10	18 Years	No High S	10% High S	50% High S	100% High S
Key Parameters									
pH	S.U.	6.89	7.27	7.25	7.67	7.4	7.39	7.35	7.29
Nitrate	mg/l	1.181	3.813	1.544	6.696	0.369	0.369	0.369	0.368
Chloride	mg/l	4.44	9.76	9.76	6.39	8.82	8.8	8.8	8.8
Sulphate	mg/l	131	47.4	45.3	134	281	282	289	297
Iron	mg/l	0.616	0.000888	0.000949	0.000361	0.000225	0.00023	0.000254	0.00029
Aluminium	mg/l	0.0257	0.00158	0.00158	0.00186	0.00172	0.00169	0.00156	0.0014
Arsenic	mg/l	0.000889	0.0000832	0.000127	8.32E-05	0.0000121	0.0000031	2.23E-06	0.00000189
Cadmium^	mg/l	0.00029	0.0000182	0.0000166	2.66E-05	0.000666	0.00076	0.00102	0.00135
Cobalt	mg/l	0.0111	0.00487	0.00288	0.00392	0.00706	0.0137	0.0398	0.0723
Chromium	mg/l	0.000941	6.92E-06	0.00000733	1.62E-05	3.77E-06	0.0000215	0.000014	0.0000112
Copper	mg/l	0.00519	0.0187	0.0105	0.014	0.000787	0.0343	0.0362	0.0397
Mercury^	mg/l	0.0000451	2.29E-06	7.62E-07	1.45E-05	0.000688	0.000756	0.00103	0.00137
Manganese	mg/l	1.003	0.233	0.232	0.18	0.482	0.487	0.491	0.496
Molybdenum	mg/l	0.0000516	0.00124	0.000959	0.0265	0.0402	0.0397	0.0393	0.0388
Nickel	mg/l	0.00963	0.00698	0.00509	0.00933	0.0143	0.021	0.0444	0.0733
Lead	mg/l	0.00128	0.000211	0.000215	0.000292	0.0000165	0.0000821	0.0000503	0.000037
Uranium	mg/l	0.000176	0.000237	0.000221	0.00731	0.606	0.605	0.605	0.605
Zinc	mg/l	0.0137	0.00975	0.00916	0.00955	0.017	0.0219	0.028	0.0357
Other Parameters									
Phosphate	mg/l	0.0278	0.403	0.418	0.439	0.00567	0.00604	0.00829	0.0145
Calcium	mg/l	35.9	18.8	18.6	27.3	211	211	211	211
Potassium	mg/l	4.33	3.66	3.46	16.3	89	89.1	89.1	88.9
Magnesium	mg/l	15.9	6.93	6.85	9.87	27.3	27.5	27.5	27.5
Sodium	mg/l	6.82	17	16.8	26.7	29.8	29.9	29.9	29.8
Silicon	mg/l	2.28	6.03	6.03	3.96	5.45	5.45	5.45	5.44
Barium	mg/l	0.015	0.0405	0.0405	0.0394	0.0158	0.0158	0.0154	0.015
Strontium	mg/l	0.0847	0.0894	0.0894	0.0584	0.671	0.671	0.671	0.671
Antimony	mg/l	0.000873	0.0000229	0.00000762	0.000895				
Additional Parameters									
Alkalinity	mg/L as HCO_3	20.92	60.7	56.7	156	76.9	75	68.3	59.2

^ Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent

9.9 Wetlands and Springs

The primary source of impact to wetlands and springs at Hannukainen is drawdown of the groundwater levels due to pit dewatering and burial of such features beneath project infrastructure.

9.9.1 Extent of Pit Dewatering

Figure 9-11 shows drawdown around the pits predicted by the numerical groundwater model at LOM. The influence of the pits is clearly visible. The cone of depression is relatively steep; individual sumps in theor sub-pits can be identified indicating that the groundwater surface closely follows the contour of pits.

The limit of drawdown is defined as the point beyond which drawdown is less than or equal to the minimal seasonal variation in groundwater level observed at Hannukainen. During Phase 1 this was defined as 0.33m (recorded at SP-314). However, more data is available for this Phase 2 study and it has been observed that 75% of the boreholes where multiple groundwater level records are available have a seasonal variation of less than 2 m (Section 6.4). Therefore the limit of drawdown has been refined from 0.33 m to 2 m to reflect the new data available.

The maximum extent of the cone of depression at LOM from the pit edge is approximately 2,000 m at Hannukainen and 1,600 m at Kuervitikko.

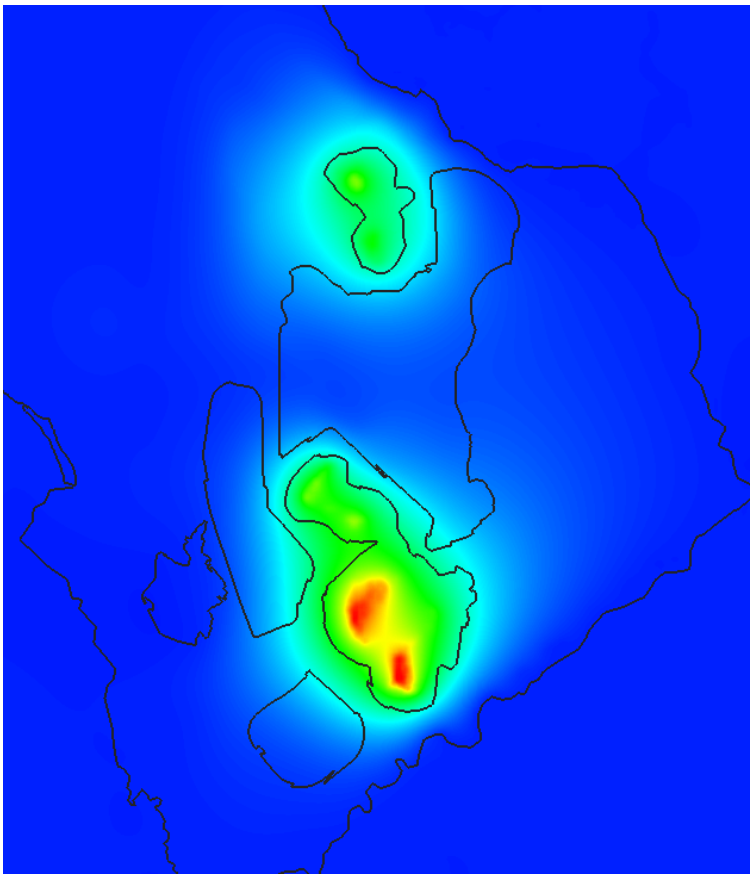
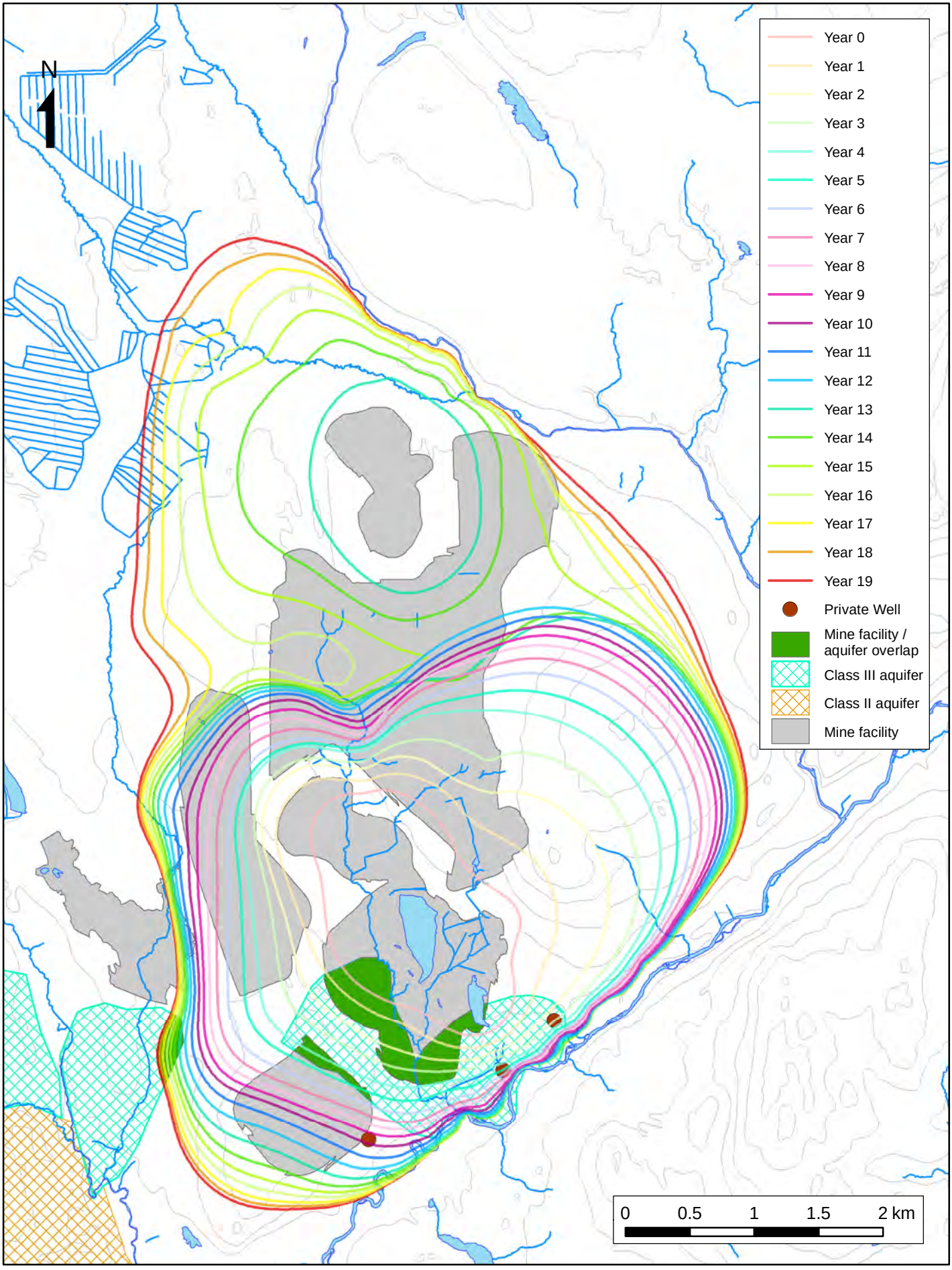


Figure 9-11: Predicted drawdown around the Hannukainen and Kuervitikko pits at life of mine

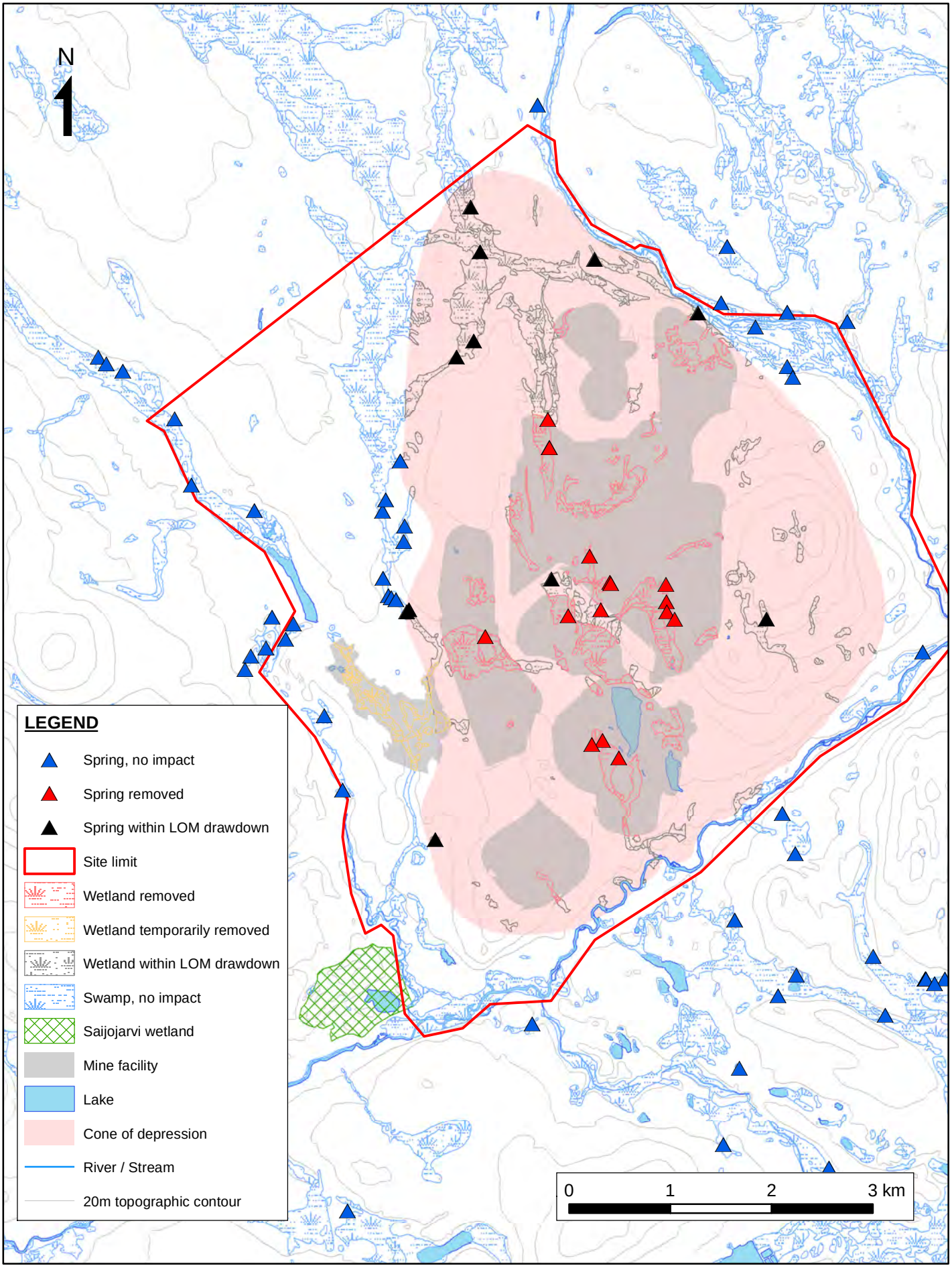
Figure 9-12 shows the annual progression of the cone of depression at the Hannukainen site in response to mining operations and shows that:

- The cone of depression is evident from Year 0 onwards (i.e. second year of pre-stripping). Drawdown around Hannukainen pit progresses east, west and north during operational mining, eventually merging with the cone of depression caused by Kuervitikko pit in Year 15. The Hannukainen cone of depression is limited in the south by the Äkäsjoki river; and
- Drawdown around Kuervitikko pit begins in Year 13 when the pit comes online. The Kuervitikko cone of depression expands to the north and southwest during the life of the mine. It is limited to the northeast by the Kuerjoki River.



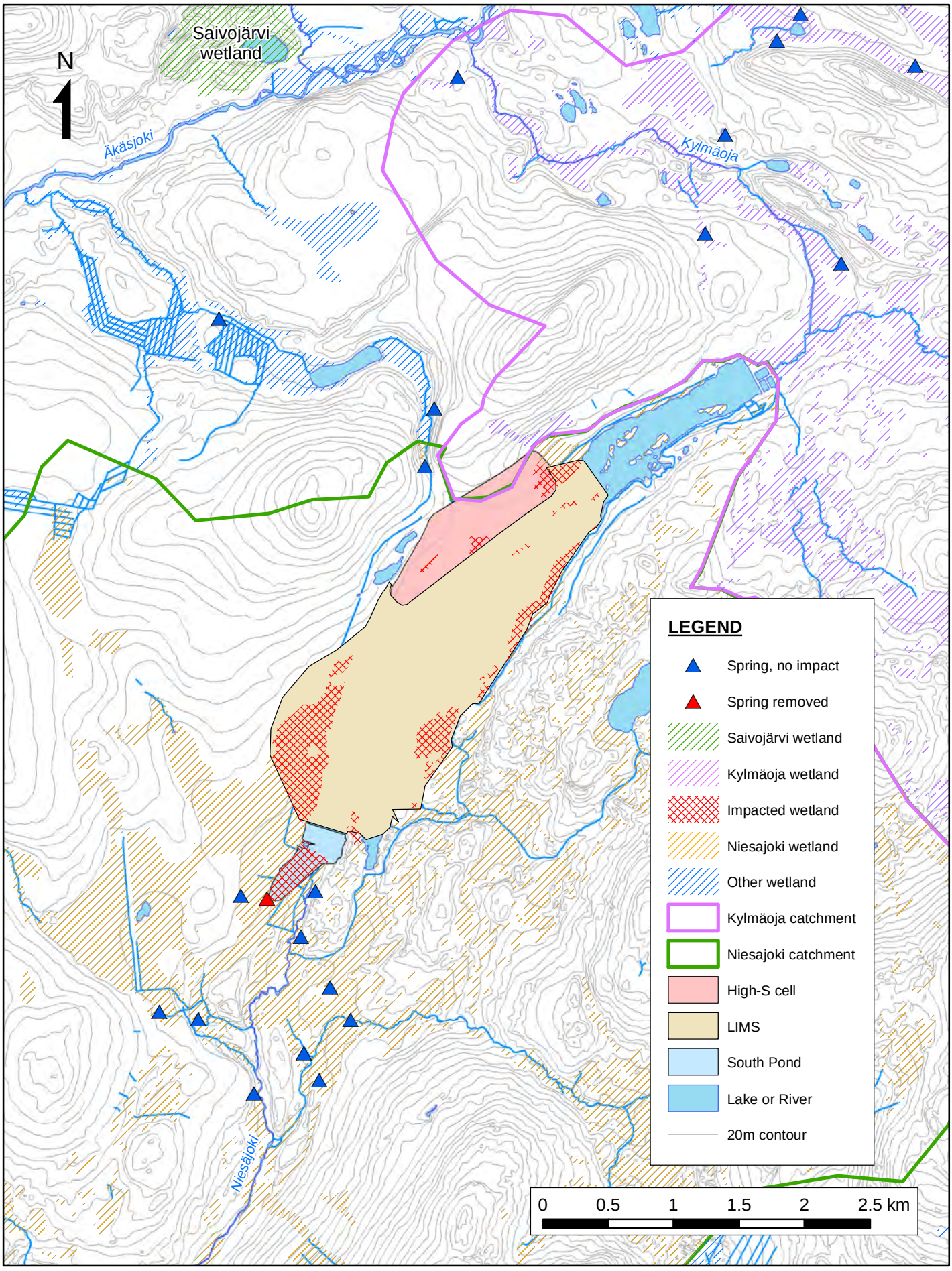
JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Cone of Depression Development and Impact on Groundwater Receptors	Figure 9.12

P:\U4518 Hannukainen HIA\Project\CAD\Drawdown progression_PH2.mxd



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Impact of Mining on Wetlands and Springs	Figure 9.13

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JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Impact of the Rautuvaara TMF on Springs and Wetlands	Figure 9.14

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9.9.2 Springs

The impact of mining on springs in the Hannukainen and Rautuvaara areas is show in Figure 9-13 and Figure 9-14 respectively, and is summarised in Table 9-57.

Table 9-57: Predicted Impact on Hannukainen Springs at LOM

Description of spring	Number of springs
Identified in Ramboll data	106
Within the Hannukainen mine site (defined in Figure 9-13)	63
Within LOM drawdown area	27
Affected by LOM drawdown only	11
Within LOM drawdown and pit footprint	12
Within LOM drawdown and within 20 m of WRD	4
Beneath LOM TMF	1

Operational mining: Pit dewatering

The total number of springs identified in the Hannukainen area is 63 (M. Heikkinen (Ramboll), pers. comm.), of which 27 are located within the LOM cone of depression. Of these 27 springs, 16 will be permanently removed due to mine infrastructure (WRD, pits).

Table 9-57 shows that springs on the Valkeajoki and Kuerjoki are located beyond the LOM cone of depression. Numerical groundwater modelling shows that groundwater continues to enter these rivers as baseflow and therefore these springs are not impacted by the pit dewatering during operational mining. There is a theory (Prof. Salonen, University of Helsinki, pers. comm.) that these springs may be spawning grounds for the fish and therefore it is potentially highly significant that these springs in the rivers will not be impacted by mining operations.

The impact of losing these springs on river flow has been included in the surface water catchment modelling during the assessment of changes to surface runoff to the Äkäsjoki and tributaries due to changes to the natural drainage patterns as a result of the mine footprint (described in Section 8.1.2). While the hydrological effects of springs have been considered, there are additional features that have not been considered in this HIA; for example springs may provide temperature effects on spawning eggs (warmer) or might provide some nutrients or oxygen. Assessment of the potential impact to river ecology was not within the scope of this study; the principle receptor for the purpose of this HIA is the surface water environment. The significance of any changes to river water quantity or quality on river ecology will be addressed by the ESIA studies.

Operational mining: TMF expansion

Table 9-57 shows that the extension of the South Pond will result in the loss of one groundwater spring. There is potential for impact on a second spring located approximately 110 m from the proposed water retention dam.

9.9.3 Non-classified wetland areas

Figure 9-13, Figure 9-14 and Table 9-58 summarise the potential impact on the non-classified wetland areas throughout the project site.

Table 9-58: Predicted Impact on Wetlands at LOM

Region	Area (m^2)	Area (% total)	Area (% swamp)
Area of Hannukainen site	40,045,430		
Total wetland area in Hannukainen site	6,430,690	16	
Wetland affected by LOM drawdown	3,233,480		50
Wetland beneath:			
- WRD	1,002,920		16
- Pits	397,900		6
- CP	277,340		4
Area of Niesajoki Basin	69,738,400		
Total wetland area in Niesa Basin	16,679,810	24	
Wetland affected by LOM TMF	658,790		10
Area of Kylmäoja Stream catchment	38,631,720		
Total wetland area in Kylmäoja Stream catchment	16,679,810	43	100
Wetland affected by LOM TMF	0		0

Operational mining: Pit dewatering and mine infrastructure

Within the Hannukainen area (shown in red on Figure 9-13) approximately 50% of the wetland areas are located within the LOM cone of depression predicted by the numerical groundwater modelling, and so will be affected by pit dewatering. Since drawdown decreases with increasing distance from the pits, it follows that the extent of the impact will decrease further away from the pits. The cone of depression around the pits is steep (Figure 9-11) and only wetlands located within approximately 600 m of the pit will experience drawdown of greater than 10 m at LOM.

At LOM 16% of the wetland area is covered by WRDs and 6% has been removed by the pits (Table 9-58). This wetland area will not be recovered. It can be seen that 4% of the wetland area will be covered temporarily during operational mining by the CP. Upon closure this facility will be removed and the wetlands are expected to return to their natural condition.

Operational mining: TMF expansion

At present there are areas of wetland downstream of the water retention dam on the south side of the South Pond. Much of this area will be buried under the proposed South Pond within the new development (Figure 9-14).

It is estimated that the expansion of the TMF will result in a loss of approximately 0.7 km^2 of wetland area, which equates to 4% of the mapped wetland in the Niesajoki catchment. There is no loss of wetland area in the Kylmäoja catchment.

Changes in flow within the Niesajoki River downstream of the new facility may also impact wetland areas.

9.9.4 Saivojärvi wetland

The Saivojärvi wetland lies just to the west of the confluence of the Äkäsjoki and Valkeajoki rivers (Figure 9-14).

There is no groundwater monitoring data in the region of the wetland, however it is anticipated that changes in water levels in the rivers would impact water levels in the wetland. An assessment of the impact of developments at the Hannukainen mine site on water levels in the Äkäsjoki and Valkeajoki rivers was undertaken in Section 0 and Section 9.3 respectively.

The results indicate minimal changes in water levels in the two rivers, which would suggest no significant impact on the Saivojärvi wetland. However, it is noted that there is very limited information on the wetland at present and if it is considered a valued component of the ecosystem, monitoring during construction and operations may be required.

No site runoff can directly impact the Saivojärvi wetland.

Figure 9-12 demonstrates that the LOM cone of depression does not extend to the Valkeajoki River or the Äkäsjoki River in the region of the Saivojärvi wetland, so there is no predicted impact on the wetland from mine-related drawdown.

9.10 Classified Aquifers

Operational mining: Impact of drawdown on aquifers

Figure 9-12 shows the footprints of Class II and Class III aquifers in the vicinity of the Hannukainen site. Throughout the lifetime of the mine, the two Class III aquifers located close to the Hannukainen pit are impacted by drawdown. From Year 5 of production, the drawdown cone extends across the entire footprint of the aquifers. In Year 12 the cone of depression encroaches on the Class III aquifer located west of the mine, impacting approximately 8% of the aquifer at LOM.

It can be seen in Figure 9-12 that the cone of depression encompasses the private wells located close to Hannukainen pit. The drawdown at the wells ranges from 13.3 to 16.8 m at LOM. However, since these wells will be the property of Northland (M.Smith, Northland, pers. comm.) and will not be used for abstraction they are not sensitive receptors.

Operational mining: Impact of WRDs and pits on groundwater water quality

The western class III aquifer will experience a water quality impact from seepage from the CP. Aquifer water quality predictions are summarised in Table 9-59.

From Table 9-59 drinking water quality limits will potentially be exceeded for sulphate, cadmium, manganese and nickel, rendering it unfit for human consumption without prior treatment to reduce elemental concentrations. It can be expected that water quality within the Western aquifer will improve with distance away from the CP. This is due to dispersion and dilution of contaminants with uncontaminated recharge. Water quality impacts to the western Class III aquifer could be reduced by reducing the seepage loss from the CP through installation of an impermeable liner.

The Eastern Class III aquifer and the private wells will not experience negative water quality impacts during LOM as groundwater flow is largely from the aquifers to the Hannukainen pits.

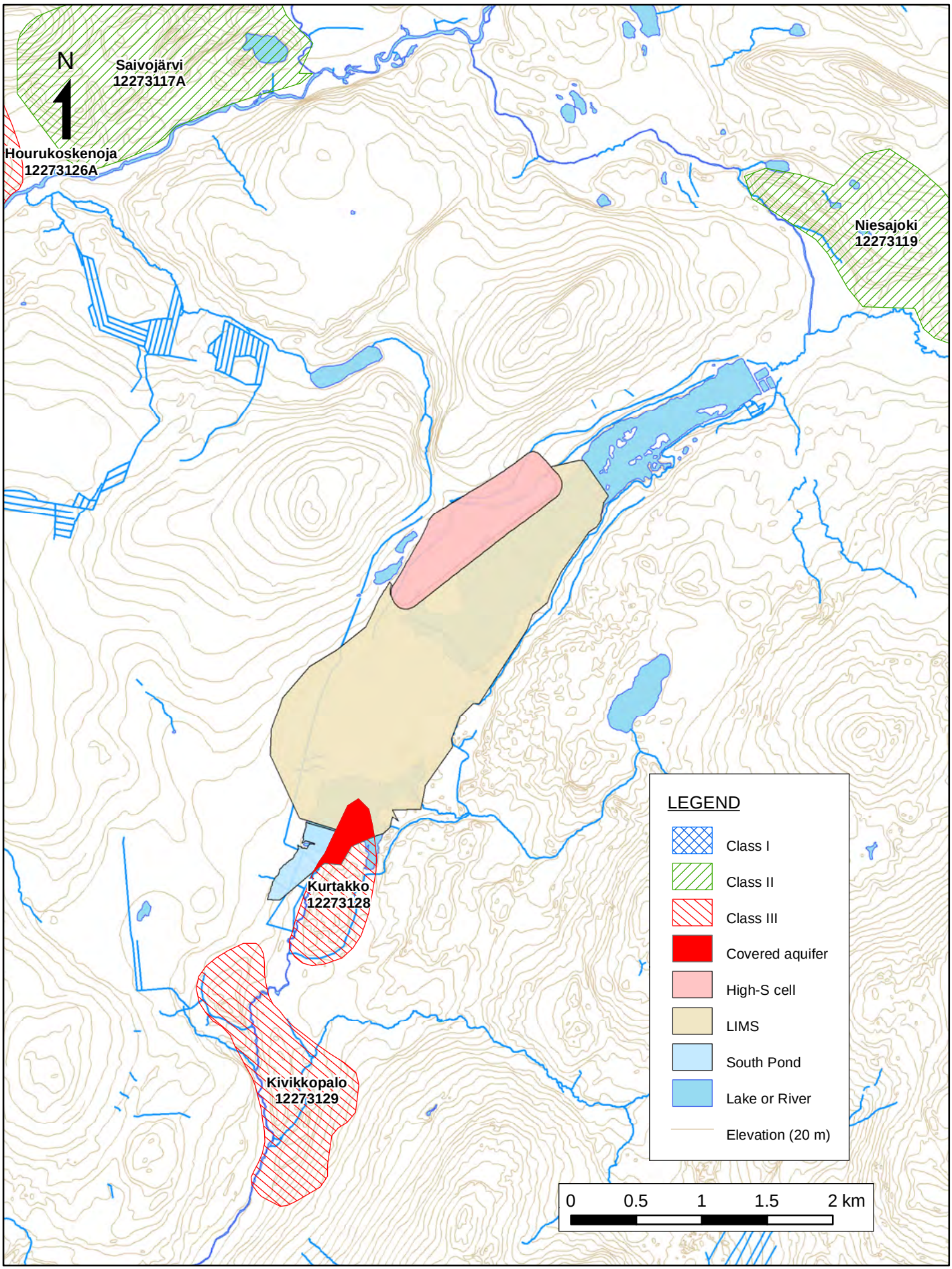
Table 9-59: Predicted concentrations within the Western Class III aquifer compared with Drinking Water Guidelines

		Drinking Water Guidelines			West Class III Aquifer
		Limits from STM 401/2001	Recommended limits from STM 401/2001	WHO (2011)	
NO3	**µg/l**	50		50	43.6
SO4	**mg/l**		250		329
Ca	**mg/l**				27.5
Fe	**mg/l**		0.2		0.0654
K	**mg/l**				25
Mg	**mg/l**				8.51
Na	**mg/l**				25.5
Al	**mg/l**		200		0.0336
As	**µg/l**	10		10	1.45
Cd^	**µg/l**	5		3	3.41
Co	**µg/l**				56.8
Cr	**µg/l**	50		50	18.3
Cu	**µg/l**	2000		2000	247
Hg^	**µg/l**			6	0.682
Mn	**µg/l**		50		190
Mo	**µg/l**				8.21
Ni	**µg/l**	20		70	86
Pb	**µg/l**	10		10	0.918
Sb	**µg/l**			20	2.27
U	**µg/l**	100		30	17.9
Zn	**µg/l**				30.7
	Exceeds drinking water imits from STM 401/2001				
	Exceeds recommended drinking water limits from STM 401/2001				
	Exceeds WHO (2011) drinking water guidelines				
0.001	Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model				
^	**Cd and Hg concentrations elevation partially due to detection limits in testwork**				

Operational mining: Impact of TMF expansion on groundwater water quality

Figure 8-4 shows the footprints of Class II and Class III aquifers in the vicinity of the proposed TMF. It can be seen that the Class III aquifer, which is partially (16%) covered by the existing South Pond, is also partially (20%) covered by the proposed extension of the pond. It is likely that this Class III aquifer will experience a water quality impact from seepage from the clarification pond and in order to quantify the potential impact it has been assumed that solute concentrations within the Class III aquifer will be equivalent to solute concentrations in the overlying South Pond (that the system will be in hydraulic continuity). Predicted concentrations are shown in Table 9-60 below.

Predicted water quality within the aquifer has been assessed against Finnish SRM 401/2001 drinking water limits. Exceedances of drinking water guidelines are predicted for sulphate manganese and nickel during life of mine and for pH, sulphate, manganese, and nickel following closure. Exceedances for uranium are also predicted for the post closure conditions and iron and copper in the event of 100% load release from the High-S TMF. This is likely to render the aquifer unusable without prior treatment. It is anticipated that there will be no significant impacts on other classified aquifers identified in the vicinity of the proposed TMF.



JANUARY 2013	U4970	HANNUKAINEN HIA PHASE 2	
srk consulting		Impact of the Rautuvaara TMF on Classified Aquifers	Figure 9.15

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Table 9-60: Predicted concentrations in the Class III aquifer assuming water quality equivalent to seepage from the TMF South Pond

		Drinking Water Guidelines			EOML	Post Closure			
		Limits from STM 401/2001	Recommended limits from STM 401/2001	WHO (2011)		No High S	10% High S Load	50% High S Load	100% High S load
pH	S.U.	6.5-9.5			7.36	6.38	6.34	5.98	5.46
Alkalinity	mg/L as HCO3				79.4	9.19	8.54	4.11	1.41
Nitrate	µg/l	50,000		50,000	28630	138	138	138	137
Phosphate	µg/l				39.8	1000	1036	2347	4439
Chloride	mg/l		100		0.273	3.23	3.23	3.22	3.22
Fluoride	mg/l	1.5		1.5	0.0023	0.0285	0.0285	0.0285	0.0285
Sulfate	mg/l		250		292	475	476	486	498
Calcium	mg/l				114	336	336	338	340
Iron	mg/l		0.2		0.000761	0.00752	0.00815	0.023	0.251
Potassium	mg/l				26.8	139	139	138	138
Magnesium	mg/l				8.86	41.8	41.8	41.8	42
Sodium	mg/l				26.2	29.7	29.7	29.7	29.7
Silicon	mg/l				0.248	3	3	3	3
Silver	µg/l				0.0000259	0.000322	0.000321	0.000321	0.000321
Aluminium	µg/l		200		1.62	3.71	3.67	3.94	12.5
Arsenic	µg/l	10		10	0.0933	1.38	0.996	4.45	5.86
Barnium	µg/l			700	5.05	7.94	7.94	7.8	7.65
Cadmium^	µg/l	5		3	2.8	1.12	1.23	1.66	2.21
Cobalt	µg/l				37.2	26.4	37	79	132
Chromium	µg/l	50		50	12.1	0.00295	0.0183	0.0931	0.183
Copper	µg/l	2000		2000	19.4	12.7	212	1906	4648
Mercury^	µg/l			6	0.398	1.09	1.2	1.64	2.19
Manganese	µg/l		50		155	836	841	846	855
Molybdenum	µg/l				11.4	63.4	63.4	64.1	64.5
Nickel	µg/l	20		70	64.4	46.4	56.2	95.1	144
Lead	µg/l	10		10	0.585	0.0626	0.303	0.893	1.15
Antimony	µg/l			20	1.81	0.00161	0.00161	0.00161	0.0016
Selenium	µg/l			40	0.000734	0.00829	0.00821	0.00908	0.00928
Strontium	µg/l				7.8	1037	1034	1034	1037
Thorium	µg/l				0.00446	0.0554	0.0554	0.0554	0.0554
Uranium	µg/l	100		30	15	965	964	964	965
Zinc	µg/l				65	564	573	587	602

Exceeds drinking water imits from STM 401/2001

Exceeds recommended drinking water limits from STM 401/2001

Exceeds WHO (2011) drinking water guidelines

^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Post closure: Impact of permanent mine infrastructure

Upon cessation of mining the groundwater levels will recover in the two eastern Class III aquifers, however, approximately 60% of the total aquifer footprint area will have been removed by the Hannukainen pit. In addition, 7% of the aquifer footprint will be covered by WRD OB.

During Phase 1 the Western Class III aquifer was located down gradient of a WRD. The WRDs have been relocated in Phase 2 such that the aquifer no longer receives seepage from any WRDs.

It is predicted that, following closure, the Hannukainen pit will form a flow through pit lake. This means that, under steady state conditions once the water level within the pit lake has fully recovered, water from the pit lake has the potential to migrate as down-gradient groundwater (i.e the natural hydraulic gradient of the aquifer will have re-established itself).

As the pit lake will be located upstream of the two eastern Class III aquifers, there is potential for the water quality within aquifers to attain a water quality similar to that of the Hannukainen pit lake water quality following pit lake filling. On this basis, use of the pit lake water quality is justified in the assessment of groundwater water quality under a worst-case scenario.

Eastern Class III Aquifer: No Mitigation

Predicted water quality in the Eastern Class III aquifer is shown in Table 9-61. Water quality within the aquifer has been predicted at the time of initial discharge from the Hannukainen pit lake and shows exceedences of Finnish drinking water guidelines for iron, aluminium, manganese, and nickel. Water quality within the aquifer is predicted to decrease as the adjacent pit lake reaches steady state conditions with additional exceedences of sulphate chromium, cadmium, copper, nickel, lead, uranium, antimony, fluoride and selenium.

Eastern Class III Aquifer: With Mitigation

Addition of limestone to the PAF dump is shown to improve water quality in the aquifer but is not predicted to fully mitigate water quality with concentrations of sulfate, iron, chromium, nickel, and uranium still predicted to exceed the relevant water quality guidelines.

Based on predicted water quality within the Eastern Class III aquifer, abstracted water from the aquifer following groundwater recovery will not be suitable for domestic use without prior treatment.

Table 9-61: Predicted water quality within the Eastern Class III aquifer

		Drinking Water Guidelines			First Spill			Steady State		
Parameter	Unit	Limits from STM 401/2001	Recommended limits from STM 401/2001	WHO (2011)	HCT	NAG	NAG - $CaCO_3$ added to WRD	HCT	NAG	NAG - $CaCO_3$ added to WRD
Nitrate	mg/L	50		50	0.487	0.488	0.488	3.12	3.29	3.24
Chloride	mg/L		100		2.27	1.74	1.73	77.5	37.3	36.3
Sulfate	mg/L		250		31	41.6	37.1	264	1880	878
Iron	mg/L		0.2		0.295	2.98	0.489	0.409	180	0.332
Aluminium	mg/L		0.2		0.0109	0.206	0.115	0.102	65.6	0.0445
Arsenic	mg/L	0.01		0.01	0.000612	0.00051	0.000508	0.00361	0.00818	0.00344
Cadmium^	mg/L	0.005		0.003	0.000124	0.000114	0.000095	0.00179	0.00321	0.000959
Coballt	mg/L				0.00129	0.0187	0.00453	0.068	1.86	0.11
Chromium	mg/L	0.05		0.05	0.00404	0.0035	0.00347	0.0808	0.131	0.0767
Copper	mg/L	2		2	0.00213	0.162	0.0116	0.0114	18.8	0.0103
Mercury^	mg/L			0.006	0.0000438	0.0000332	0.0000298	0.00212	0.00113	0.000754
Manganese	mg/L		0.05		0.0974	0.0826	0.0503	5.27	4.71	0.405
Molybdenum	mg/L				0.00287	0.00139	0.00137	0.0419	0.0479	0.0341
Nickel	mg/L	0.02		0.07	0.00353	0.0213	0.00349	0.0497	2.15	0.0292
Lead	mg/L	0.01		0.01	0.000417	0.000549	0.00042	0.00134	0.0466	0.00104
Zinc	mg/L				0.00873	0.0136	0.00678	0.0703	0.85	0.0633
Uranium	mg/L	0.1		0.03	0.00594	0.00496	0.00495	0.321	0.278	0.271
pH	s.u.	6.5-9.5			6.08	4.57	5.18	6.06	3.47	6.31
Phosphate	mg/L				0.0533	0.0531	0.052	0.391	2.28	0.468
Calcium	mg/L				15.7	11.4	11.6	396	88.6	91.9
Potassium	mg/L				5.47	3.21	3.43	435	247	230
Magnesium	mg/L				2.71	2.83	2.7	84.6	106	34.1
Sodium	mg/L				5.46	4.72	4.71	175	112	107
Silicon	mg/L				2.39	2.91	2.92	5.46	5.45	5.52
Barium	mg/L			0.7	0.0129	0.012	0.012	0.0167	0.00235	0.00304
Strontium	mg/L				0.0679	0.0493	0.0493	2.74	0.661	0.722
Antimony	mg/L			0.02	0.00311	0.000182	0.000182	0.243	0.00733	0.00997
Alkalinity	mg/L				5.15	-1.59	0.344	6	-54.7	9.95
Fluoride	mg/L	1.5		1.5	0.0481	0.123	0.0525	0.779	9.94	1.06
Silver	mg/L				0.000619	0.000176	0.000169	0.0516	0.00972	0.00796
Selenium	mg/L			0.04	0.000541	0.000761	0.000262	0.00483	0.0892	0.00498

Exceeds drinking water imits from STM 401/2001

Exceeds recommended drinking water limits from STM 401/2001

Exceeds WHO (2011) drinking water guidelines

^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

10 IMPACT MANAGEMENT

The potential exists for negative impacts to the environment as a result of proposed activities at the Hannukainen Project and therefore practical measures should be undertaken to mitigate the potential negative impacts.

The suggested strategy for selecting practical mitigation measures is as follows:

- Avoid the impact wherever possible by removing the cause(s) – always preferred;
- Reduce the impact as far as possible by limiting the cause(s) – preferred where impacts cannot be avoided;
- Ameliorate the impact by protecting the receptor from the cause(s) of the impact – only where the cause of the impact cannot be reduced; and
- Providing compensatory measures to offset the impact – this is used only when none of the above are appropriate and is often used where impacts to biodiversity resources cannot be mitigated.

Impact management will be investigated in full as part of the ESIA. However, Table 10-1 identifies specific management methods to mitigate against potential negative impacts at the project site. The table includes suggested assessment criteria to determine the success of each management method.

10.1 Monitoring

A baseline monitoring programme and a strategy for the monitoring of impacts are required to accurately characterise existing conditions. Without a reliable baseline characterisation it will not be possible to objectively derive the cause of any water level or quality changes. The task of ongoing groundwater and surface water quality sampling is currently undertaken by Northland.

Recommendations are given below for ongoing baseline monitoring and future operational monitoring. It is important that data collection is sufficient to:

- Accurately characterise existing conditions, including seasonal changes in the local hydrological regime;
- Identify changes to pre-mining conditions;
- Identify the cause of any changes; and
- Demonstrate that mitigation strategies are working effectively.

Table 10-2 provides a summary of SRK's recommendations for ongoing baseline water level, flow and quality monitoring. Monitoring should continue throughout operations and be modified to reflect changes to the conditions of the local hydrology, e.g. increased monitoring in an area where water quality is decreasing.

Table 10-3 shows the recommended suite of analysis to be undertaken on water quality samples.

Table 10-1: Mitigation Methods at Rautuvaara

Cause	Potential Impact	Possible Management Method	Assessment Criteria
Pre-Operational			
Construction of infrastructure in Niesa Basin	Reduction in water quality in Niesajoki and Kylmäoja, e.g. increased sediment load	• Assume appropriate sediment control measures and environmental management planning	Target values and action criteria for e.g. TSS in rivers
Discharge resulting from pit dewatering of existing pit lakes	Reduction of water quality in region of sedimentation pond	• Passive treatment of discharge using a wetland (with retention time of 48 hours) and aeration cascade (described in more detail in SRK (2012a)). The calculations assume that mixing ratios between the Laurinoja and Kuervaara pit lakes and discharge flows are regulated as stated in the BRC decision (BRC, 2007)	Target values and action criteria for e.g. Fe, pH, O_2 in Äkäsjoki.
Operational			
Reduced stream flows due to pit dewatering, mine infrastructure and water management plan	Reduced flow and river stage in rivers surrounding the site. Note that impact assessment predicts that changes in flow are generally <4% in Äkäsjoki, <7% in Kuerjoki and <4% in Valkeajoki. Changes in river stage are generally <0.01m. Reduced flow and river stage in Niesajoki River downstream of Rautuvaara TMF. Flows will be substantially reduced due to pumping of treated water to Muonionjoki.	• No mitigation for Äkäsjoki, Kuerjoki or Valkeajoki Rivers. • Augmentation of flows in Niesajoki using treated mine water. • Diversion of natural catchments to the north-west of the Rautuvaara TMF around edge of facility to drain to Niesajoki River.	Target values and action criteria for changes in river flow. Criteria should be developed with an aquatics expert
Seepage from WRDs	Reduction in water quality of Äkäsjoki and Kuerjoki	• Assessment of attenuation of potential contaminates along groundwater flow path	Target values and action criteria for e.g. Cu, Ni, SO_4 in rivers
Seepage from clarification ponds at Rautuvaara TMF	General improvement in water quality within Niesajoki. Negligible impact on water quality in Kylmäoja for selected parameters.	• No management required; however, assessment of attenuation of potential contaminates along groundwater flow path during operations to confirm groundwater model predictions	Target values and action criteria for e.g. Cu, Ni, SO_4, U in rivers
Discharge to Muonionjoki	Channel bed or bank erosion	• Engineering of outfall; managed release	Bed and bank erosion at pre-determined, vulnerable sections; Turbidity of water at outfall

Cause	Potential Impact	Possible Management Method	Assessment Criteria
Discharge to Muonionjoki	Reduction in water quality of Muonionjoki. Requirement for mixing zone close to outfall.	• Improve treatment of mine water prior to release; Treatment of High-S tailings with lime (CaO) to neutralise the seepage and bring the pH to 7.0. • Increase on-site storage to limit discharge rates during critical periods of low flows in the river. • Effective diffuser design to improve mixing close to the outfall. • Agree mixing zone with regulators.	Target values and action criteria for e.g. Cu, Ni, SO4, U in Muonionjoki
Water quality in North and South Ponds due to seepage from the TMF facility	Potential for negative impact to ecological receptors	• Toxicological risk assessment of predicted water quality against specific species exposed. • Look at long term feasibility of preventing access to facility (fencing etc)	Target values and action criteria for e.g. Cu, Ni, SO4, U in ponds
Water quality in existing Rautuvaara pit lakes due to tailings backfilling	Potential for negative impact to ecological receptors	• Backfill pits above the predicted water level with till / waste rock to prevent access to water	Target values and action criteria for e.g. Cu, Ni, SO4, U in pit lakes
Uncontrolled release from Hannukainen CP (Hannukainen) or TMF Clarification Ponds (Rautuvaara)	Increase in flows and discharge of poor quality water to downstream watercourses.	• Design appropriate freeboards within water ponds. Provide adequate pumping capacity at Hannukainen to allow pumping and discharge of water to treatment or temporary storage in open pits in the case of high water levels in ponds	Develop appropriate water management plan in the case of extreme rainfall events. Have plan approved by appropriate professional and regulators.
Impacts to Western Class III aquifer at Hannukainen site through seepage from Hannukainen CP	Reduction in water quality within the aquifer potentially making unfit for human consumption	• Installation of impermeable liner below CP to ensure minimal seepage from the clarification pond occurs during LOM	Target values and action criteria for e.g. Cu, Ni, SO4, U in pit lakes
Post-closure			
Discharge of poor quality seepage from Hannukainen PAF WRD to the Hannukainen and Kuervitikko pit lakes	Reduction in water quality within the pit lakes and therefore in the receiving rivers	• Addition of neutralising ameliorant (e.g. limestone) to the PAF dump to attenuate acidity and reduce solute load exiting to catchment • Addition of low permeability, oxygen limiting cover to the PAF WRD to decrease metals load	Target values and action criteria for e.g. Cu, Ni, SO4, U in pit lakes

Cause	Potential Impact	Possible Management Method	Assessment Criteria
Seepage and overtopping of Hannukainen and Kuervitikko pit lakes	Reduction in water quality of Äkäsjoki and Kuerjoki	• Passive treatment through a wetland system prior to release • Active treatment of pit lake discharge prior to release • Detailed modelling to include stratification of pit lakes • Addition of chemical ameliorant directly to the pit lake such as lime (CaO) for pH correction • Improve loadings at source (e.g. mitigation of seepage load from PAF WRD)	Target values and action criteria for e.g. Cu, Ni, SO_4 in rivers
Water quality in Hannukainen and Kuervitikko pit lakes	Potential for negative impact to ecological receptors	• Toxicological risk assessment of predicted water quality against specific species exposed. • Look at long term feasibility of preventing access to facility (fencing etc.) • See potential mitigation options above	Target values and action criteria for e.g. Cu, Ni, SO_4, U in the ponds
Water quality in North and South Ponds due to seepage from the TMF facility	Potential for negative impact to ecological receptors	• Toxicological risk assessment of predicted water quality against specific species exposed. • Look at long term feasibility of preventing access to facility (fencing etc)	Target values and action criteria for e.g. Cu, Ni, SO_4, U in the ponds
Seepage of potential contaminates from Hannukainen mine site and Rautuvaara tailings site that cannot be mitigated cost effectively though engineering design	Reduction in water quality of Äkäsjoki, Kuerjoki, Valkeajoki, Niesajoki and Muonionjoki	• Toxicological risk assessment of predicted water quality against specific species exposed.	Target values and action criteria for e.g. Cu, Ni, SO_4 in rivers

Cause	Potential Impact	Possible Management Method	Assessment Criteria
Seepage and surface runoff from South Pond to Niesajoki	Reduction in water quality in Niesajoki River	• Assessment of attenuation of potential contaminates along groundwater flow path. • Continue treating runoff from Rautuvaara TMF until water-quality meets WQOs. • Continue piping excess water in South Pond to Muonionjoki until water quality meets WQOs. • Assessment of potential for attenuation of tailings seepage within the clarification pond through the use of lime or peat, or by establishment of a wetland.	Target values and action criteria for e.g. Cu, Ni, SO_4, U in rivers
Seepage from North Pond to Kylmäoja Stream	Potential for slight negative impact on water quality in Kylmäoja for selected parameters.	• Assessment of attenuation of potential contaminates along groundwater flow path	Target values and action criteria for e.g. Cu, Ni, SO_4, U in rivers
Discharge to Muonionjoki	Reduction in water quality of Muonionjoki. Requirement for mixing zone close to outfall.	• Impacts of mitigation measures identified above on discharge water quality and resulting quality in the Niesajoki (namely use of peat, wetlands or lime to improve water quality in and around the TMF and clarification ponds) to enable discharge to cease. • Effective diffuser design to improve mixing close to the outfall. • Agree mixing zone with regulators.	Target values and action criteria for e.g. Cu, Ni, SO4, U in Muonionjoki
Uncontrolled release from TMF Clarification Ponds (Rautuvaara)	Increase in flows and discharge of poor quality water to downstream watercourses.	• Design appropriate freeboards within water ponds.	Develop appropriate water management plan in the case of extreme rainfall events. Have plan approved by appropriate professional and regulators.

Table 10-2: Baseline and Operational monitoring recommendations

Parameter	Frequency	Location	Justification
Groundwater level	Monthly (manual) Hourly (loggers)	• In boreholes positioned in both the overburden and the bedrock; located throughout the site including both Hannukainen and Rautuvaara sites	• Characterise seasonal variation • Improve conceptual hydrogeological model • Identify changes during operations
Groundwater water quality	Approximately 5 times annually	• Downstream and upstream of existing infrastructure; samples from both the Quaternary sediments and the bedrock.	• Identify and characterise any existing contamination • Improve conceptual hydrogeological model • Improve conceptual contaminant transport model • Improve impact prediction • Current monitoring programme sufficient, although additional samples would be required if there was a need for assessment of seasonal variation in key parameters • Identify changes during operations and, where necessary, assess the effectiveness of mitigation measures
River stage/flow	Continuous water level recording with bi-weekly spot flow measurements to allow development of ratings curves for gauged sites	• Six water level recorders were installed in 2012, including three on Niesajoki, one on Äkäsjoki and one on Kylmäoja. The other was installed on Valkeajoki. Loggers should be re-installed at these sites in 2013.	• Characterise river catchments, e.g. response to rainfall events and snow melt • Allow comparison of site-specific flow data (e.g., monthly average flows) with regional flow data • Identify changes during operations and, where necessary, assess the effectiveness of mitigation measures

Parameter	Frequency	Location	Justification
Surface water quality	Approximately 5 times annually	• Continue current monitoring programme / routine monitoring of treated water discharge	• Current monitoring programme sufficient, although additional samples would be required if there was a need for assessment of seasonal variation in key parameters • It is the opinion of SRK that field filtration is not required. However, it is recommended that the laboratory should undertake filtration on receipt of the samples to avoid anomalously high concentrations (e.g. metals) in samples with high suspended solids load. However, it should be noted that, international standards (used to define AVs) may be for Total Metals, and therefore it may be necessary to obtain both Total and Dissolved samples for key sites. This should be clarified with the regulator • Identify changes during operations and, where necessary, assess the effectiveness of mitigation measures
Flow conditions close to proposed outfall location on Muonionjoki	Two additional flow surveys under low flow conditions and moderate flow conditions (flow data for high flow conditions have already been collected)	• Cross-sections of Muonionjoki at and close to proposed outfall location	• Obtain field data to parameterise and calibrate dilution calculations for proposed outfall in Muonionjoki • Identify changes during operations and, where necessary, assess the effectiveness of mitigation measures
Dilution at Muonionjoki outflow location	Once, under low flow conditions. Second survey under higher flow conditions could be considered	• Release of dye or salt at the proposed outfall location, with monitoring of dilution downstream of that point	• Obtain field data to calibrate dilution calculations for proposed outfall in Muonionjoki

Table 10-3: Suite of Determinants to be Analysed (Not Field Filtered)

Parameter
Aluminium , Total as Al
Antimony, Total as Sb
Arsenic, Total as As
Barium, Total as Ba
Beryllium, Total as Be
Boron, Total as B
Cadmium , Total as Cd
Calcium , Total as Ca
Chromium - Hexavalent
Cobalt , Total as Co
Copper , Total as Cu
Iron , Total as Fe
Lead , Total as Pb
Magnesium, Total as Mg
Manganese , Total as Mn
Mercury, Total as Hg
Molybdenum, Total as Mo
Nickel , Total as Ni
Potassium , Total as K
Selenium, Total as Se
Silver , Total as Ag
Sodium , Total as Na
Strontium , Total as Sr
Sulphur, Total as S
Tin , Total as Sn
Uranium, Total as U
Vanadium, Total as V
Zinc , Total as Zn
Alkalinity as CaCO3
Ammonium as NH_4, Low Level
Carbonate Alkalinity
Chemical oxygen demand (Mn method)
Chloride as Cl
Cyanide, Total Low Level
Dissolved oxygen
Fluoride as F
Nitrate as N
Nitrite as N
Phenols Mono (Phenol Index)
Phosphate, Ortho as P
Phosphorus , Total as P
Total dissolved solids (TDS)
Total organic carbon (TOC)
Total Petroleum Hydrocarbon (TPH)
Total suspended solids (TSS)
Turbidity
pH – in-situ and laboratory
Conductivity- Electrical – in-situ and laboratory
Temperature – in-situ

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Key Findings

This assessment focuses on the impact of the development of the proposed Rautuvaara TMF on groundwater levels, groundwater quality, surface water flows and water quality within the TMF and in rivers lying downstream of the facility and potentially impacted by the development of the TMF (Niesajoki, Kylmäoja, Äkäsjoki and Muonionjoki). However, the report also updates the assessment of the impact of mine site infrastructure (open pits, clarification pond and WRDs) on groundwater levels, groundwater quality, surface water flows and water quality in the Hannukainen area, work that formed part of the Hannukainen HIA Phase 1 assessment. This work includes an assessment of impacts on surface waters in the project area including the Kuerjoki, Valkeajoki and Äkäsjoki Rivers, together with groundwater, wetlands and other water features.

Key changes in the management of mining wastes between the Phase 1 and Phase 2 studies are that tailings have been moved from the Hannukainen area (Phase 1) to the Rautuvaara TMF (Phase 2), WRDs have been relocated outside of the groundwater catchment of Valkeajoki River and treated effluent from the Hannukainen CP and Rautuvaara TMF are now discharged by way of a pipeline to the Muonionjoki. In Phase 1 treated effluent was discharged into Niesajoki River.

As a result of the changes in the management of mining wastes the Phase 2 report predicts improvements in water quality in Valkeajoki, Kuerjoki, Äkäsjoki and Niesajoki Rivers, compared to the Phase 1 report. Overall impacts on Muonionjoki remain as before, although discharges to the river are now focussed at a single outfall point. In addition, this report considers a wider range of water quality parameters than considered in the Phase 1 study and issues related to selected parameters in Muonionjoki are identified in the Phase 2 study.

It is noted that rivers in the study area are impacted by the existing mine site at Hannukainen and an existing, but disused TMF at Rautuvaara. The Phase 2 report provides a more detailed analysis of the present day conditions in the Niesajoki River and identifies loadings to the river from the existing TMF (surface and groundwater). As a result, the Phase 2 study provides an improved assessment of the baseline conditions in the Rautuvaara area.

After the end of mining operations Hannukainen and Kuervitikko pit lakes will be allowed to fill with water becoming pit lakes. In Phase 2 it is proposed that pit infilling is accelerated by the pumping of river water to the pit lakes. As a result, potentially acid generating pit walls are submerged more quickly and the predicted pit lake water quality in Phase 2 is considerably better than predicted in Phase 1.

11.1.1 Operational mining

The key findings of the impact assessment during operational mining are:

Surface Water Flows

Overall there are limited impacts of the Hannukainen and Rautuvaara developments on surface water flows on any of the main rivers located downstream of mining infrastructure. There are negligible impacts on the Muonionjoki and Valkeajoki Rivers and the Kylmäoja Stream. Due to the impoundment of the Rautuvaara TMF stream flows in the Niesajoki immediately downstream of the facility are predicted to decrease by around 40%; however, by the mouth of the river the impacts are reduced to 8% of baseline flows. Although flows will be significantly impacted in the upstream reaches of the Niesajoki River, this will be balanced by an improvement in water quality in this river.

In the Kuerjoki and Äkäsjoki dewatering of open pits will draw down the local groundwater table and reduce baseflow to the nearby rivers. During average winter conditions flows are predicted to decrease by a maximum of 2% in the Äkäsjoki and 4% during extreme dry year conditions. In the Kuerjoki under average winter conditions flows are predicted to decrease by a maximum of 4% and 7% during extreme dry year conditions. However, hydraulic calculations indicate that such a decrease in flow would have negligible impact on water levels and surface flow areas in these rivers, which are critical parameters for aquatic life.

Surface Water Quality

Significant improvement in the quality of water in the Niesajoki is predicted due to the impoundment and treatment of surface runoff from the existing Rautavaara TMF.

Negligible or no impacts on water quality are predicted for the Valkeajoki, Kuerjoki and Kylmäoja Streams during operations.

Predictions for the Äkäsjoki River indicate that there are no exceedances of AVs for key parameters during operational mining. During winter months exceedances of TVs for cadmium, chromium, mercury and uranium are predicted.

Treated effluent and runoff from the Rautuvaara TMF will be stored within the South Pond in the Rautuvaara area before being piped to, and discharged into, the Muonionjoki River. Modelling work indicates that for selected parameters (e.g., nitrate, cadmium, cobalt, nickel, uranium and zinc) discharges to the Muonionjoki would increase concentrations in the river by more than 50% above baseline conditions in Year 5 of operations. The impacts on the river are predicted to be lower during early years of operations, but the impacts are predicted to increase over time as the flow rate to the river increases.

For most parameters the main impacts are during winter months when flows in the river are at their lowest. Modelling predicts an effluent plume downstream of the outfall to the Muonionjoki within which there is the potential for exceedances of TVs and AVs. Further work is proposed (Section 11.2) in order to minimise these exceedances and, where necessary, identify suitable mitigation measures. Discussions with regulators are required to determine effluent quality and flow rates that would be considered acceptable.

Failures or uncontrolled releases of water from the clarification ponds at Hannukainen or Rautuvaara TMF would have a significant negative impact on water quality within the streams downstream of the mine site. Insufficient information was available at the time of this report regarding the site water management plan to allow a detailed assessment of the impacts of uncontrolled releases. However, the availability of substantial water pumping capacity on site and emergency water storage (open pits) would suggest that the risk of uncontrolled releases to the environment is low.

Wetlands and Springs

The total number of springs identified in the Hannukainen area is 63 (M. Heikkinen (Ramboll), pers. comm.), of which 27 are located within the LOM cone of depression. Of these 27 springs, 16 will be permanently removed due to mine infrastructure (WRD, pits). One spring is covered by the expansion of the Rautuvaara TMF.

Approximately 50% of the wetland areas at Hannukainen are located within the LOM cone of depression. At LOM 16% of the wetland area is covered by WRDs and 6% has been removed by the pits. About 4% of the wetland area will be covered temporarily during operational mining by the CP. The expansion of the TMF will result in a loss of 4% of the mapped wetland in the Niesajoki catchment and no loss in the Kylmäoja catchment.

Groundwater Quantity and Quality

Class II and Class III aquifers in the vicinity of the Hannukainen site are located within the predicted cone of depression. The cone of depression also encompasses the private wells located close to Hannukainen pit. However, these wells will be the property of Northland and will not be used for abstraction. At Rautuvaara the Class III aquifer, which is partially (16%) covered by the existing South Pond, is also partially (20%) covered by the proposed extension of the pond.

The western Class III aquifer at Hannukainen and Rautuvaara Class III aquifer will experience an adverse water quality impact from seepage, rendering them unfit for human consumption without prior treatment to reduce elemental concentrations. The Eastern Class III aquifer and the private wells at Hannukainen will not experience negative water quality impacts during LOM as groundwater flow is largely from the aquifers to the Hannukainen pits and it is anticipated that there will be no significant impacts on other classified aquifers identified in the vicinity of the proposed TMF.

11.1.2 Post closure

The closure plan for the Rautuvaara TMF has not been fully developed, leading to uncertainties in predictions of water quality in the TMF and downstream post-closure.

Surface Water Flows

Post-closure of mining operations surface water flows in the Äkäsjoki, Muonionjoki, Niesajoki, Kuerjoki, Valkeajoki and Kylmäoja will return close to baseline conditions. There will be a period of time while the Hannukainen and Kuervitikko pit lakes are infilling when impacts on flows would be expected to be similar to those during operations, but once the pit lakes are full catchments diverted during operations will be reconnected with their natural watercourses. There also may be a period of time after the end of operations when runoff from Rautuvaara TMF are routed to Muonionjoki, bypassing the Niesajoki; however, once water quality in the TMF is of sufficient quality it will be allowed to flow into Niesajoki River, as under baseline conditions.

Surface Water Quality

Post-closure excess water from the Hannukainen mine will not be discharged to the Rautuvaara TMF. Hence, the volume of water accumulating in the water ponds at Rautuvaara will decrease. Predictions indicate that without treatment or management of runoff from the TMF there is a risk that water quality in Niesajoki and Muonionjoki rivers could be adversely impacted by runoff from the TMF post-closure. Calculations predict elevated concentrations of many parameters in the Niesajoki and Muonionjoki rivers, whether water is released to the Niesajoki River or piped to Muonionjoki River. In the Muonionjoki River predictions indicate exceedances of TVs for a number of parameters even with encapsulation of High-S tailings (e.g., cobalt, molybdenum, uranium and zinc). Mitigation options such as treatment of excess water in the TMF may need to be considered. In addition, a review of the Rautuvaara water balance (Pöyry) may need to be undertaken as flow estimates from the TMF during closure (especially during winter) appear high.

At closure there is also the potential for groundwater seepage from the TMF to Kylmäoja Stream and the Niesajoki River but the impact of seepage alone is not considered significant.

After the end of mining operations Hannukainen and Kuervitikko pit lakes will be allowed to fill with water becoming pit lakes. Using artificial flooding the time required to fully flood the Hannukainen and Kuervitikko pits is 13 – 81 years and 4 – 18 years respectively. Seepage from WRDs at the Hannukainen site will flow into the pit lakes and will not discharge directly to natural streams.

It is predicted that both the Hannukainen and Kuervitikko pits lakes may overtop to the Äkäsjoki and Kuerjoki respectively once fully recovered. Potential exceedances of AVs are predicted for selected key parameters in both Hannukainen and Kuervitikko pit lakes. Concentrations in the Hannukianen pit lake under steady state conditions are predicted to be of a lower quality than initial overspill water quality. This is due to the greater proportion of seepage received from the PAF WRD to the pit lake and the absence of continued inflow of river water with good water quality. No exceedences of AVs for key parameters are predicted for the Kuervitikko pit lake under steady state conditions for all predicted scenarios. Addition of limestone to the PAF WRDs is predicted to cause a marked improvement to pit lake water quality under steady state conditions.

Wetlands and Springs

It is predicted that 17 springs and approximately 26% of the wetland area across the mine site will be permanently removed due to mine infrastructure.

It is anticipated that the remaining springs and wetland areas that are temporarily covered during operational mining will return to pre-mining conditions following cessation of mining.

Ground Water Quantity and Quality

It is predicted that at Hannukainen approximately 60% of the total aquifer footprint area will have been removed by the Hannukainen pit and a further 7% covered by WRD OB. The Class III aquifer at Rautuvaara will remain beneath the South Pond.

The WRDs have been moved in Phase 2 such that no seepage from mine facilities will report to the western Class III aquifer post-closure and so water quality should be close to baseline conditions. It is likely that the eastern Class III aquifers will receive water from the pit lake; water quality is likely to deteriorate at these sites due to the seepage rendering water abstracted from these aquifers unsuitable for domestic use without prior treatment. The Class III aquifer at Rautuvaara will attain the water quality of the South Pond and will also require treatment prior to domestic use.

11.2 Recommendations

The following works are recommended at Rautuvaara:

- Surface water:
    - Continue monitoring at all six stream flow gauging stations. Data available to date (4 months) suggests that regional hydrological flow estimates for the main rivers on site may under-predict actual stream flows. With additional on-site flow data hydrological estimates for the rivers could be updated, improving the quality of hydrological and water quality predictions on site;
    - Undertake monthly water quality sampling at key sampling sites (i.e., those for which WQOs have been prepared) during open water season for one or two years. This will increase the number of samples used in calculation of WQOs and will allow an assessment of seasonal variations in water quality in response to flow conditions.
    - In order to improve predictions of dilution of effluent in the Muonionjoki we would recommend;
        - Additional ADCP flow survey under low flow conditions. This should include GPS survey allowing the ADCP data to be tied to a consistent elevation datum;
        - Dilution tests within the river under high and low flow conditions. This could include release of tracers and/or drogues; and
        - Updated mathematical modelling using new field data and extending modelled domain further downstream of outfall.
    - Discussions need to be held with regulators to agree WQOs and permitted water quality limits. The need also exists to initiate discussions related to initial dilution zones for the outfall into the Muonionjoki. It is noted that the Muonionjoki is an international river and discussions will need to be held with both Finnish and Swedish regulators;

- Analyse data from the continuous flow monitoring stations located to further characterise baseflow to the rivers;
- Investigation of the hydraulic connection between the Valkeajoki, Äkäsjoki and the Saivojärvi wetland;
- Continue current surface water quality monitoring programme in the Niesa Basin; and
- Continue operation of on-site meteorological station. Consider installation of additional station at Rautuvaara and / or installation of rain gauges in study area to allow assessment of spatial variability in rainfall.

- Groundwater:
  - Increased frequency of groundwater level baseline data to determine longer term seasonal trends and the variation in response across the Hannukainen site;
  - Further ground investigations, including groundwater quality monitoring, to determine, with certainty, the cause of elevated sulphate at SP305, SP310 and HAN11HYDR01(D);
  - Undertake regular water level monitoring and water quality sampling in all RAU12HYD- series holes and the GTK holes;
  - Continue to maintain groundwater pressure transducers and expand the network of transducers if possible to include loggers in both the shallow and deep piezometer at each well;
  - Drill individual deep and shallow wells at monitoring location RAU12HYD12 in order to be certain that the response of the overburden and bedrock aquifers are being monitored independently and to better characterise the hydrological regime at this location in combination with the surface water monitoring;
  - Drill one deep (>100 m) well in the vicinity of RAU12HYD25 in order to characterise the hydraulic properties of the deep, non-weathered bedrock at this location and also to act as a groundwater sampling location to identify any existing contamination of the deep aquifer at the Rautuvaara site;
  - Incorporate the findings of the University of Helsinki study into the groundwater data to develop the conceptual hydrogeological model of the Niesa Basin;
  - Extent the numerical groundwater modelling to reflect the developments in the conceptual model. This may include variation in overburden thickness, refinement of the boundary conditions to limit extent of the model such that it is a local model of the Niesa Basin rather than a regional scale model, improved estimates of lake bed conductance using field data of the lake sediment hydraulic properties where possible and quantification of the surface water inflows and outflows from the North and South Ponds under current conditions; and
  - Attenuation testing of materials along PAF WRD groundwater flow path to determine potential for attenuation of copper and other metals from WRD seepage.

It is recommended that further studies consider the following options for management of the proposed TMF at Rautuvaara:

- Due to the high sensitivity of the water quality prediction models to the Hannukainen tailings source terms and the potential knock on impacts that this has to the water quality of the receiving water courses, it is recommended that refinement of the LIMS and High-S tailings source terms be undertaken to take into account site specific hydrological conditions, tailings facility design impacts and tailings leaching characteristics taking into account the latest round of metallurgical testing;
- The potential for attenuation of contaminates through adsorption and mineral equilibration and precipitation along the flow path should be investigated. This should include the potential for uranium mineral controls with inclusion of vanadium water quality data from future analysis;
- Feasibility and potential benefit of relocating High-S tailings back to the Hannukainen pit by means of the conveyor;
- Feasibility and potential benefit of adding neutralising agent to in-situ High-S tailings to prevent generation of acidic leachates;
- Assessment of potential for improvements to water treatment options at Hannukainen mine to reduce loadings of key water quality parameters that are predicted to be high within Muonionjoki River;
- Improvements to the Hannukainen water management plan to identify if water flows to Muonionjoki can be lowered in winter months and to identify flows and flow pathways under extreme rainfall conditions. It is suggested that the mine site water balance is linked to dilution models considering the impacts of discharges on receiving environment, so that there is better integration of water balance modelling at the site. Water balance tools such as GoldSim allow the development of large water balance models within a single modelling environment;
- Improvements to Rautuvaara TMF water balance for closure period. Current predictions of flows from the TMF are based on data from Pöyry. These flows appear high (especially during winter) and a review of the water balance should be undertaken in tandem with the modelling work outlined in the previous bullet point;
- Review of potential passive and active treatment options for post closure mitigation of the Rautuvaara South Pond;
- Review of the potential mitigation measures that could be implemented for reducing discharge from the High-S Rautuvaara tailings facility, including long term treatment, neutralisation and alternative cover and placement options; and
- Feasibility of continuing to pipe water directly to the Muonionjoki River post-closure to avoid deterioration of water quality in the Niesajoki River.

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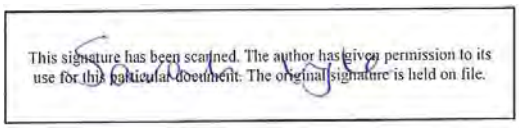
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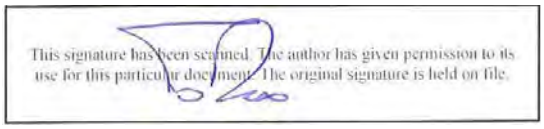
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APPENDIX

A SURFACE WATER CLASIFICATION

Table 1: Criteria for the general water quality classification in Finland (Finnish Environment Institute)

Class	Class interpretation	Variables and their threshold values
I Excellent	The watercourse is in a natural state, usually oligotrophic, clear or with some humus. Water use is not restricted by any special occurrence of algae. Highly suitable for all modes of use.	– Colour < 50 mg Pt/l – Transparency > 2.5 m – Turbidity < 1.5 FTU – Feacal coliforms or fecal streptococci < 10 CFU/100 ml – Total phosphorus < 12 µg/l – Mean chlorophyll-a in the growing season < 4 µg/l (in Baltic Sea < 2 µg/l)
II Good	The watercourse is in a near-natural state, slightly eutrophic or clearly humic. Locally restricted algal blooms can occur occasionally. Water is still suitable for most modes of use.	– Oxygen concentration in epilimnion 80–110% – No oxygen defiency in the hypolimnion – Colour 50–100 mg Pt/l (< 200 in natural humic waters) – Transparency 1–2.5 m – Turbidity > 1.5 FTU – Feacal indicator bacteria < 50 CFU/100 ml – Total phosphorus < 30 µg/l (in Baltic Sea 12–20 µg/l – Mean chlorophyll-a in the growing season < 10 µg/l (in Baltic Sea < 2–4 µg/l)
III Satisfactory	The watercourse is slightly affected by wastewaters, diffuse loading or other changing activity, or is appreciably eutrophic or humic due to natural causes. Algal blooms can occur repeatedly. Concentrations of harmful substances in water, sediment or biota can be slightly higher than in pristine conditions. The watercourse is usually satisfactory for most modes of use.	– Oxygen concentration in epilimnion 70–120% – Some oxygen defiency may occur in the hypolimnion – Colour < 150 mg Pt/l – Transparency < 1 m – Feacal indicator bacteria < 100 CFU/100 m – Total phosphorus < 50 µg/l (in Baltic Sea 20–40 µg/l) – Mean chlorophyll-a in the growing season < 20 µg/l (in Baltic Sea 4–12 µg/l)
IV Passable	The watercourse is strongly affected by wastewaters, diffuse loading or some other changing activity. Algal blooms are common and may restrict water use for a long period. Concentrations of harmful substances in water, sediment or biota can be clearly higher than in pristine conditions. In catchments with Littorina Sea* clay deposits, the pH of water can be very low for short periods and die-offs of fish caused by the acidic conditions can sometimes occur. Water is suitable only for modes of use having few water quality requirements.	– Oxygen concentration in epilimnion 40–150%, frequent oxygen deficiency in the hypolimnion – Feacal indicator bacteria < 1 000 CFU/100 ml – Total phosphorus 50–100 µg/l (In Baltic Sea 40–80 µg/l) – Mean chlorophyll-a in the growing season 20–50 µg/l (In Baltic Sea 12–30 µg/l) – Algal blooms common – Concentrations of harmful substances: As < 50 µg/l, Hg < 2 µg/l, Cd < 5 µg/l, Cr < 50 µg/l, Pb < 50 µg/l, total cyanide < 50 µg/l – Off-flavours often found in fish

Class	Class interpretation	Variables and their threshold values
V Poor	Wastewaters, diffuse loading or other changing activity extensively pollute the watercourse. Algal blooms occur frequently and are often abundant, restricting water use for a long period. Oxygen concentrations are clearly affected by eutrophication. Concentrations of harmful substances in water, sediment or biota can be at levels that cause a clear risk to the use of water or biota. In catchments with Littorina Sea* clay deposits, the pH of water can be very low for long periods and die-offs of fish caused by the acidic conditions occur repeatedly. Poorly suited to any mode of use.	– Major problems of oxygen balance, oxygen saturation in the epilimnion during summer may exceed 150%; on the other hand total oxygen depletion at the surface may occur; at the end of the stratification season the whole hypolimnion may be anaerobic – Feacal indicator bacteria >1 000 CFU/100 ml – Total phosphorus > 100 µg/l (In Baltic Sea > 80 µg/l) – Mean chlorophyll-a in the growing season > 50 µg/l (In Baltic Sea > 30 µg/l) – One or more of the following exceeds the threshold-limit specific for class IV: As, Hg, Cd, Cr, Pb or total cyanide – Mercury concentration in predatory fish species > 1 mg/kg – Oil film on the water surface often observed

APPENDIX

B SURFACE WATER RATING CURVES

Station: RAUSW001 – Niesajoki

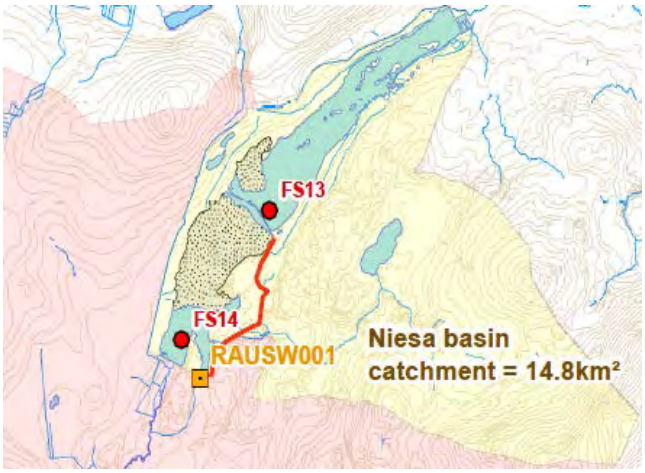




Photo B1: Gauging station RAUSW001 downstream of south pond spillway

Table B1: Observed spot flow measurements at RAUSW001

Date	Flow (m^3/s)	Water Level (m)
15/06/2012	0.56	-
04/07/2012	0.29	497
27/07/2012	0.10	414
10/08/2012	0.31	517
09/10/2012	0.63	663
12/09/2012	0.13	441

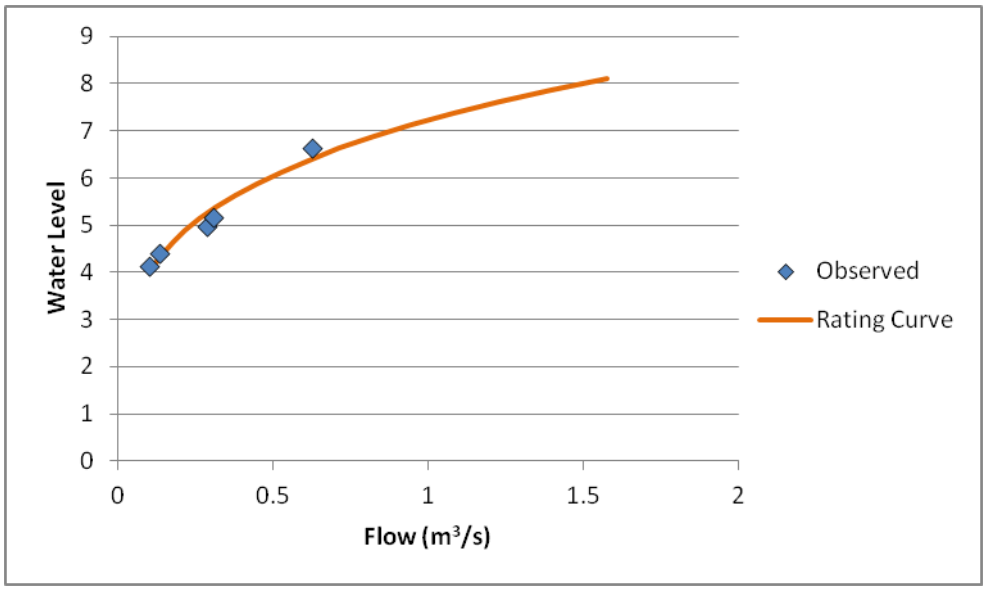


Figure B1: RAUSW001 rating curve and observed spot flows

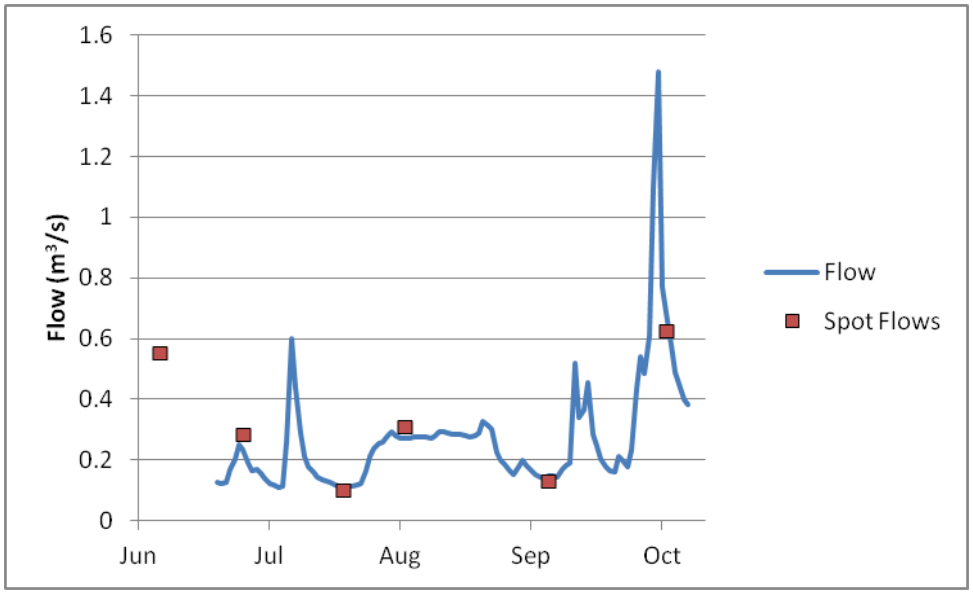


Figure B2: Flow graph generated with the RAUSW001 rating curve and observed spot flows

Table B2: Calculated average monthly flows at RAUSW001

Month	Amount of measurements	Average flow m^3/s
June	4	0.15
July	31	0.18
August	31	0.27
September	30	0.21
October	14	0.62

Station: RAUSW002 – Niesajoki

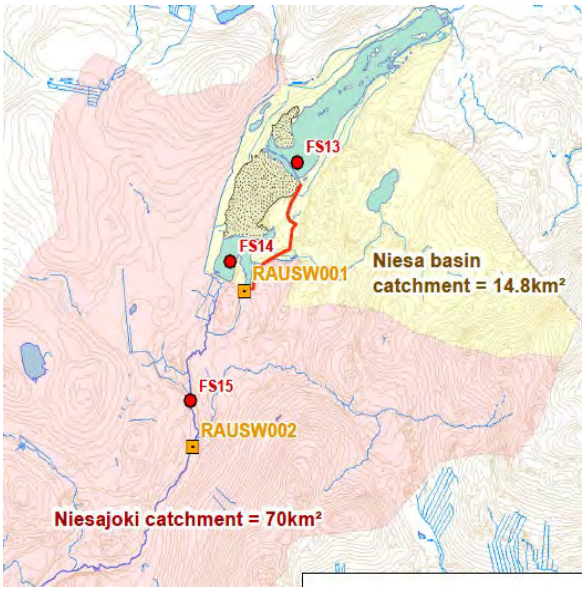




Photo B2: Gauging station RAUSW002 downstream of a road bridge

Table B3: Observed spot flow measurements at RAUSW002

Date	Flow (m^3/s)	Water Level (-)
29/06/2012	0.48	13.7
27/07/2012	0.24	13.6
10/08/2012	0.32	14.2
09/10/2012	1.12	16.2
12/09/2012	0.26	13.9

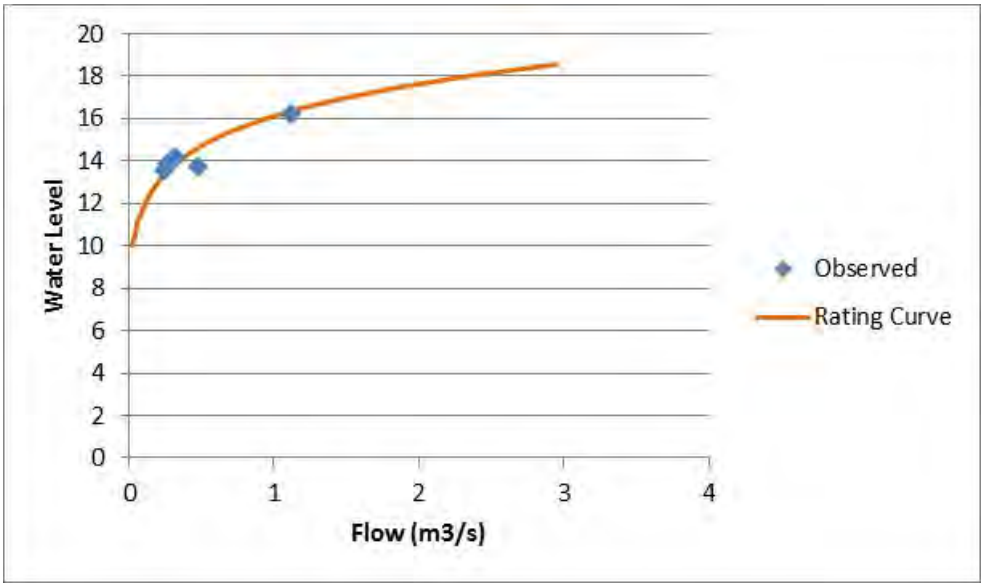


Figure B3: RAUSW003 rating curve and observed spot flows

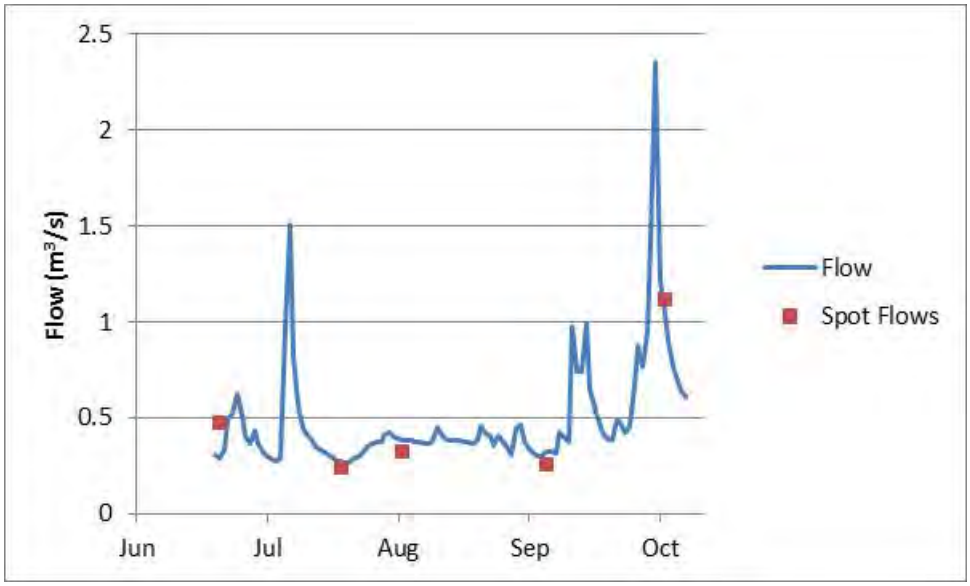


Figure B4: Flow graph generated with the RAUSW002 rating curve and observed spot flows

Table B4: Calculated average monthly flows at RAUSW002

Month	Amount of measurements	Average flow m3/s
June	4	0.23
July	31	0.44
August	31	0.38
September	30	0.46
October	14	0.95

Station: RAUSW003 – Niesajoki

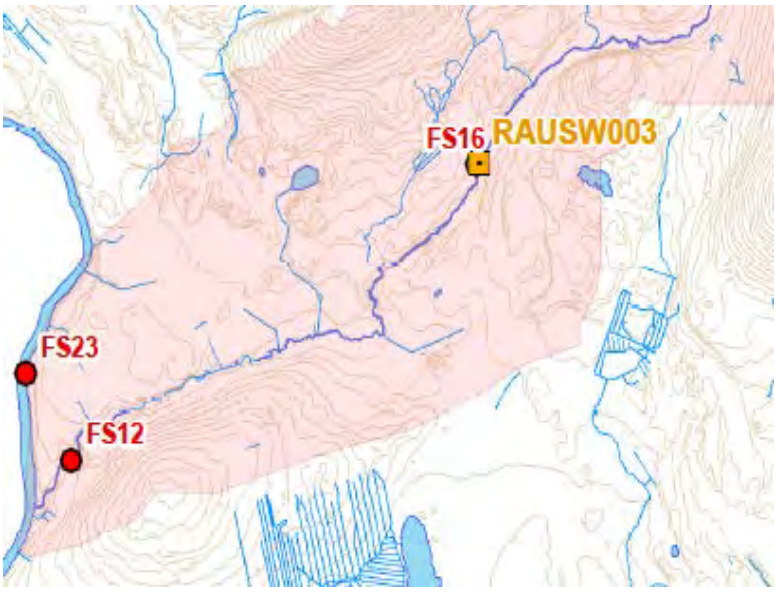




Photo B4: Gauging station RAUSW003. Picture taken looking upstream.

Table B5: Observed spot flow measurements at RAUSW003

Date	Flow (m3/s)	Water Level (m)
15/06/2012	0.91	
29/06/2012	0.60	483
27/07/2012	0.55	469
10/08/2012	0.56	508
09/10/2012	1.5	700
12/09/2012	0.45	481

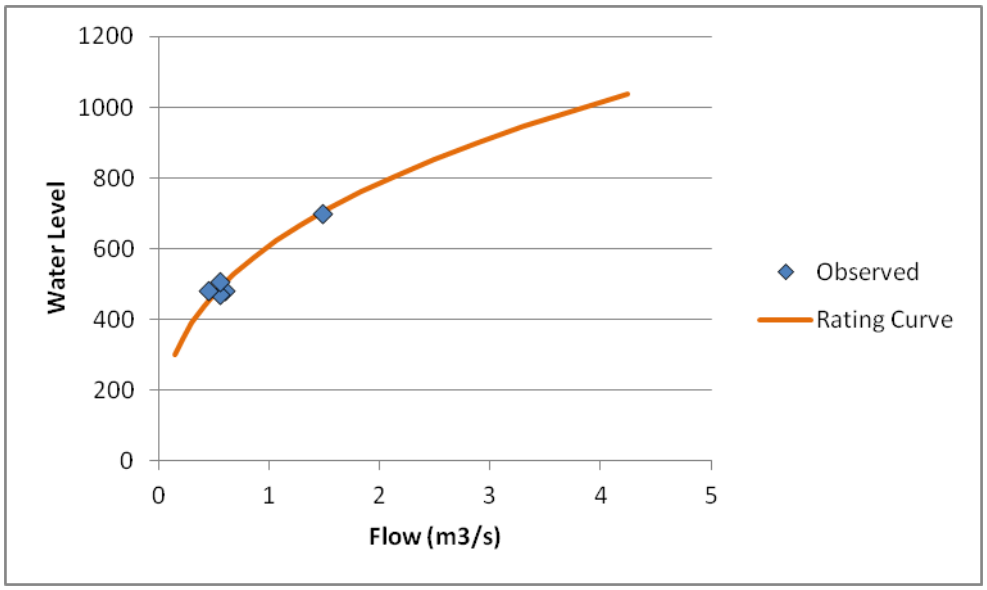


Figure B5. RAUSW003 rating curve and observed spot flows

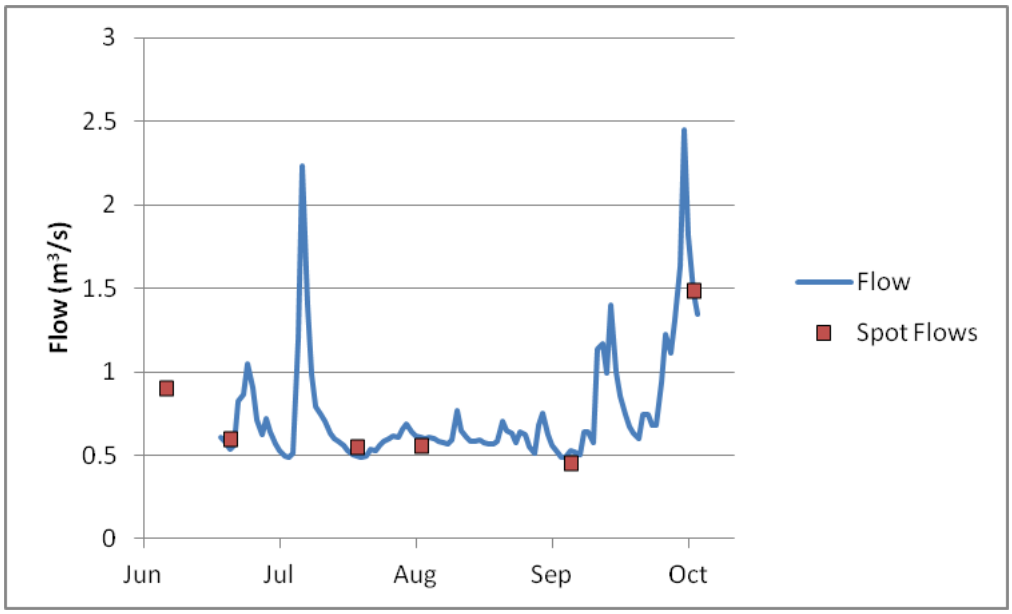


Figure B6: Flow graph generated with the RAUSW003 rating curve and observed spot flows

Table B6: Calculated average monthly flows at RAUSW003

Month	Amount of measurements	Average flow m^3/s
June	5	0.57
July	31	0.74
August	31	0.61
September	30	0.71
October	10	1.4

Station: RAUSW004 – Niesajoki

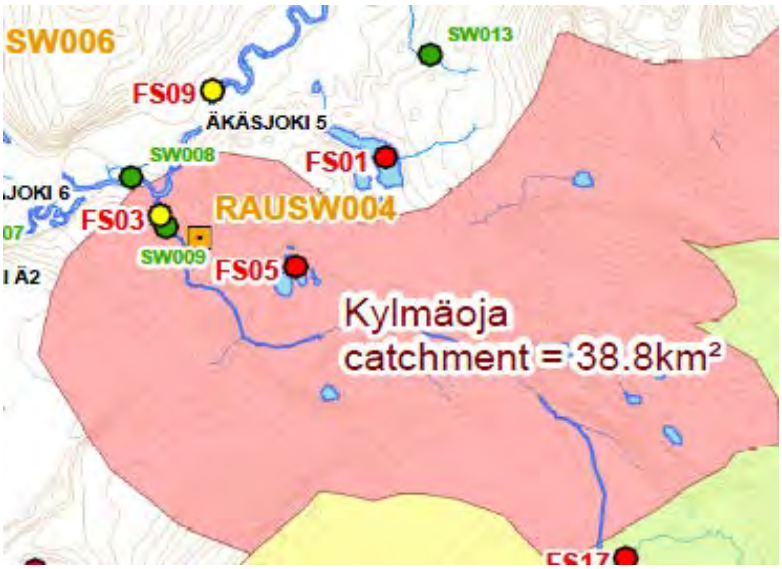




Photo B3: Gauging station RAUSW004 upstream the confluence with Äkäsjoki. Picture taken looking downstream.

Table B7: Observed spot flow measurements at RAUSW004

Date	Flow (m^3/s)	Water Level (m)
15/06/2012	0.54	-
19/06/2012	1.1	-
04/07/2012	0.92	327
27/07/2012	0.52	246
09/08/2012	0.51	234
09/10/2012	1.3	393
12/09/2012	0.47	247

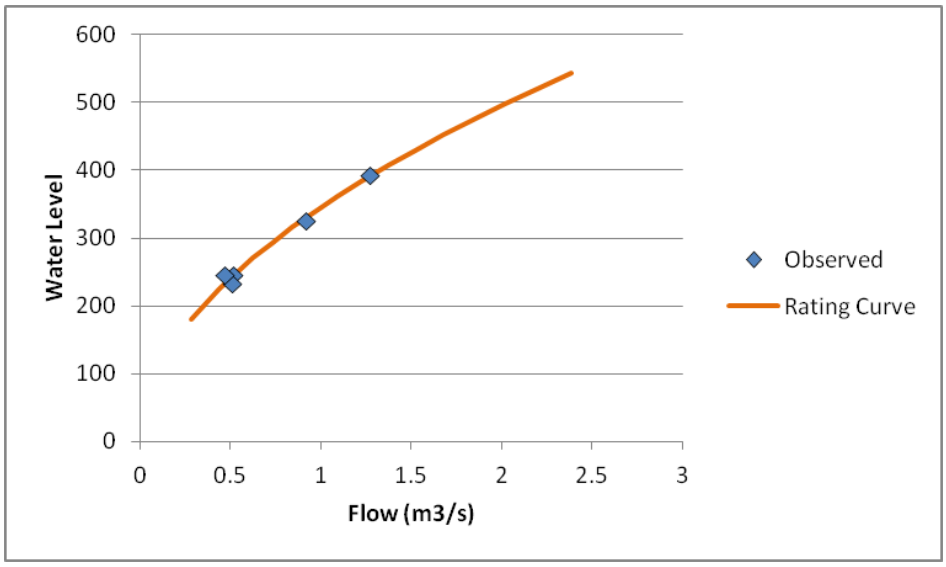


Figure B7: RAUSW004 rating curve and observed spot flows

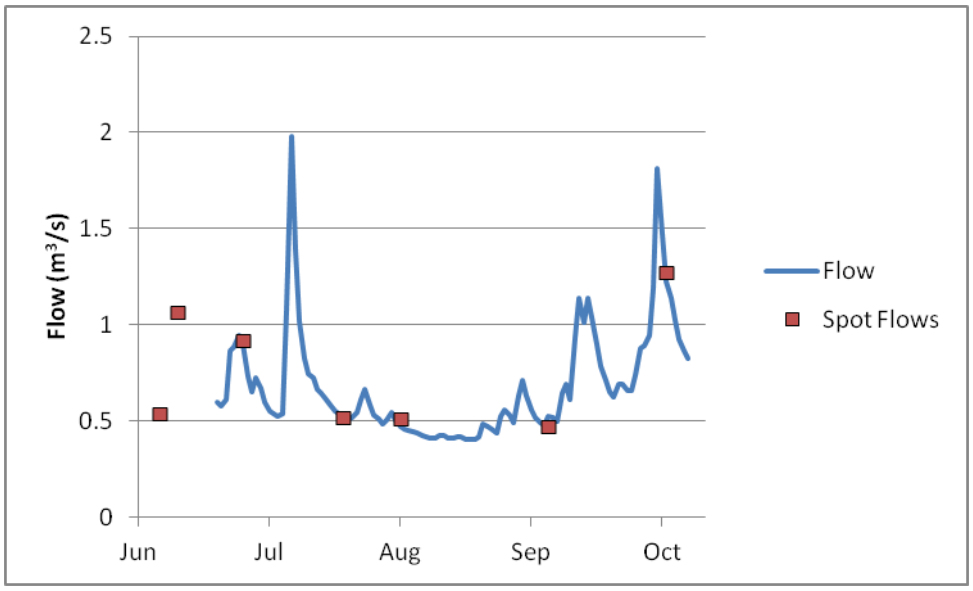


Figure B8: Flow graph generated with the RAUSW004 rating curve and observed spot flows

Table B8: Calculated average monthly flows at RAUSW004

Month	Amount of measurements	Average flow m^3/s
June	4	0.96
July	31	0.75
August	31	0.50
September	30	0.69
October	14	1

Station: RAUSW005 – Äkäsjoki

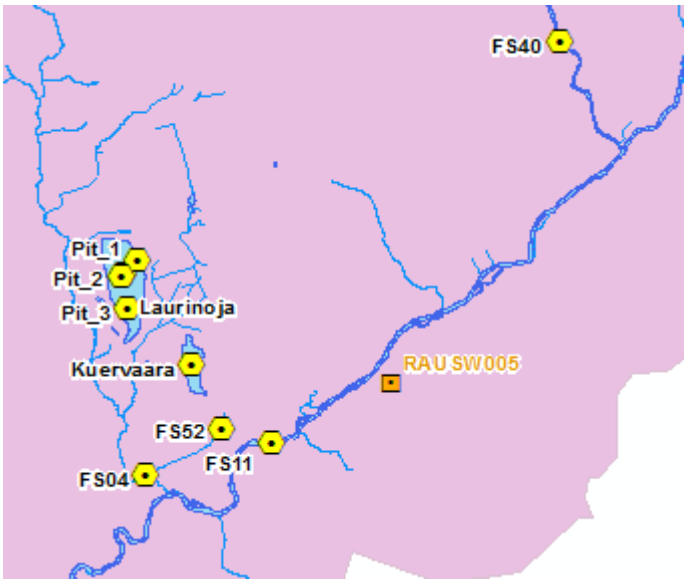




Photo A3: River near gauging station RAUSW005. Picture taken looking upstream.

Table A7: Observed spot flow measurements at RAUSW005

Date	Flow (m^3/s)	Water Level (m)
04/07/2012	10.65	665.83
27/07/2012	6.14	540.31
09/08/2012	5.26	512.92
09/10/2012	12.7	810.00
12/09/2012	4.06	483.65

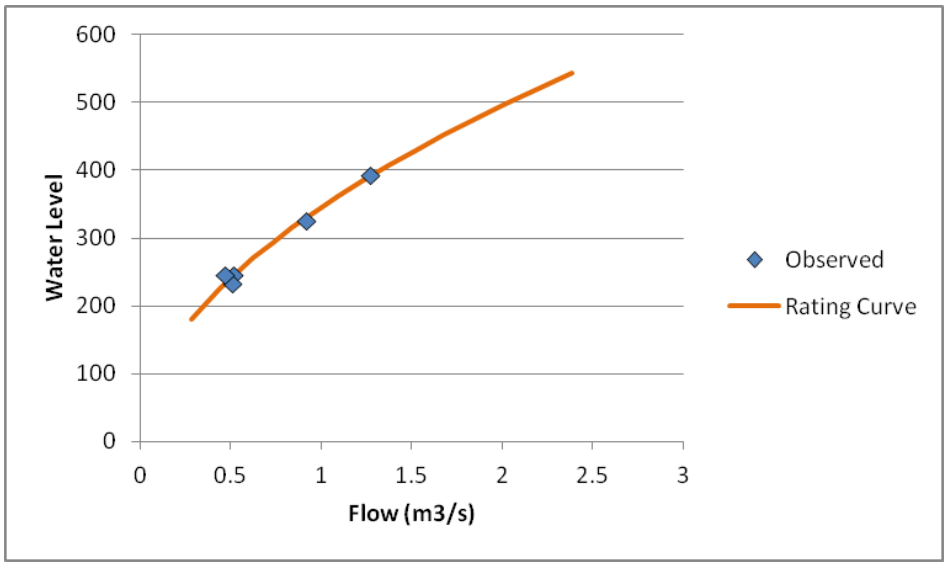


Figure A7: RAUSW005 rating curve and observed spot flows

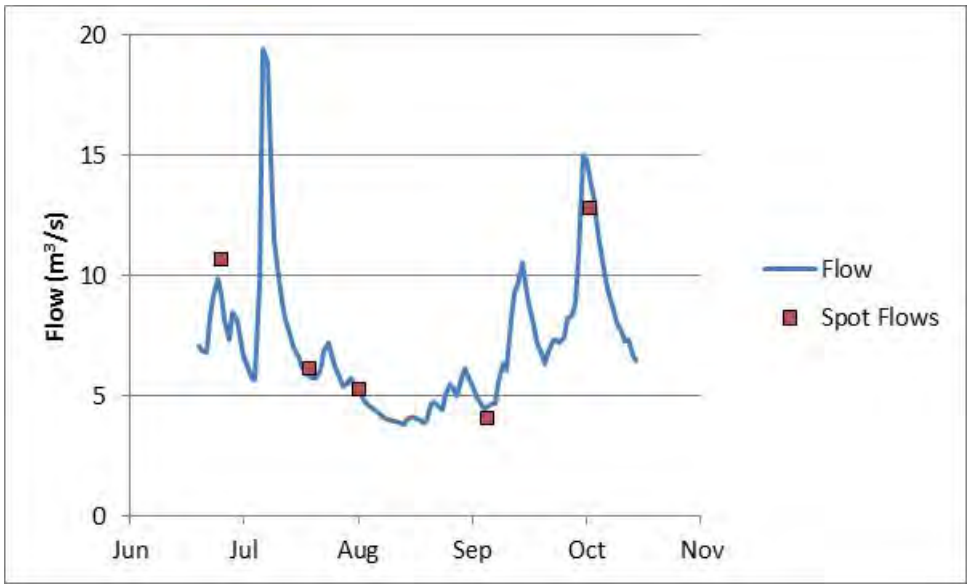


Figure A8: Flow graph generated with the RAUSW005 rating curve and observed spot flows

Table A8: Calculated average monthly flows at RAUSW005

Month	Amount of measurements	Average flow m^3/s
June	4	2.6
July	31	8.5
August	31	4.7
September	30	6.5
October	24	9.7

Station: RAUSW006 –Valkeajoki





Photo A3: Valkeajoki at gauging station RAUSW006. Picture taken looking downstream.

Table A7: Observed spot flow measurements at RAUSW006

Date	Flow (m^3/s)	Water Level (m)
19/06/2012	1.23	-
04/07/2012	1.25	284.38
27/07/2012	1.06	264.54
09/08/2012	0.87	247.14
09/10/2012	1.01	281.25
12/09/2012	0.75	236.72

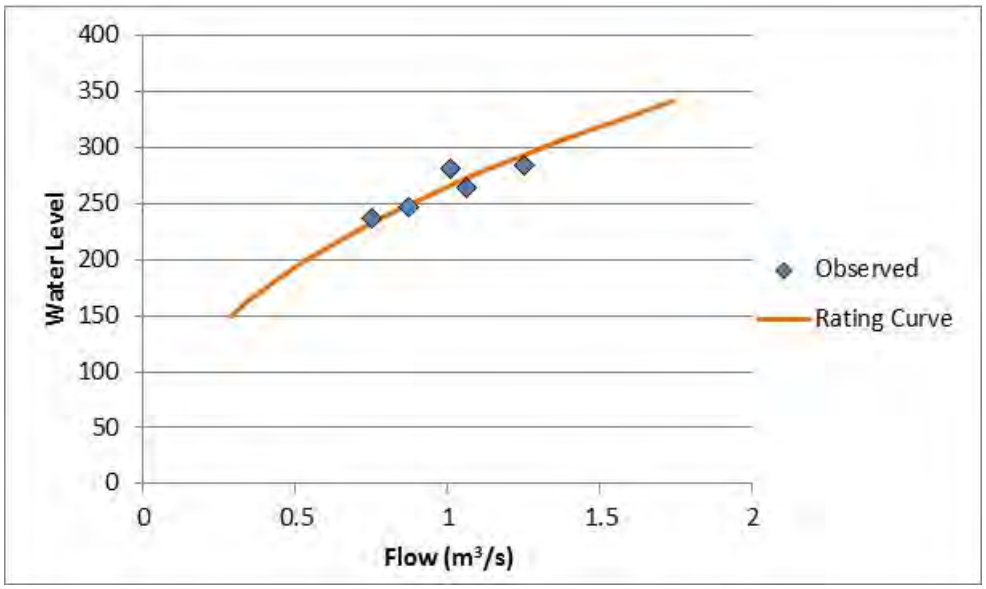


Figure A7: RAUSW006 rating curve and observed spot flows

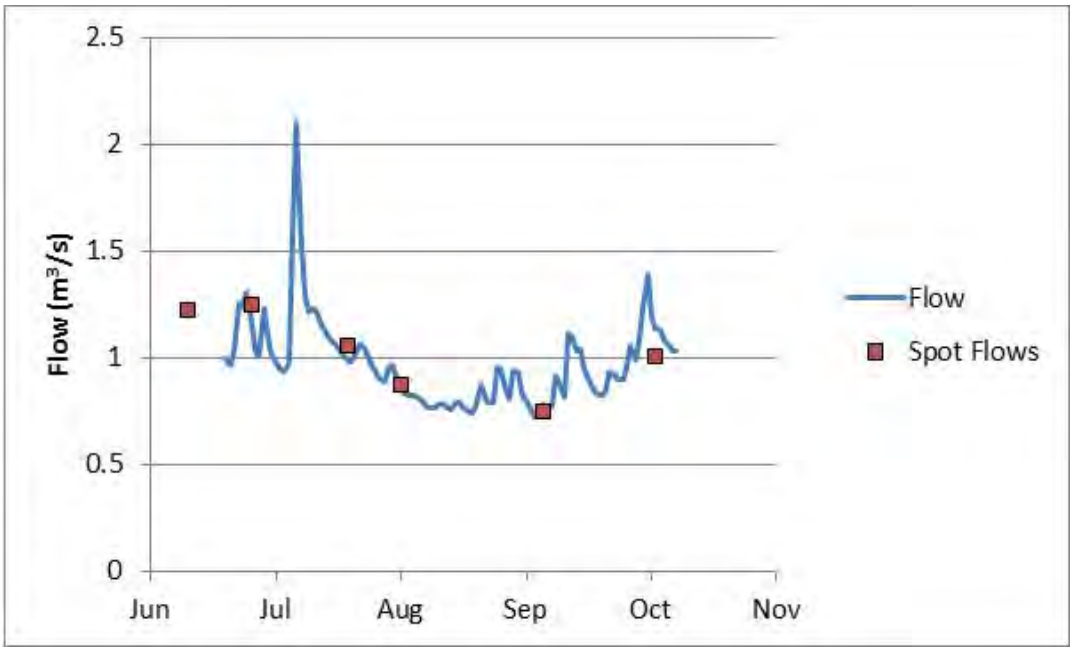


Figure A8: Flow graph generated with the RAUSW006 rating curve and observed spot flows

Table A8: Calculated average monthly flows at RAUSW006

Month	Amount of measurements	Average flow m^3/s
June	4	1.70
July	31	1.16
August	31	0.83
September	30	0.88
October	25	1.72

APPENDIX

C SURFACE WATER MODELLING

APPENDIX C: SW MODELLING

1. INTRODUCTION

Baseline flow estimates are required for the rivers and catchments within the study area, i.e., Äkäsjoki, Kuerjoki, Niesajoki, Klymaoja and Valkeajoki Rivers that flow adjacent to the proposed development, and the Muonionjoki River downstream of the project. In the absebce of multiple years of flow data for the rivers in the study area (except Muonionjoki which is gauged), estimates of key hydrological parameters are based on a regional hydrological analysis using available gauged flow data collected by the Finnish Environment Institute (Suomen Ympäristökeskus) and regional environment centres (ELY-keskus).

The regional assessment derives values for a series of key hydrological parameters for each catchment, namely;

- Annual runoff totals;
- Monthly runoff totals and monthly averaged flows; and
- Low flow conditions, such as annual and July to September 7-day minimum flow

Average annual values are derived for each parameter and where possible values for different return periods (probabilities of occurrence) are also calculated.

Flow estimates for the study catchments are based on extrapolation of gauged data from relevant nearby sites to the study catchments. However, estimates based on the regional analysis are compared to flow estimates generated by the Finnish Environmental Institute's (SYKE) hydrological model and by the Northern Hemisphere Climate Processes Land Surface Experiment Project (NOPEX) model (Äkäsjoki River only).

There is a good flow record for Muonionjoki River and as a result estimates for this river are based on analysis of gauged flow data. Results for other rivers can be updated over time once data has been collected from the hydrological monitoring stations set-up in the project area in summer 2012.

2. DATA USED IN ASSESSMENT

Finnish Environment Institute (Suomen Ympäristökeskus) and the regional environment centres (ELY-keskus) operate an extensive flow monitoring network throughout Finland. Hydrological observation data from the monitoring stations are available to the public from the online OIVA database operated by Finland's environmental administration. Daily flow data for a number of gauged sites located close to the mine site were obtained. In addition, flow data for the Muonionjoki River downstream the mine site is obtained from a gauge point operated by the Swedish Meteorological and Hydrological Institute (SMHI).

Table C1: Details of gauged sites

Name	Gauge site reference	Monitoring location	Grid references	Catchment area	Lake Coverage %	Years of data	Length of record (years)	Flow records	Annual runoff (mm)
Muonionjoki	6700510	Kaaresuvanto, Enontekiö	7602104 3315490	5732 km^2	3.4	Jan 1972-present	40	daily	464
Muonionjoki	6700800	Muonio	7544261 3360141	9259 km^2	3.5	Jun 1960-present	44	daily	428
Seurujoki	6503221	Ukonvuoma, Kittilä	7538967 3430897	267 km^2	0.25	Sep 2007-present	4	daily	505
Ounasjoki	65761	Köngäs, Kittilä	7524506 3413063	4515 km^2	4.2	Jun 1960-Nov 2011	44	daily	356
Ounasjoki	6503300	Kaukonen, Kittilä	7489605 3410871	8020 km^2	2.8	Jun 1960-present	34	daily	395
Pyhäjoki	6500720	Pallasjärvi, Kittilä	7551488 3380665	42 km^2	1.6	Sep 2004-present	7	daily	605
Ylläsjoki	6701100	Pakola, Kolari	7479437 3369191	435 km^2	1.5	Sep 1960-May 1972	10	daily	342
Kallio	2395	Kallio, Sweden	7479620 1833710	14477 km^2	3.4	Jan 1911-present	102	daily	358
Naamijoki	6701300	Sieppijärvi, Kolari	7452566 3369212	890 km^2	2.8	Jun 1960-Oct 2011	40	daily	272
Raanujärvi	6701840	Pello	7417572 3385391	339 km^2	3.8	Jan 1985-present	45	daily	294
Hosionkoski	6400310	Ranua	7314345 3447097	1981 km^2	8.5	Jan 1962-Nov 2011	41	daily	402

Data for eleven stations were obtained, with details provided in Table 1. The catchment area of the gauge sites varies between 42 and 14,477 km2. Most of the gauges have a catchment area larger than 500 km2. This is not unexpected as large catchments are over-represented in gauged flow data sets world-wide. In relatively remote regions (such as Lapland) it is not uncommon for there to be a limited flow dataset for small (< 100 km2) catchments due to difficulties and costs of maintaining gauges on small streams. As a result, care needs to be taken in extrapolating gauged data from large catchments to smaller streams. The Äkäsjoki River has a catchment area of around 523 km2 near the site, which is similar in size to many of the gauged catchments. Kuerjoki River has a catchment area of around 160 km2 at its mouth. However, it is noted that other key catchments (Valkeajoki and Niesajoki) are smaller (<100 km2). Hence, for these catchments results obtained from the regional analysis are compared to estimates from rainfall-runoff catchment models.

3. RESULTS

3.1 Annual runoff estimates

Average annual runoff totals for each of the gauged sites are shown in Table 1. Annual runoff for gauged stations with more than 10 years of data (i.e., Seurujoki and Pyhäjoki excluded) are plotted against catchment area and the latitude of site in Figure 1. The plots indicate that annual runoff generally increases with catchment area and latitude; however, the relationship with area is stronger than the relationship with latitude.

Data points for Äkäsjoki and Kuerjoki are plotted in Figure 1, based on the best fit line through the data. Based on the best fit line for the relationship with catchment area, the annual average runoff best estimate for Äkäsjoki is considered to be 310 mm with a range of around 280-340 mm, equivalent to ±10% around the best fit line through the data. For Kuerjoki the best estimate is 270 mm with a range of around 240 – 300 mm.

The SYKE model was run for the Äkäsjoki and Kuerjoki catchments (Pöyry, 2011) giving annual average runoff totals of 300 mm and 290 mm respectively. These values are consistent with the estimates made based on Figure 1. Given the similarity between the two results the values derived from Figure 1 are considered as best estimates and used in subsequent analyses.

The Valkeajoki and Niesajoki catchments are less than 100 km2 and as a result care must be taken when extrapolating data from Figure 1 to such small catchments. However, if the best fit line for the relationship to catchment area were used this gives an annual average runoff of around 250 mm for both catchments. The SYKE model results for the Valkeajoki River give an average annual runoff of 290 mm. As the key impacts of the mine development are likely to occur under low flow conditions, the lower annual runoff value of 250 mm is selected as the best estimate to provide a more conservative (low) estimate of stream flows in the rivers.

The Muonionjoki River is gauged at the Kallio gauge site some 20 km downstream of its confluence with Äkäsjoki River and close to the confluence with the Niesajoki River. The catchment at the gauge site is around 14,500 km2 and the inflowing catchment between the Äkäsjoki and the Kallio gauge is of the order of 500 km2, a small percentage of the total catchment of the Muonionjoki River. Hence, for the purpose of this assessment we use unadjusted data from the Kallio gauge as a surrogate for flows in Muonionjoki River at the confluence with Äkäsjoki River and Niesajoki River. There are 102 years of data at the Kallio gauge and the average runoff at the gauge is measured as 358 mm.

Average annual runoff totals for study catchments are summarised in Table 2. The same values can be used for other locations within the study catchments, as outlined in Table 1 (e.g., Äkäsjoki River at its mouth).

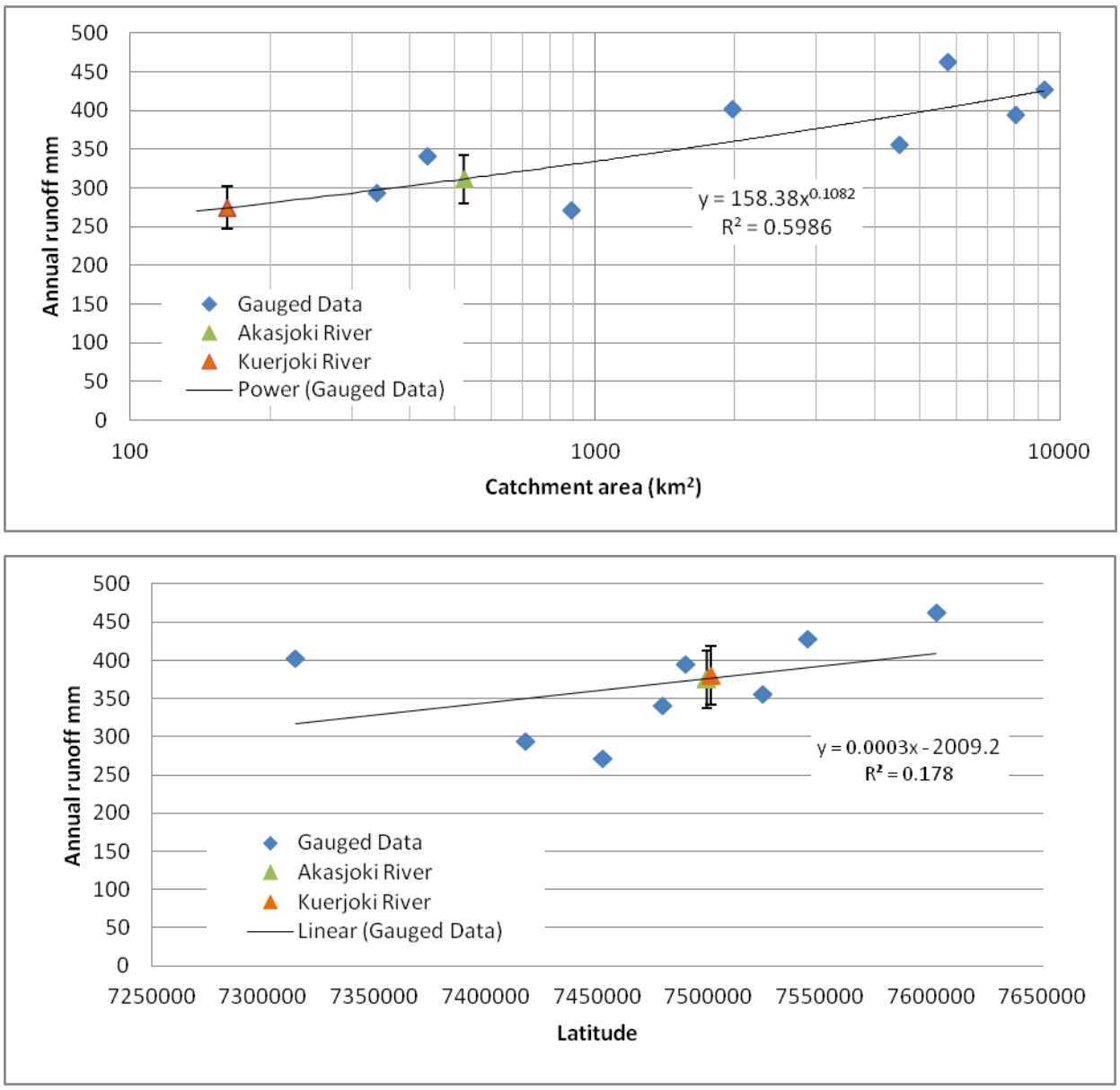


Figure C1: Plots of annual runoff against catchment area and latitude

Table C2: Annual runoff estimates used in assessment

Catchment	Äkäsjoki River at the site	Kuerjoki River at its mouth	Valkeajoki River at its mouth	Niesajoki River at its mouth	Muonionjoki River
Best estimate (mm)	[a]310	[a]270	[a]250	[a]250	[b]360

[a] *Based on regional analysis of gauged flow data*

[b] *Based on observed flow data at Kallio gauging station*

3.2 Monthly flows

3.2.1 Average monthly flows

Observed average monthly runoff totals and average monthly flow distributions for each of the gauged sites are shown in Figure 2. The results indicate that the gauged sites fall into three broad groups;

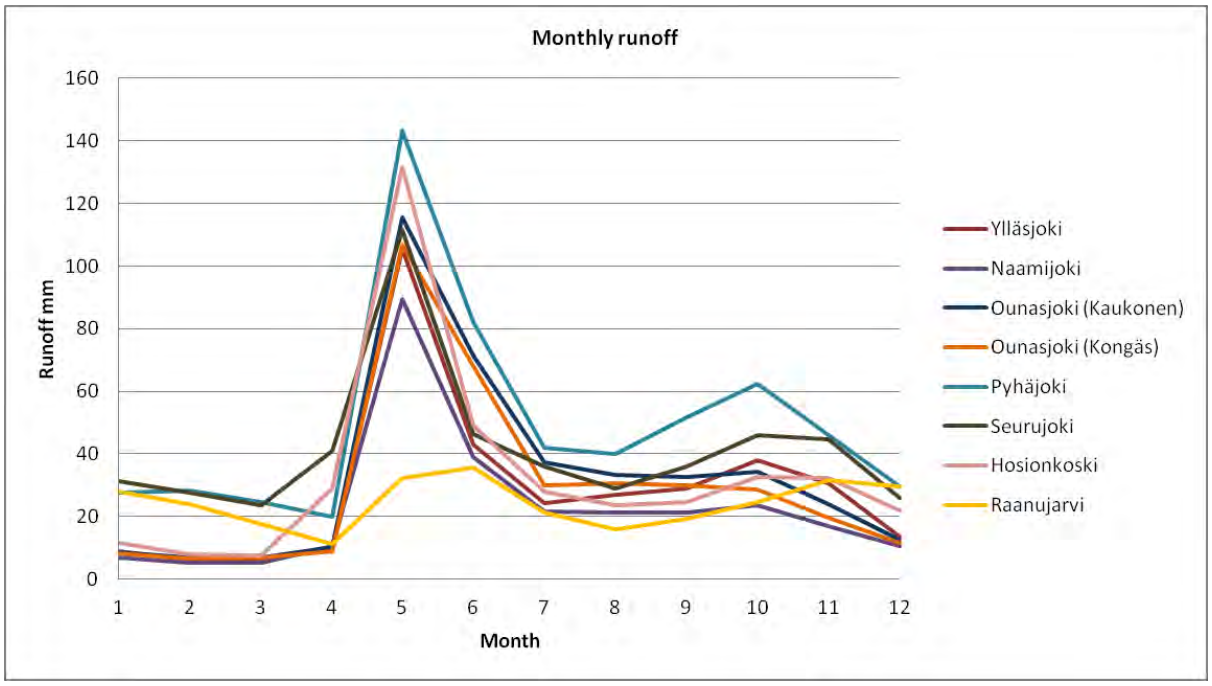
1. Sites with highest average flows in May soon after snowmelt (i.e., Köngäs, Kaukonen, Ylläsjoki, Naamijoki and Hosionkoski). These catchments appear to respond rapidly to snowmelt in spring.
2. Sites with highest average flows delayed to June (i.e., Kaaresuvanto, Muonio and Kallio). These are three of the largest rivers with peak monthly flows delayed compared to smaller gauged rivers. The delay in river response can result from a number of factors such as upstream storage in reservoirs and lakes and the fact that larger rivers contain land extending over a wide range of elevations, such that the timing of snowmelt can vary within the catchment, extending the snow melt period.
3. Site with evenly distributed monthly flows (i.e., Raanujärvi). The Raanujärvi gauge is located between two large lakes such that flows at this site are severely modified by storage and attenuation within the upstream lake.

The catchment areas of Äkäsjoki River, its tributaries and Niesajoki River are considered consistent with stations in Group 1 above. The study catchments are not extremely large (like sites in Group 2) or excessively modified by lakes or reservoirs (like Group 3). The Äkäsjoki and Niesajoki Rivers contain large lakes in their headwaters (Äkäsjärvi Lake for Äkäsjoki River and Niesa Basin for Niesajoki River); hence, flows in the rivers close to the lakes will be impacted by lake storage. However, the Äkäsjärvi Lake impacts a small percentage of the whole Äkäsjoki River catchment and at the mouth of the Niesajoki River the Niesa Basin also impacts a very small catchment area.

Average monthly flows for the Äkäsjoki River, Kuerjoki River, Valkeajoki River and Niesajoki River are calculated by dividing the average annual runoff total by monthly flow percentages based on the average of the monthly flows from Group 1 stations (i.e., Köngäs, Kaukonen, Ylläsjoki, Naamijoki and Hosionkoski).

Results for the Äkäsjoki River are shown in Table 3, where they are compared to monthly flow totals obtained from an application of the SYKE and NOPEX catchment models. There is a reasonably good comparison between the flow estimates produced by the three methods. Monthly average flow estimates for Kuerjoki River, Valkeajoki River and Niesajoki River are provided in Tables 4 to 6.

Monthly average flows for Muonionjoki River are based on analysis of gauged data from Kallio, with results presented in Table 7.



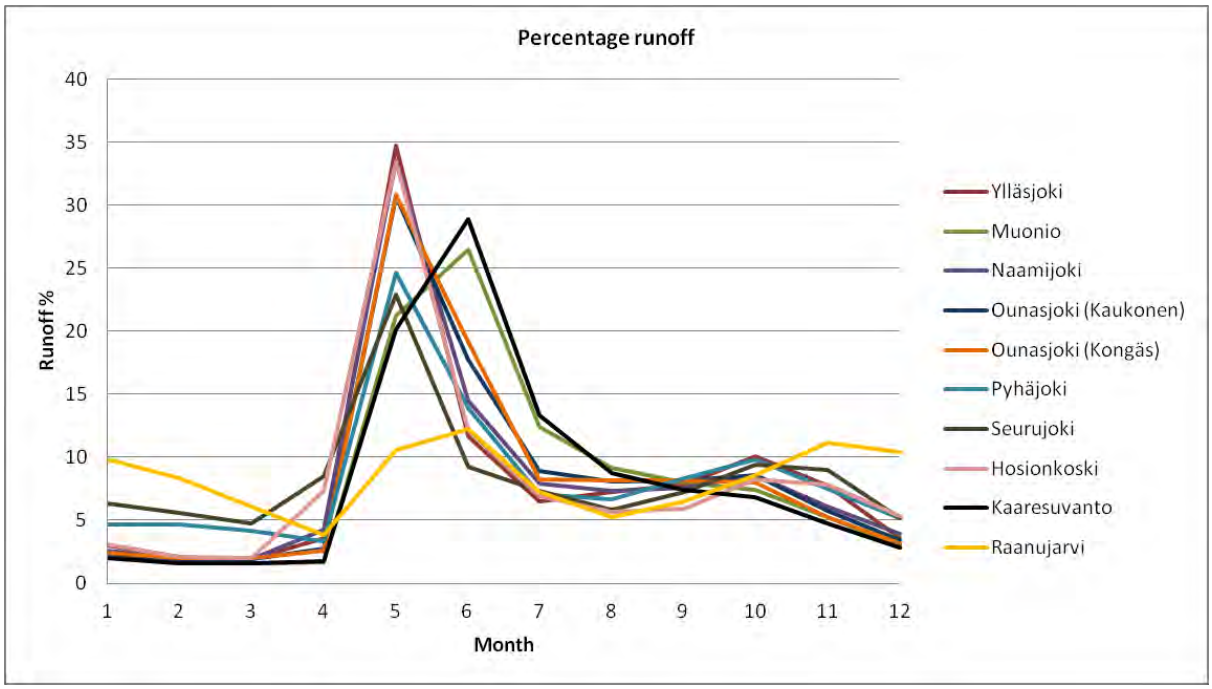


Figure C2: Average monthly flows for all sites

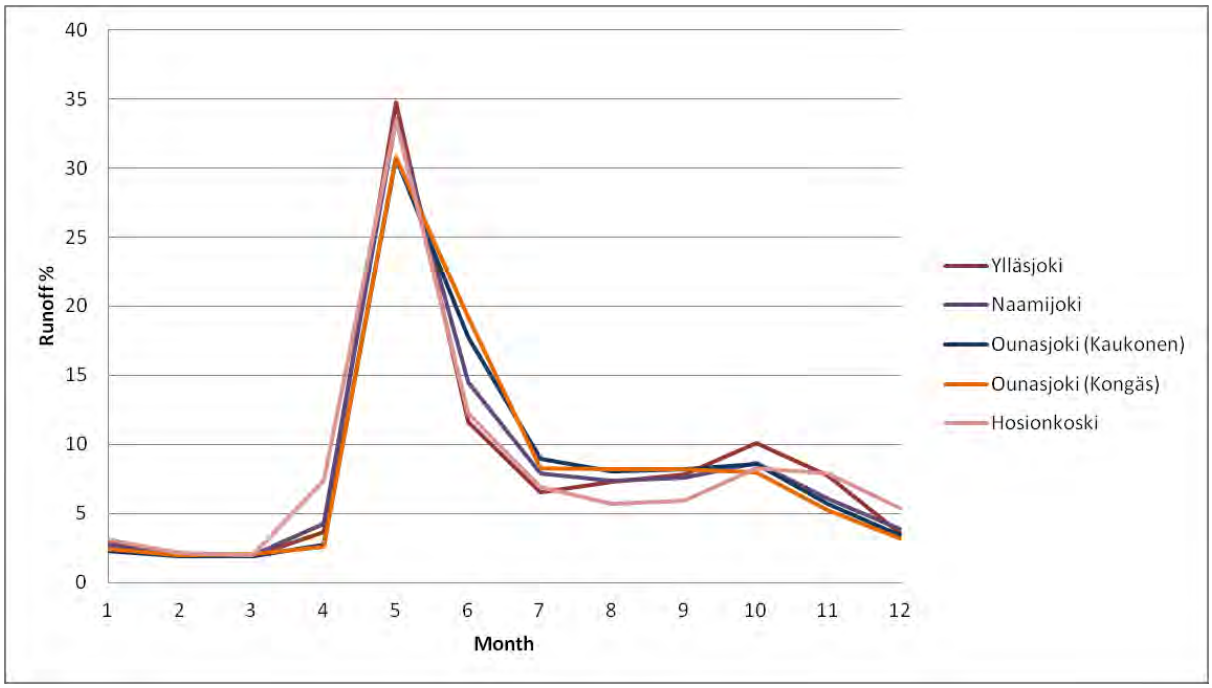


Figure C3: Average monthly flow percentages for sites relevant to study catchments (extracted from previous figures)

Table C3: Average monthly runoff and flow rates for Äkäsjoki River at site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	8.3	6.2	6.1	12.7	101.2	46.7	23.9	22.6	23.4	27	20.3	12
Average flow (m^3/s)	1.7	1.3	1.2	2.6	20.4	9.4	4.8	4.6	4.7	5.4	4.1	2.4
SYKE model (m^3/s)	2.3	1.9	2.2	5.2	21.1	6.4	2.7	3.6	4.0	4.5	3.8	2.7
NOPEX model (m^3/s)	1.9	1.4	1.0	2.5	19.5	11.7	6.3	6.0	5.8	1.0	0.5	0.3

Table C4: Average monthly runoff and flow rates for Kuerjoki River at its mouth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	7.2	5.4	5.3	11.1	88.1	40.6	20.8	19.7	20.4	23.5	17.7	10.5
Average flow (m^3/s)	0.5	0.3	0.3	0.7	5.5	2.5	1.3	1.2	1.3	1.5	1.1	0.7
SYKE model (m^3/s)	0.5	0.5	0.5	1.0	9.0	1.3	0.6	1.0	1.1	1.3	1.0	0.6

Table C5: Average monthly runoff and flow rates for Valkeajoki River at its mouth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	6.5	4.9	4.8	10.0	79.6	36.7	18.8	17.8	18.4	21.2	16.0	9.5
Average flow (m^3/s)	0.1	0.1	0.1	0.2	1.6	0.8	0.4	0.4	0.4	0.4	0.3	0.2
SYKE model (m^3/s)	0.2	0.2	0.2	0.4	2.5	0.6	0.2	0.3	0.4	0.4	0.4	0.2

Table C6: Average monthly runoff and flow rates for Niesajoki River at its mouth

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	6.8	5.1	5.0	10.4	82.6	38.1	19.5	18.5	19.1	22.0	16.5	9.8
Average flow (m^3/s)	0.2	0.1	0.1	0.3	2.4	1.1	0.6	0.5	0.6	0.6	0.5	0.3

Table C7: Average monthly runoff and flow rates for Muonionjoki River

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average runoff (mm)	7.8	6.9	6.5	9.9	86	89	42	32	31	26	14	9.6
Average flow (m^3/s)	41	37	34	46	438	449	211	154	153	128	72	50

3.2.2 Return period monthly flows

In order to determine return period monthly flows for the rivers we considered the following methodology;

- Generate return period monthly flow estimates for all relevant gauged sites based on fit to a log-normal distribution. The log-normal distribution was found to provide a good fit to the observed data.
- Identify 'scaling factors' for each return period based on dividing monthly runoff total with the median monthly total for each site.
- Derive average scaling factors for each return period and apply these to average monthly runoff totals derived for Äkäsjoki, its tributaries and Niesajoki River.
- Return period flows for Muonionjoki River at the confluence with Äkäsjoki River were estimated through analysis of gauged flow data at the Kallio gauging station.

The estimates monthly return period flows are summarised in Tables 8 to 12.

Table C8: Predicted return period average monthly flows for Äkäsjoki River adjacent to mine site

	Average Monthly Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.77	0.69	0.68	0.72	9.3	3.4	1.6	1.1	1.4	1.8	1.2	1.0
1 in 50 DRY	0.85	0.74	0.73	0.84	10.2	3.9	1.8	1.3	1.6	2.1	1.4	1.1
1 in 10 DRY	1.1	0.90	0.88	1.3	13.2	5.4	2.6	2.1	2.4	3.0	2.06	1.5
Average	**1.7**	**1.3**	**1.2**	**2.6**	**20.4**	**9.4**	**4.8**	**4.6**	**4.7**	**5.5**	**4.1**	**2.4**
1 in 10 WET	2.6	1.8	1.7	5.2	31.5	16.4	8.8	9.8	9.3	10.0	8.1	3.9
1 in 50 WET	3.3	2.1	2.1	7.9	40.8	22.9	12.7	15.6	14.0	14.4	12.3	5.2
1 in 100 WET	3.6	2.3	2.2	9.2	44.8	25.8	14.4	16.5	16.2	16.4	14.2	5.8

Table C9: Predicted return period average monthly flows for Kuerjoki River at its mout

	Average Monthly Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 in 100 DRY	0.21	0.19	0.18	0.19	2.5	0.93	0.43	0.31	0.37	0.49	0.32	0.28
1 in 50 DRY	0.23	0.20	0.20	0.23	2.8	1.0	0.49	0.36	0.43	0.56	0.37	0.31
1 in 10 DRY	0.30	0.24	0.24	0.34	3.6	1.5	0.71	0.57	0.65	0.80	0.56	0.41
Average	**0.45**	**0.34**	**0.33**	**0.69**	**5.5**	**2.5**	**1.3**	**1.2**	**1.3**	**1.5**	**1.1**	**0.66**
1 in 10 WET	0.69	0.47	0.46	1.4	8.5	4.4	2.4	2.7	2.5	2.7	2.2	1.1
1 in 50 WET	0.89	0.58	0.56	2.1	11.0	6.2	3.4	4.2	3.8	3.9	3.3	1.4
1 in 100 WET	0.98	0.62	0.60	2.5	12.1	7.0	3.9	4.5	4.4	4.4	3.8	1.6

Table C10: Predicted return period average monthly flows for Valkeajoki River at its mouth

	Average Monthly Flow (m^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1 in 100 DRY	0.06	0.06	0.05	0.06	0.75	0.28	0.13	0.09	0.11	0.15	0.09	0.08
1 in 50 DRY	0.07	0.06	0.06	0.07	0.82	0.31	0.15	0.11	0.13	0.17	0.11	0.09
1 in 10 DRY	0.09	0.07	0.07	0.10	1.06	0.43	0.21	0.17	0.19	0.24	0.17	0.12
Average	**0.13**	**0.10**	**0.10**	**0.21**	**1.64**	**0.76**	**0.39**	**0.37**	**0.38**	**0.44**	**0.33**	**0.19**
1 in 10 WET	0.21	0.14	0.14	0.42	2.52	1.31	0.71	0.79	0.75	0.80	0.65	0.31
1 in 50 WET	0.27	0.17	0.17	0.63	3.28	1.84	1.02	1.25	1.12	1.15	0.98	0.42
1 in 100 WET	0.29	0.18	0.18	0.73	3.59	2.07	1.16	1.32	1.30	1.31	1.14	0.46

Table C11: Predicted return period average monthly flows for Niesajoki River at its mouth

	Average Monthly Flow (m^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1 in 100 DRY	0.09	0.08	0.08	0.08	1.09	0.40	0.19	0.13	0.16	0.21	0.14	0.12
1 in 50 DRY	0.10	0.09	0.08	0.10	1.19	0.45	0.21	0.16	0.19	0.24	0.16	0.13
1 in 10 DRY	0.13	0.11	0.10	0.15	1.55	0.63	0.31	0.25	0.28	0.35	0.24	0.18
Average	**0.20**	**0.15**	**0.14**	**0.30**	**2.39**	**1.10**	**0.56**	**0.53**	**0.55**	**0.64**	**0.48**	**0.28**
1 in 10 WET	0.30	0.21	0.20	0.61	3.68	1.92	1.03	1.15	1.09	1.17	0.95	0.46
1 in 50 WET	0.39	0.25	0.24	0.92	4.78	2.68	1.49	1.82	1.64	1.68	1.44	0.61
1 in 100 WET	0.42	0.27	0.26	1.07	5.24	3.01	1.69	1.93	1.89	1.91	1.66	0.68

Table C12: Predicted return period average monthly flows for Muonionjoki River at Kallio gauge

	Average Monthly Flow (m^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1 in 100 DRY	24	22	21	14	182	180	87	53	55	49	28	25
1 in 50 DRY	25	24	22	16	202	201	96	60	62	55	31	27
1 in 10 DRY	30	28	26	24	270	272	129	86	87	76	42	34
Average	**41**	**37**	**34**	**46**	**438**	**449**	**211**	**154**	**153**	**128**	**72**	**50**
1 in 10 WET	56	48	45	88	709	741	343	278	269	217	117	73
1 in 50 WET	67	57	53	131	948	1003	461	396	379	298	160	92
1 in 100 WET	71	61	56	150	1051	1116	511	449	428	333	178	100

APPENDIX

D BOREHOLE LOGS

HANNUKAINEN BOREHOLE LOGS

APPENDIX D – BOREHOLE LOGS

Holes have been renamed by Northlands since being drilled and named by SRK. The table below indicates the relationship between the two naming systems. Northland names have been used to construct the borehole logs contained within this appendix.

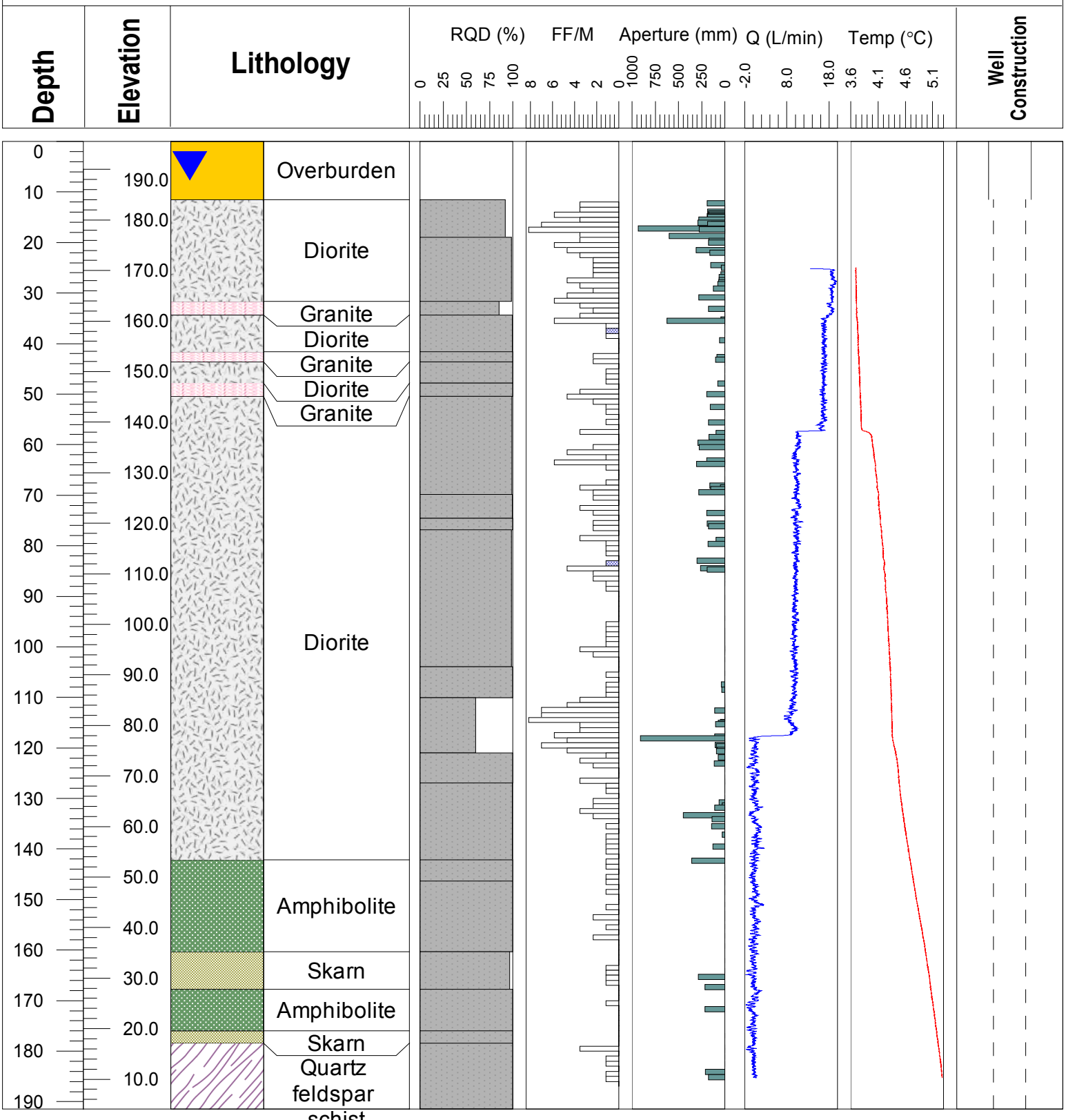
DH_ID	SRK Name	Easting	Northing	Elevation
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HAN11GT02	HAN_SRK_04	2498709.981	7496325.553	190.74
HAN11GT03	HAN_SRK_08	2498698.271	7495706.48	192.89
HAN11GT04	HAN_SRK_02	2498294.394	7496344.398	212.23
HAN11GT05	HAN_SRK_01	2498070.368	7496573.049	223.68
HAN11GT06	HAN_SRK_03	2498464.666	7496165.664	202.76
HAN11GT07	HAN_SRK_07	2498495.574	7495917.163	205.77
HAN11GT08	HAN_SRK_06	2499081.511	7495977.154	203.92
KUE11GT01	KUE_SRK_01	2498357.403	7500660.169	239.87
KUE11GT02	KUE_SRK_02	2498427.952	7500565.151	240.61
KUE11GT03	KUE_SRK_03	2498486.556	7500462.641	244.48
KUE11GT04	KUE_SRK_04	2498547.677	7500064.675	247.81
KUE11GT05	KUE_SRK_05	2498514.663	7499833.776	245.86
HAN11HYD01	HAN-OW-08	2498698.753	7495592.117	190.57
HAN11HYD02	HAN-PW-08	2498627.792	7495642.046	190.09
HAN11HYD03	HAN-OW-02	2498277.16	7496249.501	214.04
HAN11HYD04	HAN-PW-02	2498239.959	7496289.801	213.81
HAN11HYD05	KUE-OW-01	2498277.768	7500637.463	240.65
HAN11HYD06	KUE-PW-01	2498301.742	7500615.447	239.56

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT01

Easting: 2498778 **Northing:** 7496262



Drilling Date: 22-24/03/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.1
Hole Type: Geotechnical

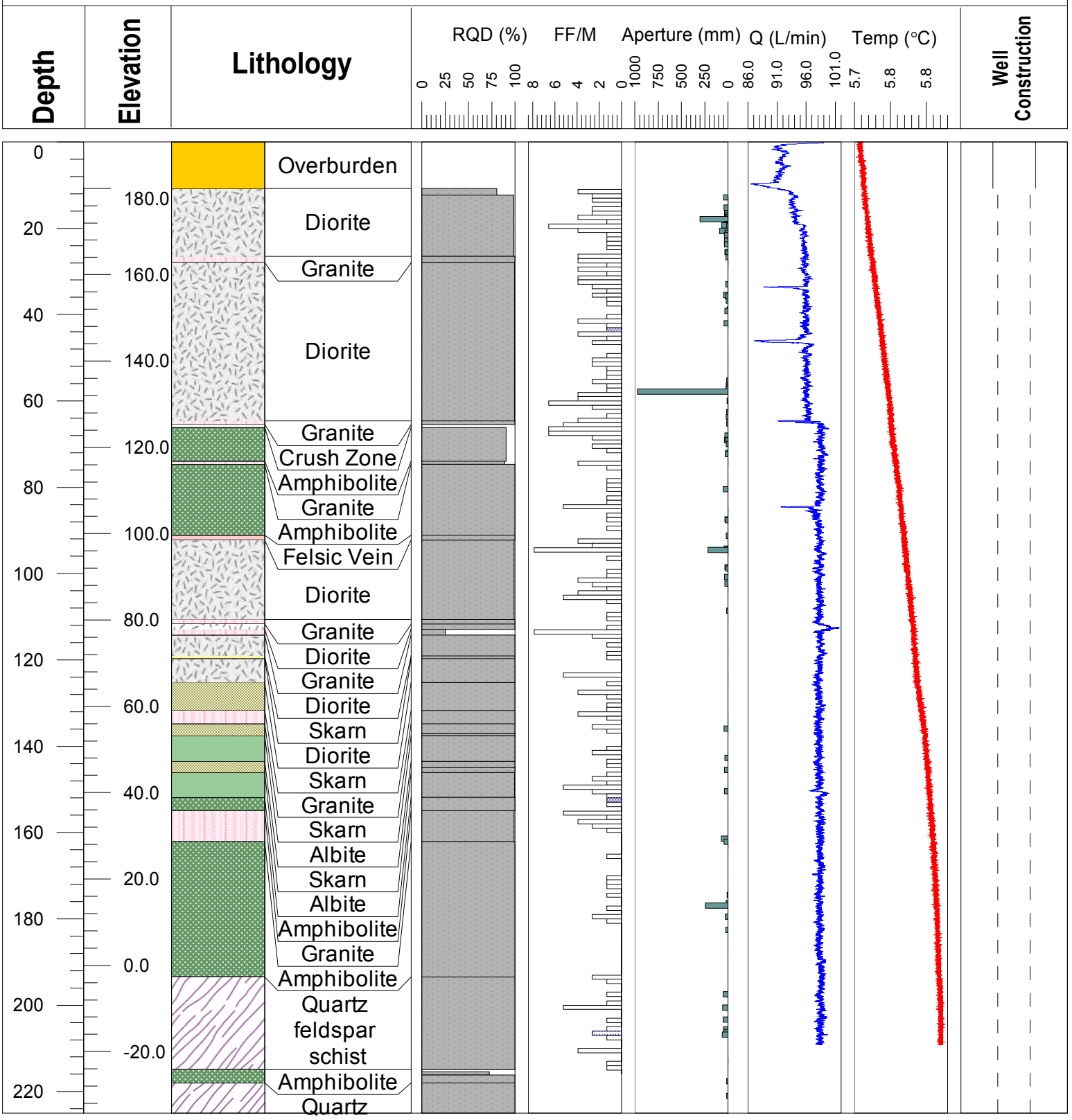
Dip (°): -78
Azi (°): 315

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT02

Easting: 2498710 **Northing:** 7496326



Drilling Date: 28-20/03/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m):
Hole Type: Geotechnical

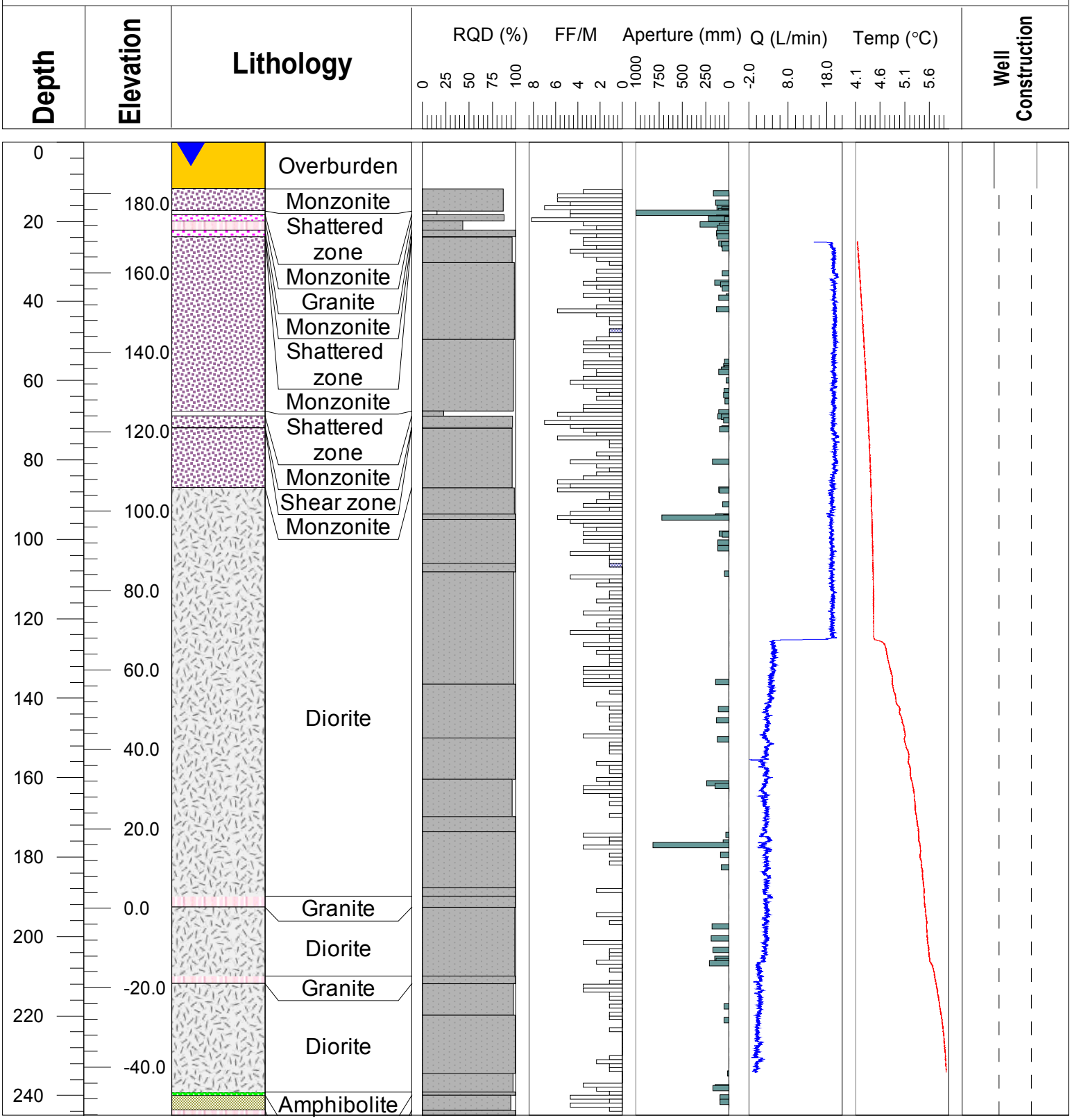
Dip (°): -60
Azi (°): 315

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT03

Easting: 2498698 **Northing:** 7495706



Drilling Date: 31/3-06/04/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.13
Hole Type: Geotechnical hole used as an observation well

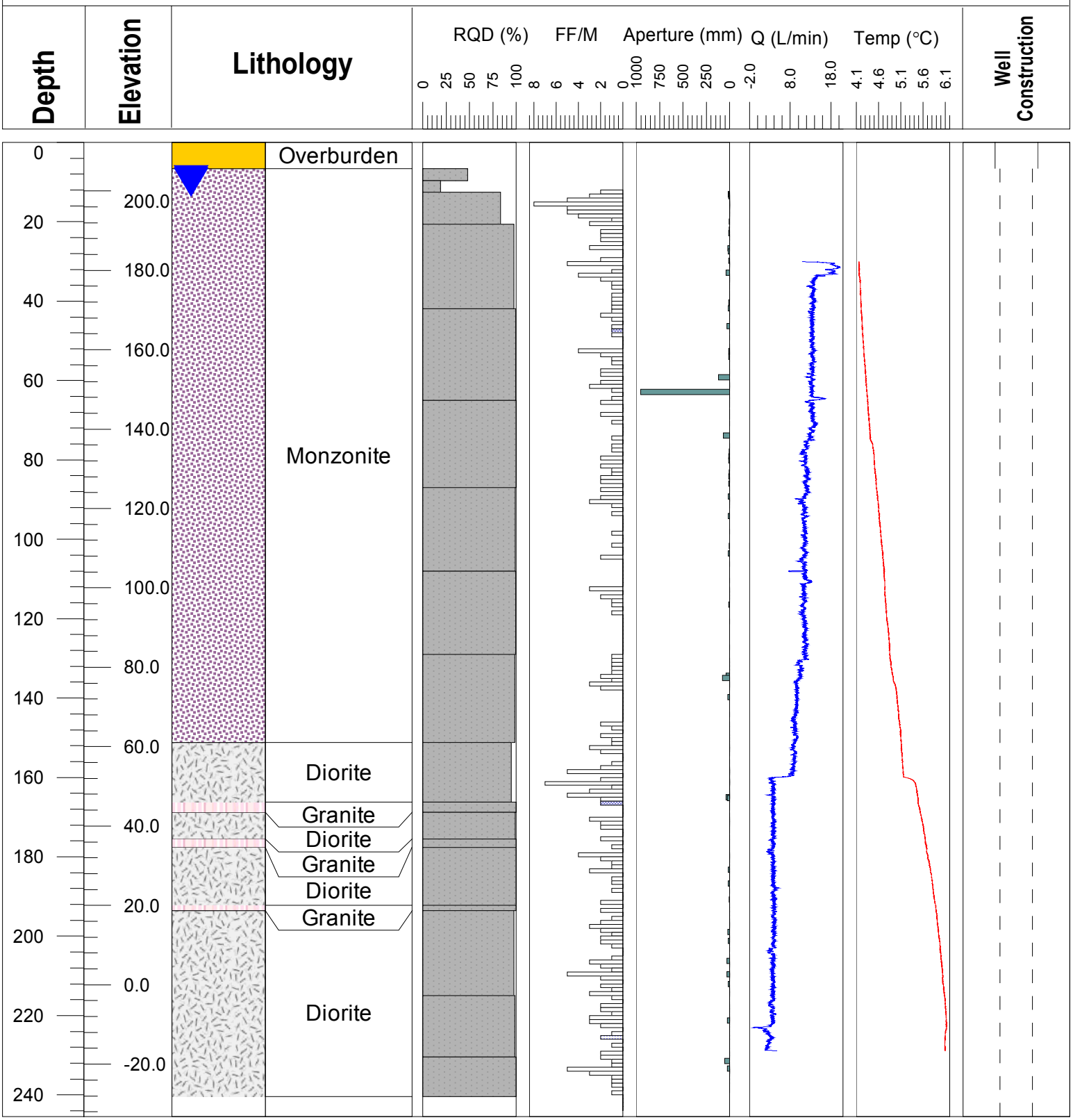
Dip (°): -78
Azi (°): 230

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT04

Easting: 2498294 **Northing:** 7496344



Drilling Date: 11-14/04/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.26
Hole Type: Geotechnical hole used as an observation well

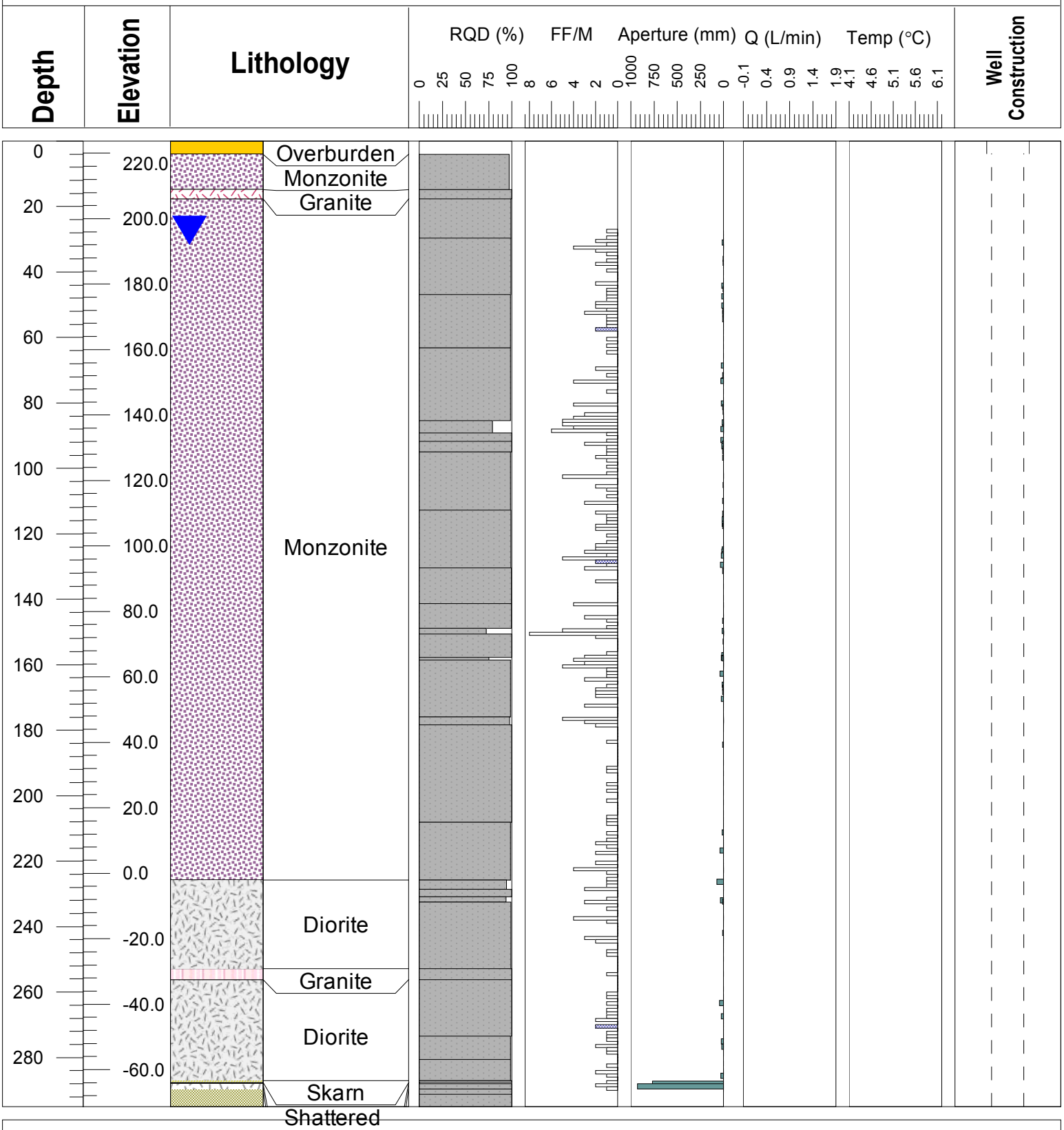
Dip (°): -80
Azi (°): 220

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT05

Easting: 2498070 **Northing:** 7496573



Drilling Date: 15-28/04/2011
Drilled ∅ (mm): 75.7
Filter pack: n/a
Dip (°): -55

Drilling Company: KATI OY
Casing ∅ (mm):
Stick-up (m): 0.07
Azi (°): 90

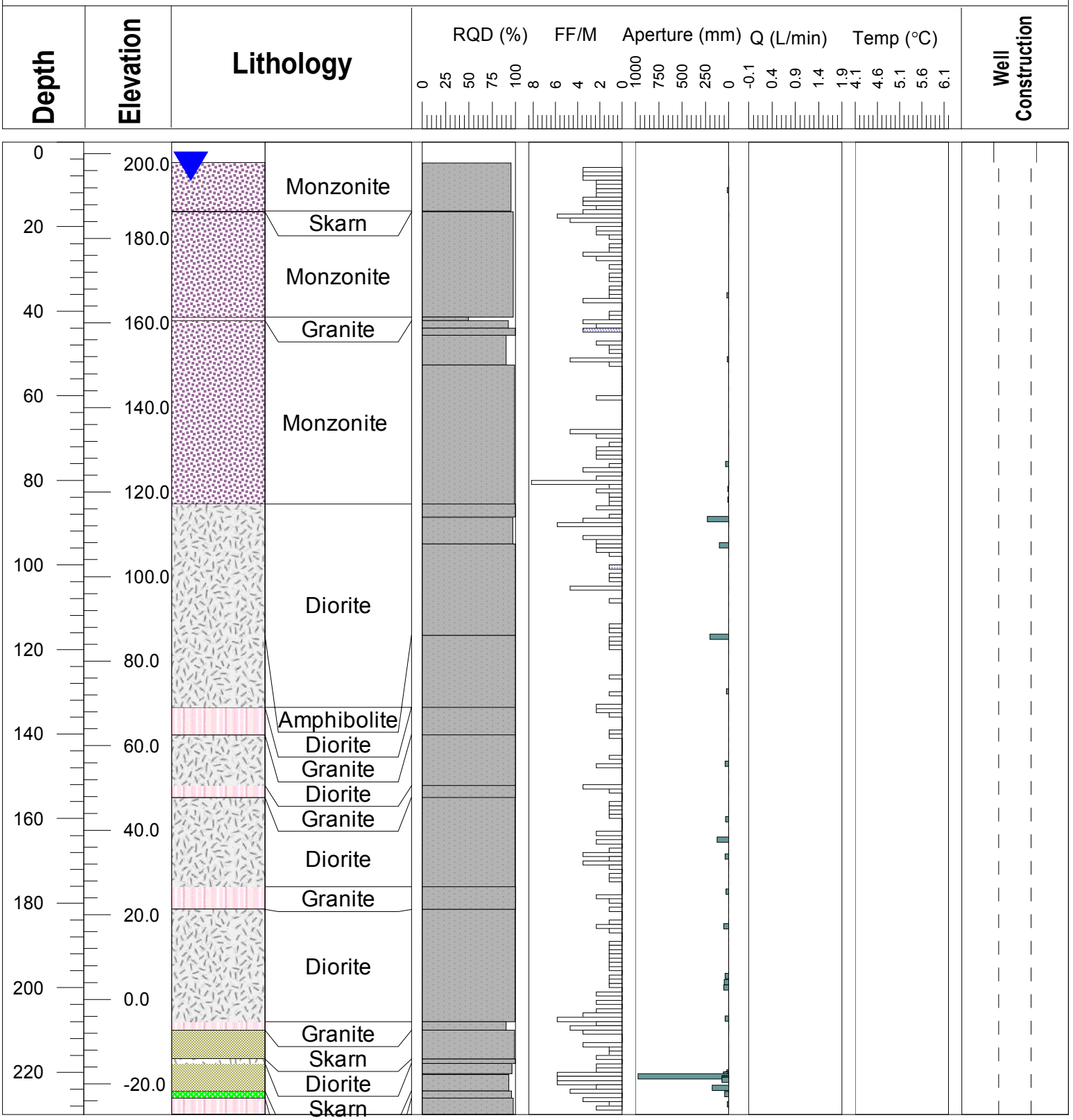
Drilling Method: DD
Slot size (mm): n/a
Hole Type: Geotechnical

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT06

Easting: 2498465 **Northing:** 7496166



Drilling Date: 02-05/05/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.11
Hole Type: Geotechnical

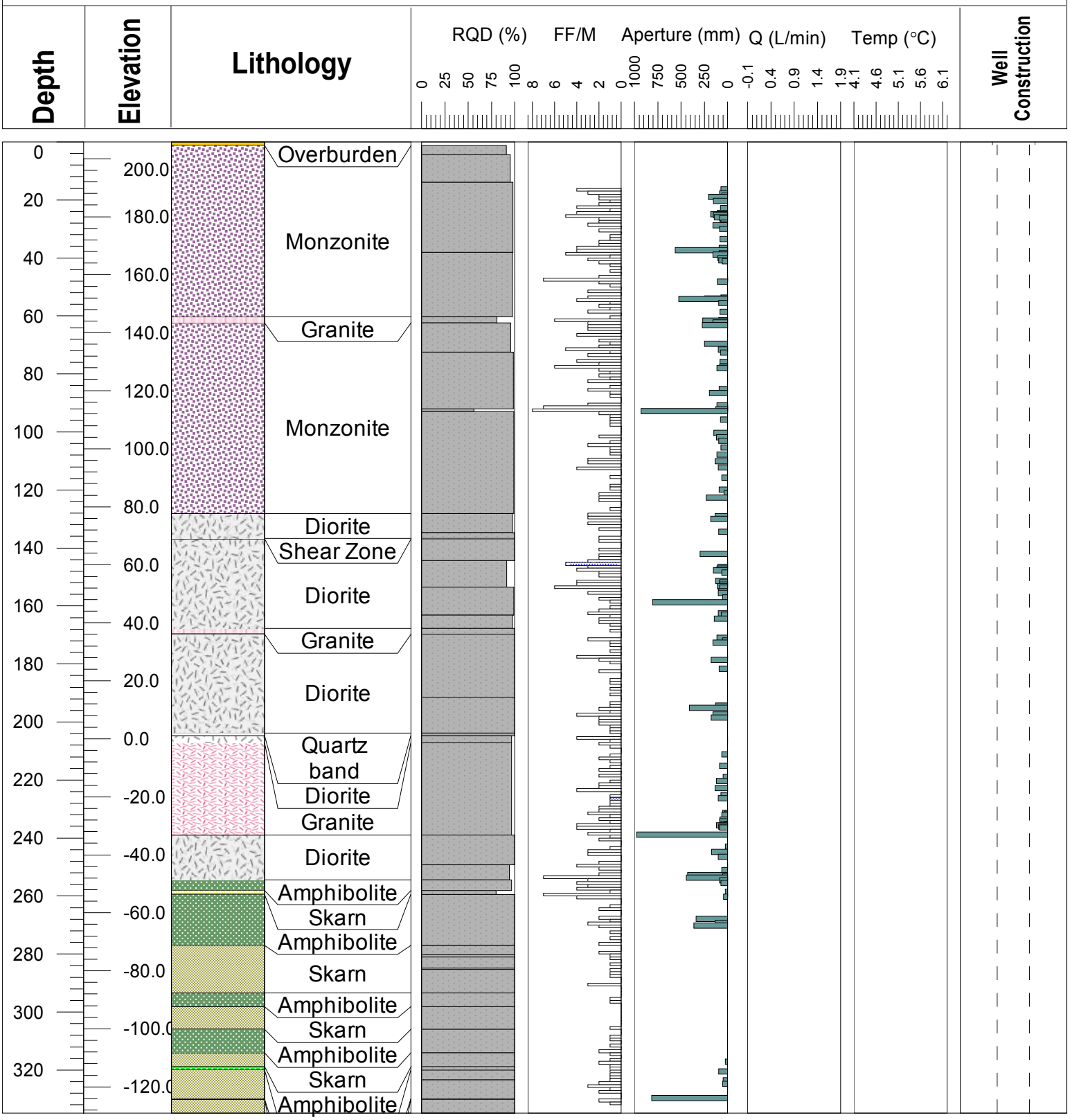
Dip (°): -65
Azi (°): 360

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT07

Easting: 2498496 **Northing:** 7495917



Drilling Date: 05-16/05/2011
Drilled ∅ (mm): 75.7
Filter pack: n/a
Dip (°): -60

Drilling Company: KATI OY
Casing ∅ (mm):
Stick-up (m):
Azi (°): 90

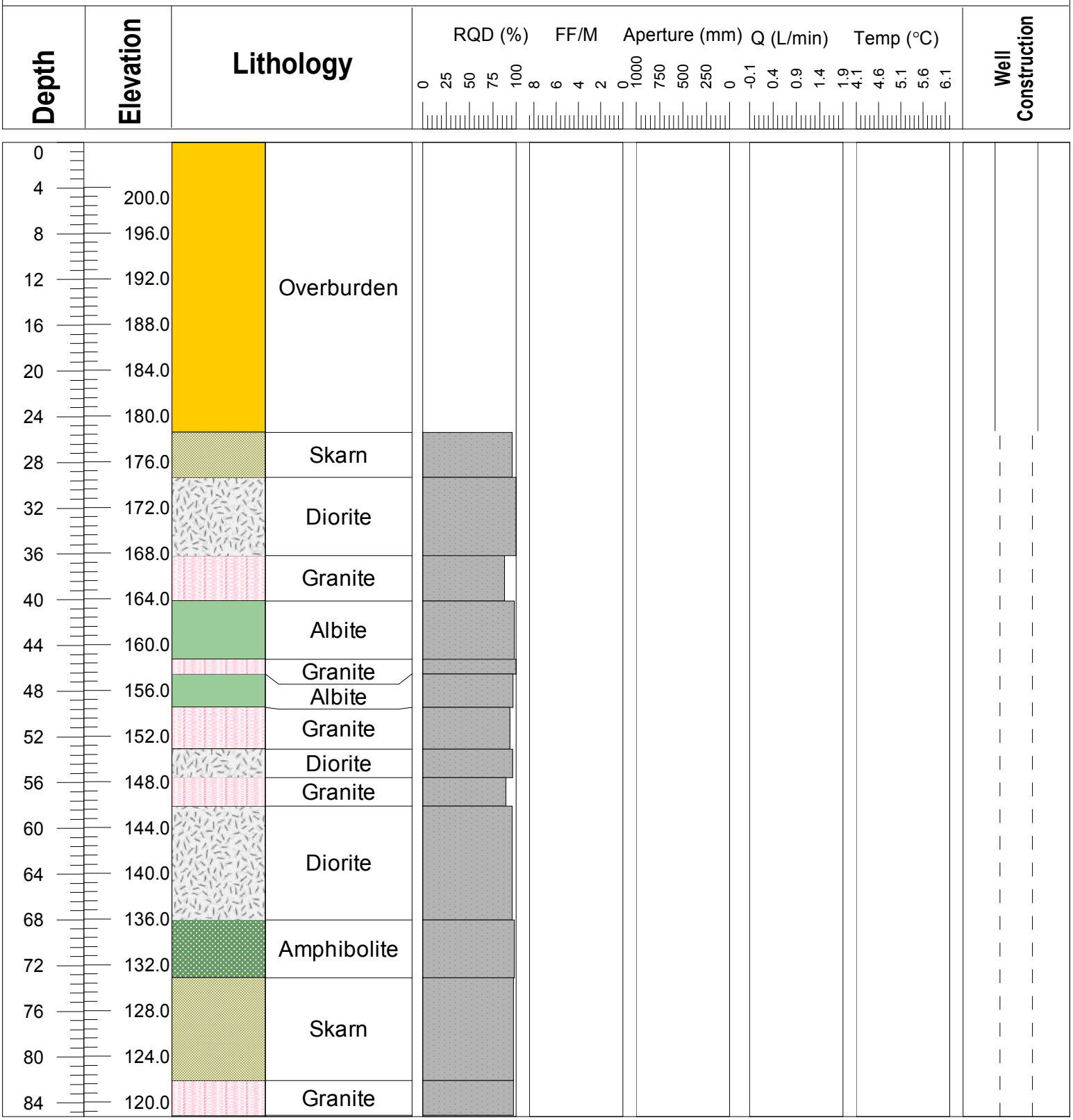
Drilling Method: DD
Slot size (mm): n/a
Hole Type: Geotechnical

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11GT08

Easting: 2499082 **Northing:** 7495977



Drilling Date: 15-17/05/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m):
Hole Type: Geotechnical

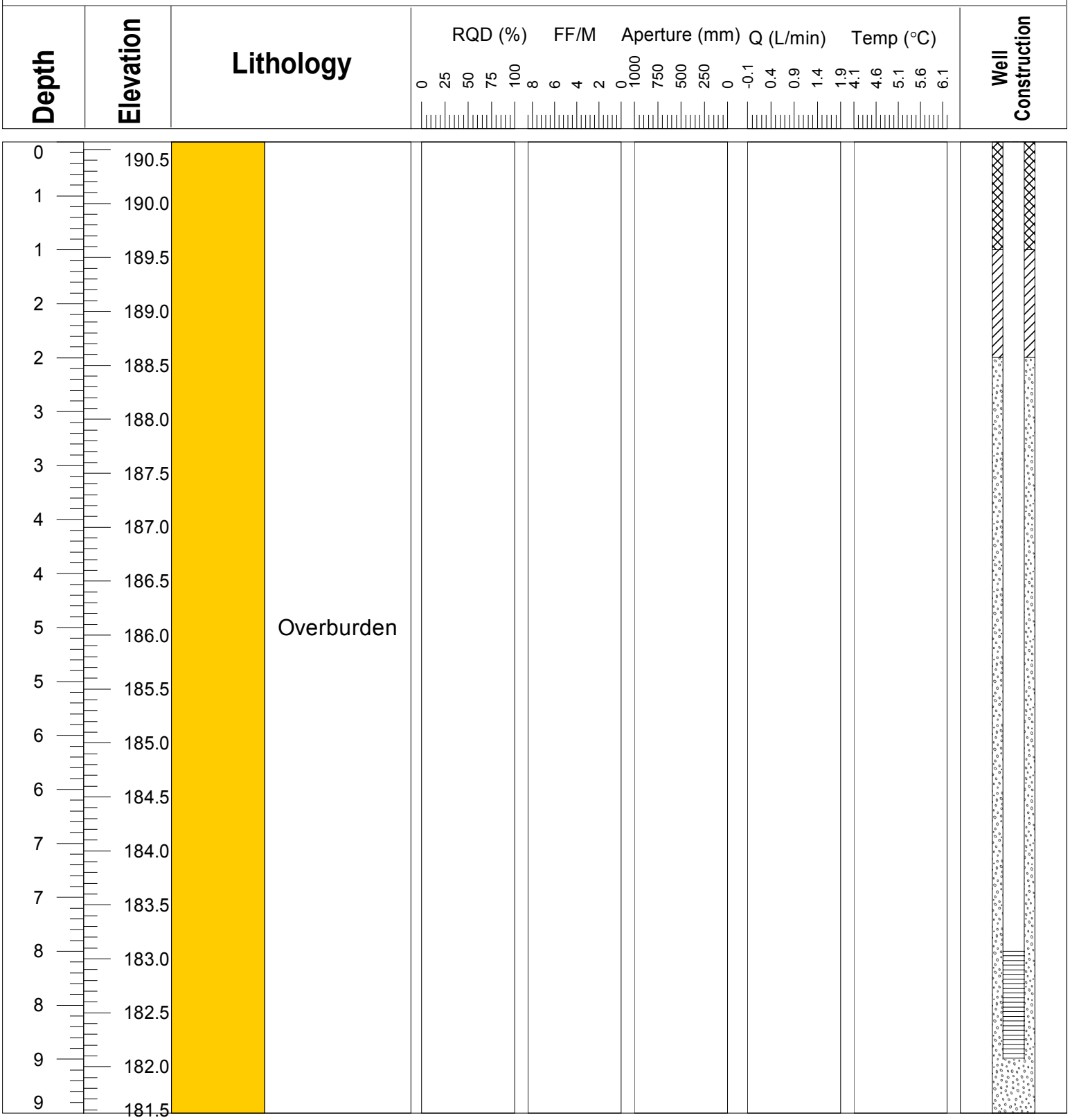
Dip (°): -75
Azi (°): 135

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR01 (S)

Easting: 2498678 **Northing:** 7495607



Drilling Date: 24/03/2011
Drilled ∅ (mm): 50
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m):
Azi (°): 0

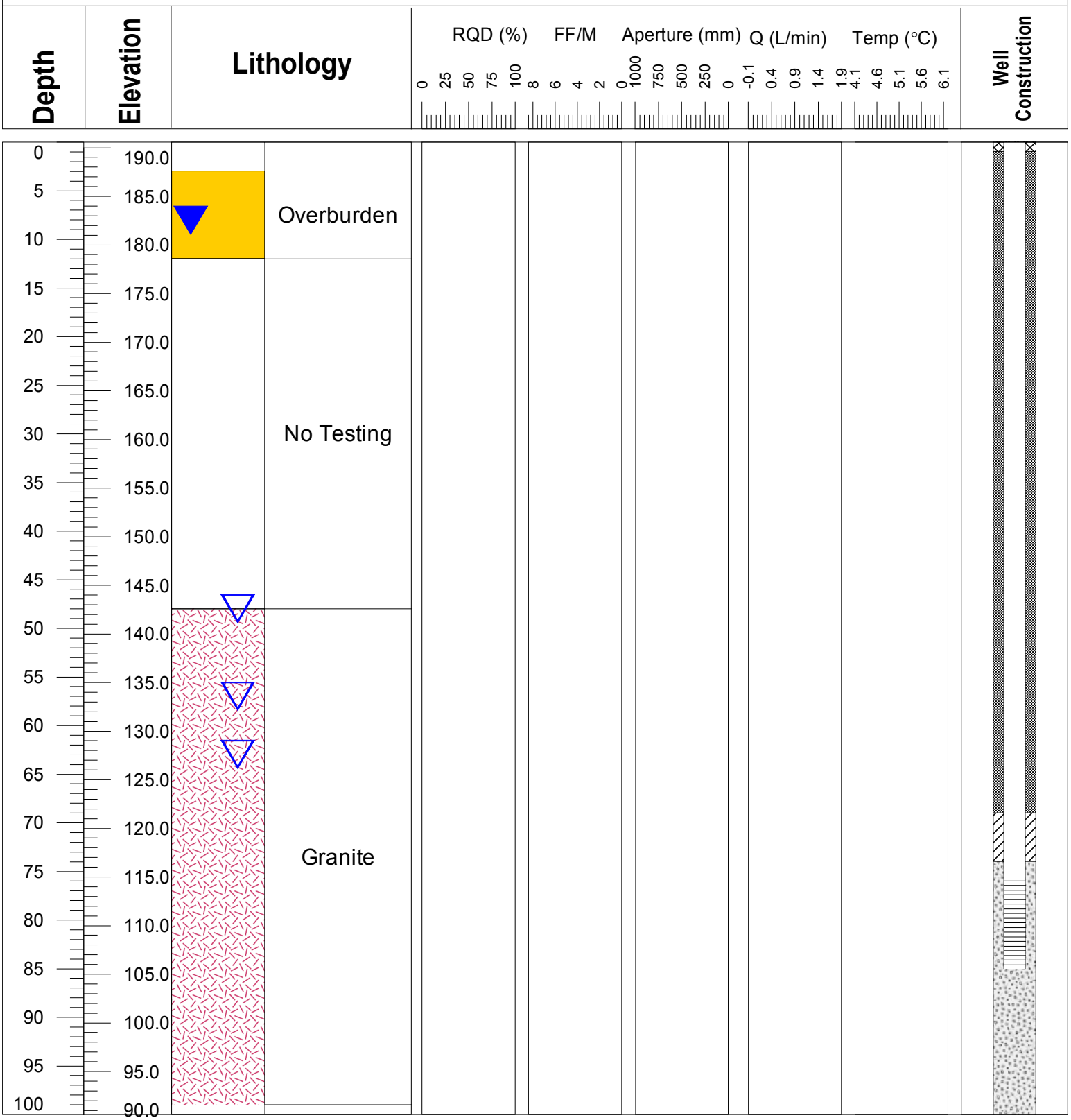
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Piezometer

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR01 (D)

Easting: 2498698 **Northing:** 7495592



Drilling Date: 23-24/03/2011
Drilled ∅ (mm): 50
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m): 0.67
Azi (°): 0

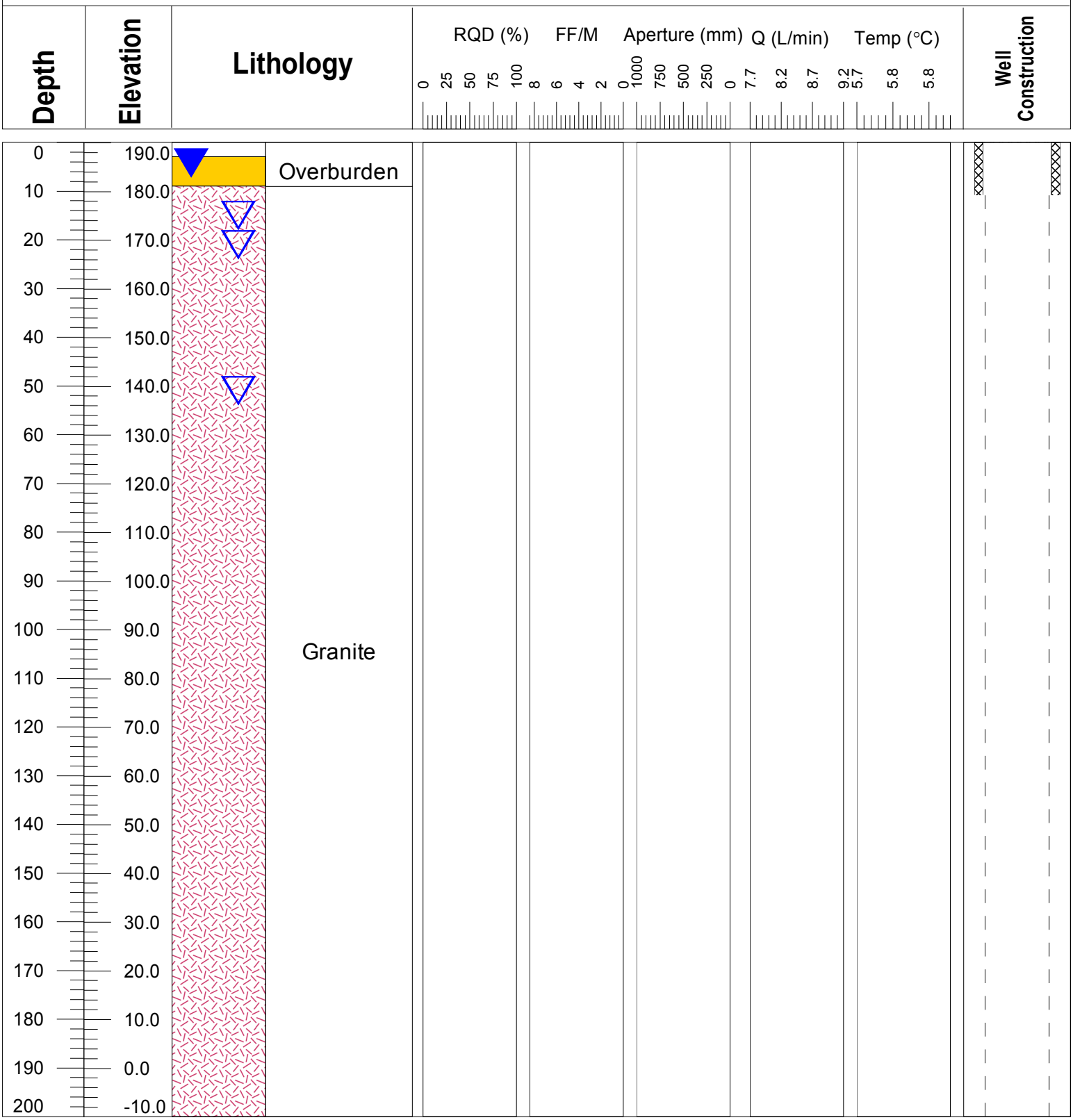
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Piezometer

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR02

Easting: 2498627 **Northing:** 7495642



Drilling Date: 28/03-07/04/2011
Drilled ∅ (mm): 170
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m): 0.32
Azi (°): 0

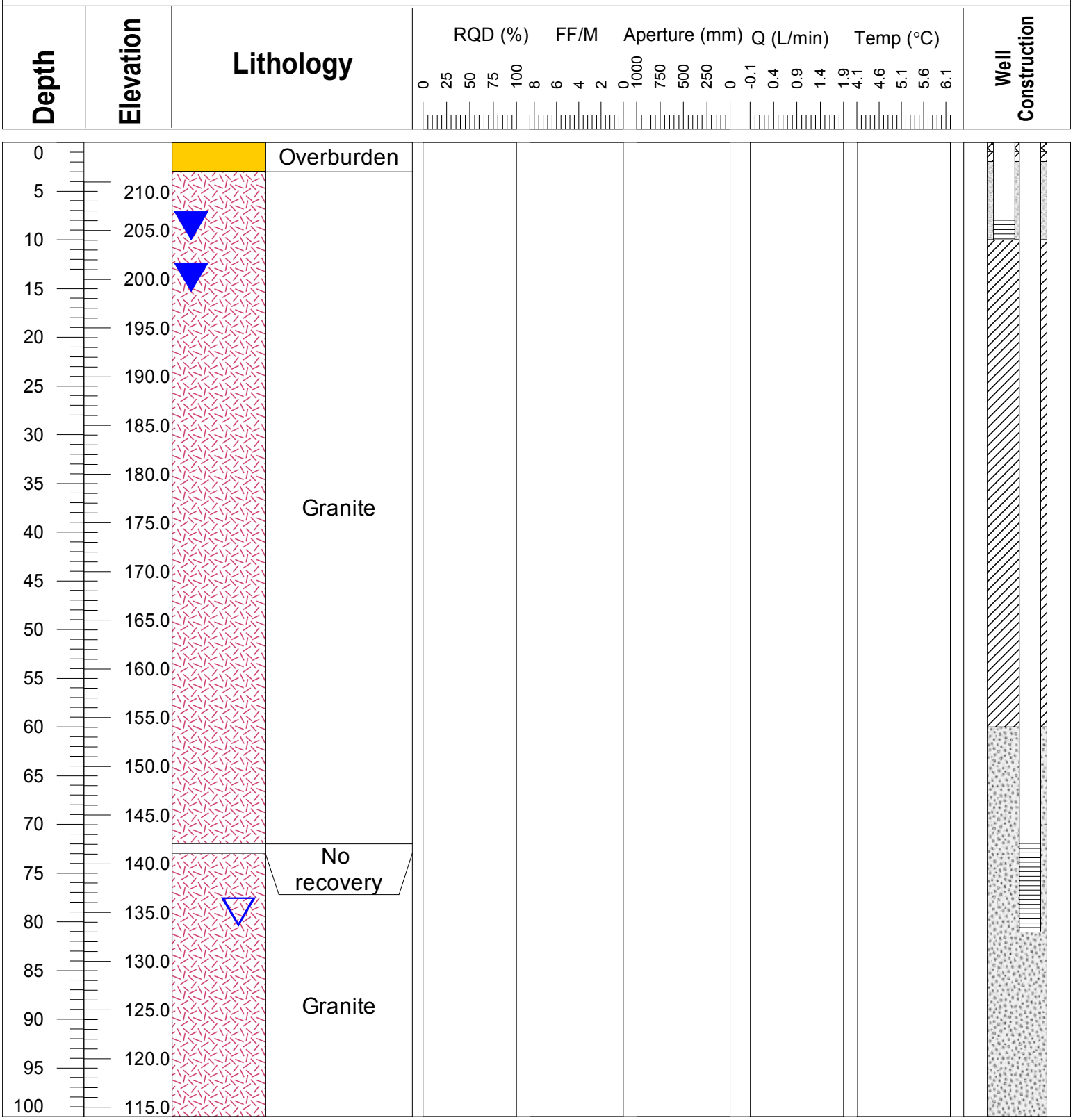
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Pumping Well

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR03

Easting: 2498277 **Northing:** 7496249



Drilling Date: 30-31/03/2011
Drilled ∅ (mm): 50
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m): 0.59
Azi (°): 0

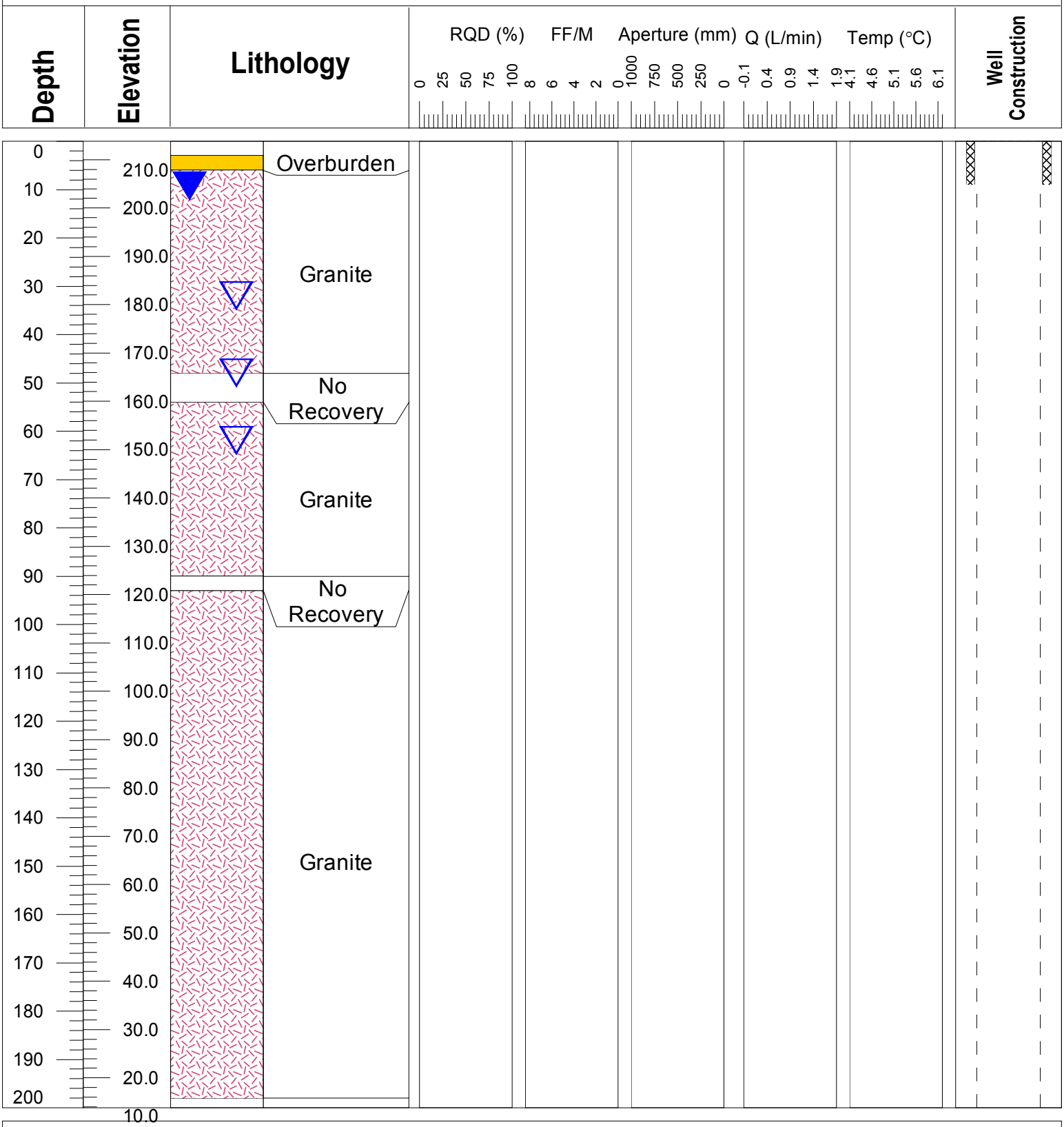
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Piezometer

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR04

Easting: 2498239 **Northing:** 7496289



Drilling Date: 01-04/04/2011
Drilling Company: MINEREC OY
Drilling Method: RC

Drilled ∅ (mm): 170
Casing ∅ (mm):
Slot size (mm): 0.5

Filter pack: 2-6mm Gravel
Stick-up (m): 0.28
Hole Type: Pumping Well

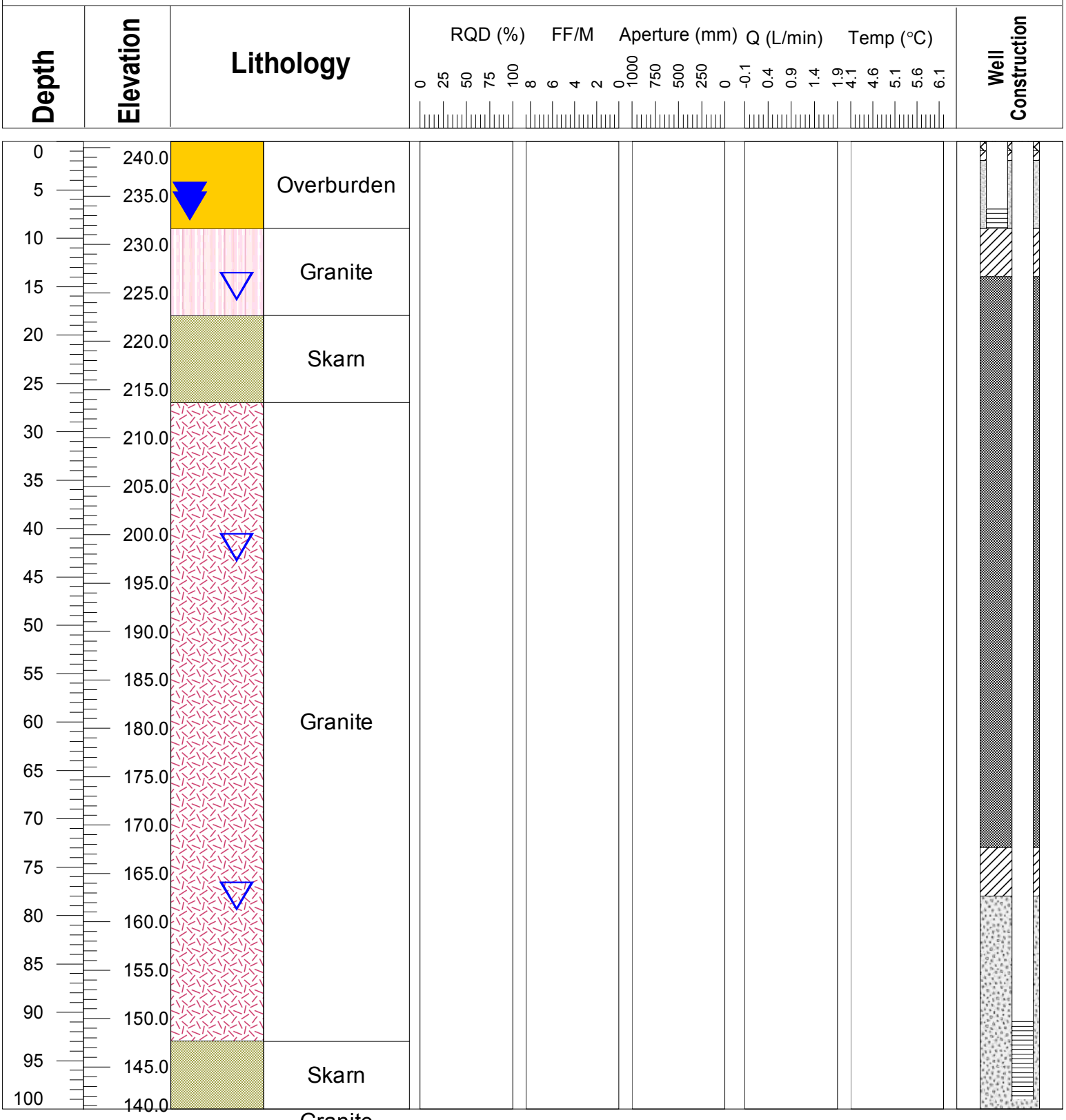
Dip (°): -90
Azi (°): 0

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR05

Easting: 2498277 **Northing:** 7500637



Drilling Date: 04-05/04/2011
Drilled ∅ (mm): 50
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m):
Azi (°): 0

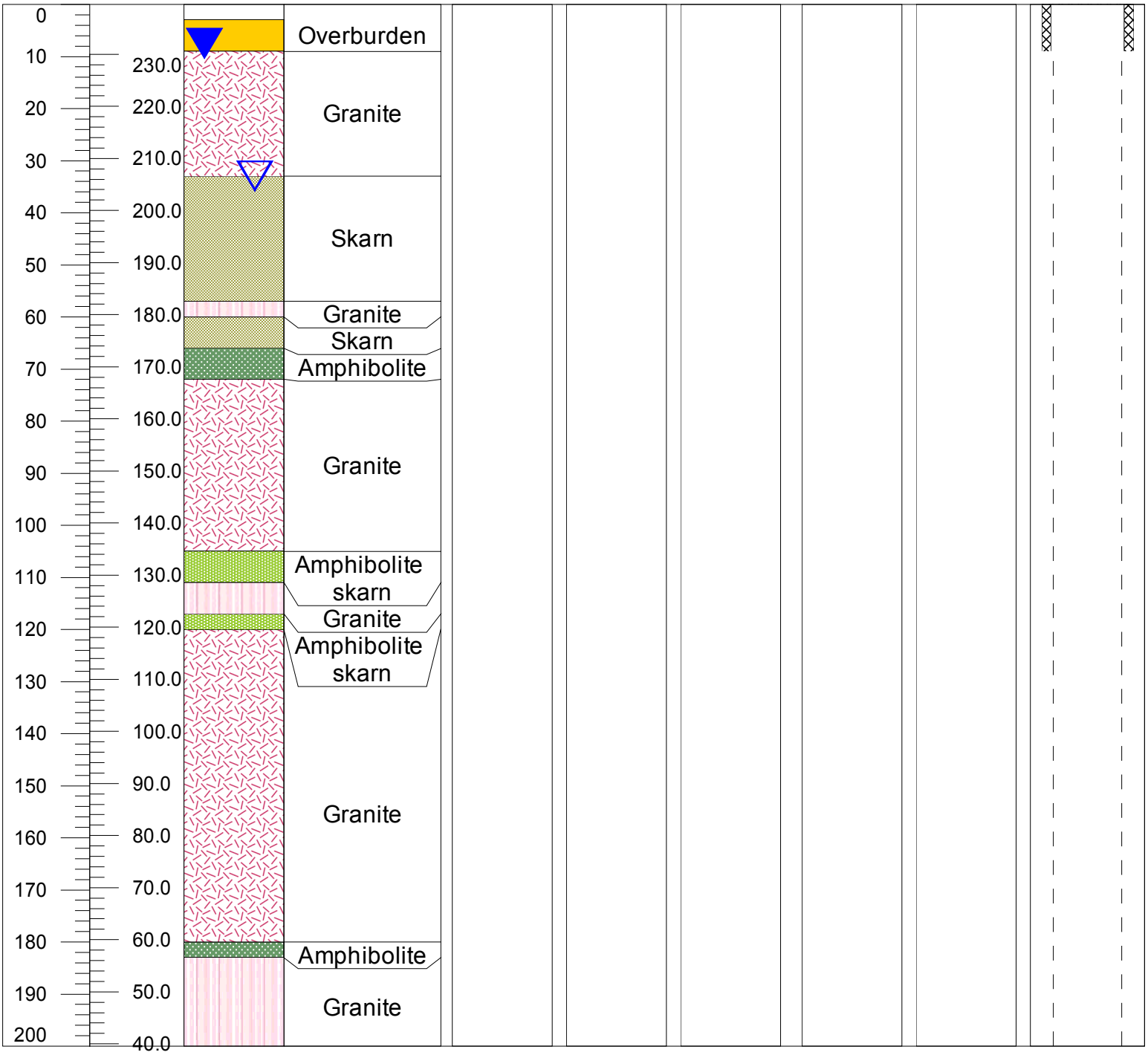
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Piezometer

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: HAN11HYDR06

Easting: 2498301 **Northing:** 7500615



Drilling Date: 01-04/04/2011
Drilled ∅ (mm): 170
Filter pack: 2-6mm Gravel
Dip (°): -90

Drilling Company: MINEREC OY
Casing ∅ (mm):
Stick-up (m):
Azi (°): 0

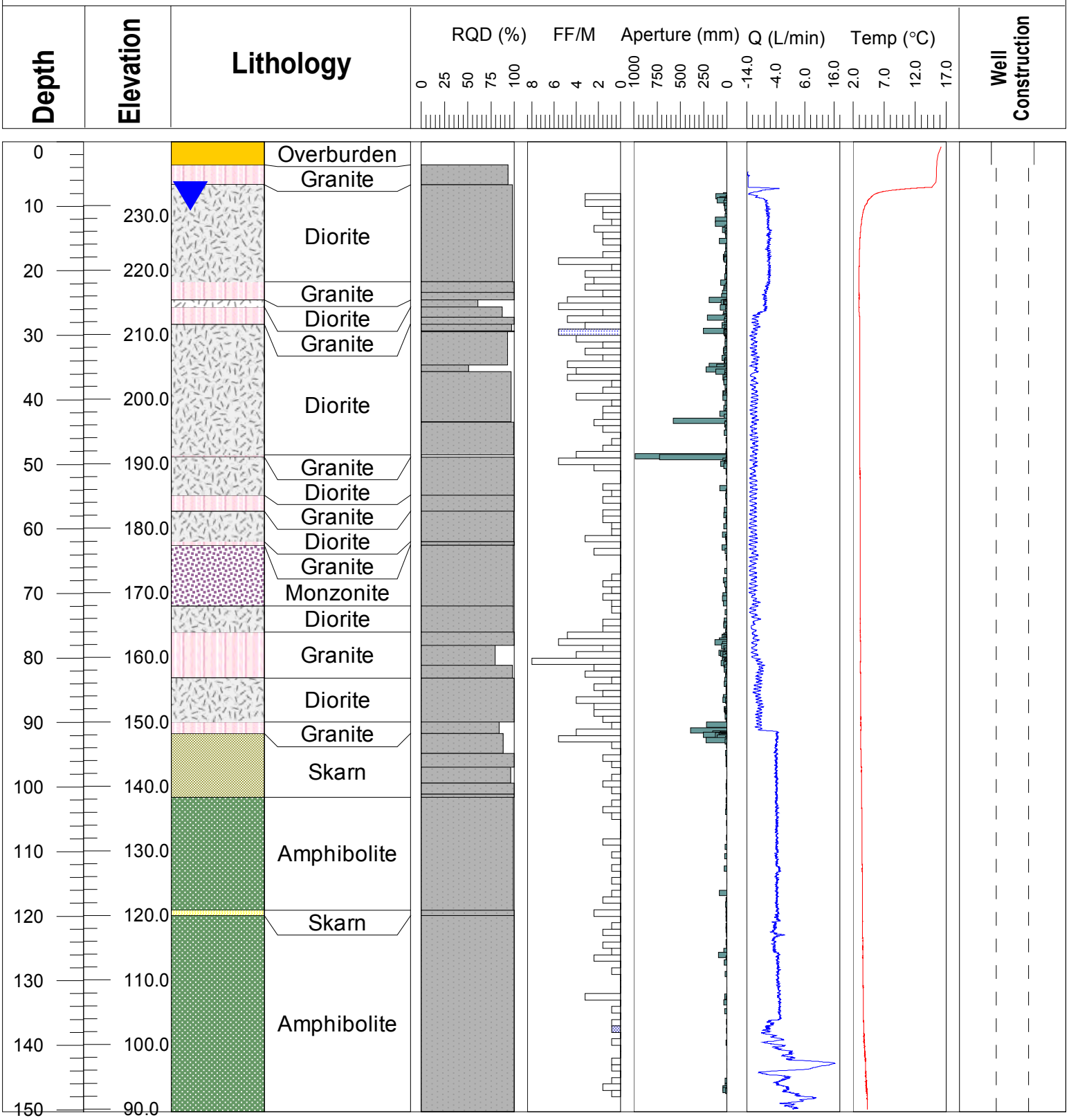
Drilling Method: RC
Slot size (mm): 0.5
Hole Type: Pumping Well

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: KUE11GT01

Easting: 2498357 **Northing:** 7500660



Drilling Date: 26-28/04/2011
Drilled ∅ (mm): 75.7
Filter pack: n/a
Dip (°): -80

Drilling Company: KATI OY
Casing ∅ (mm):
Stick-up (m): 0.25
Azi (°): 230

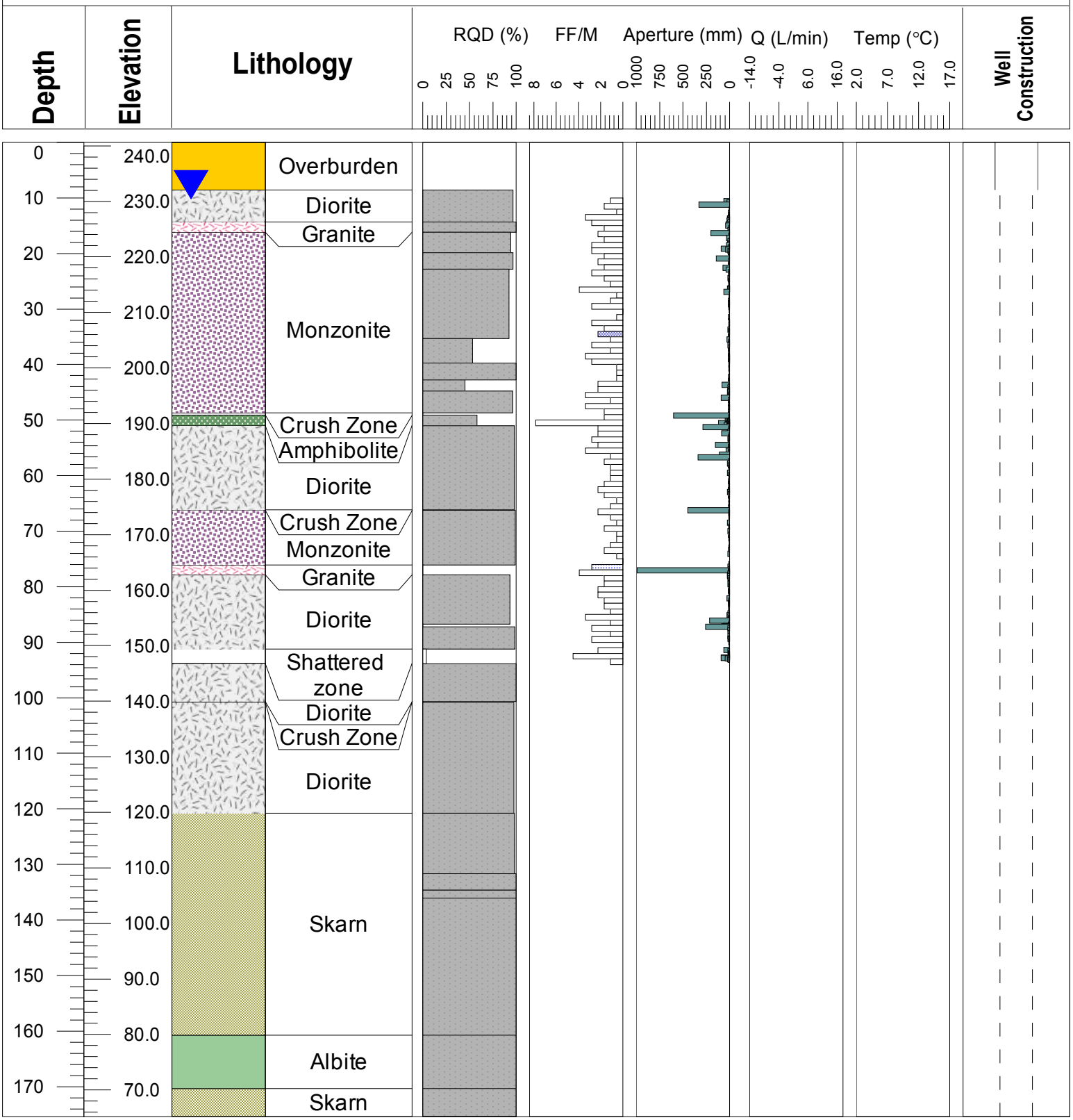
Drilling Method: DD
Slot size (mm): n/a
Hole Type: Geotechnical hole used as an observation well

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: KUE11GT02

Easting: 2498428 **Northing:** 7500565



Drilling Date: 28/04-04/05/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.09
Hole Type: Geotechnical

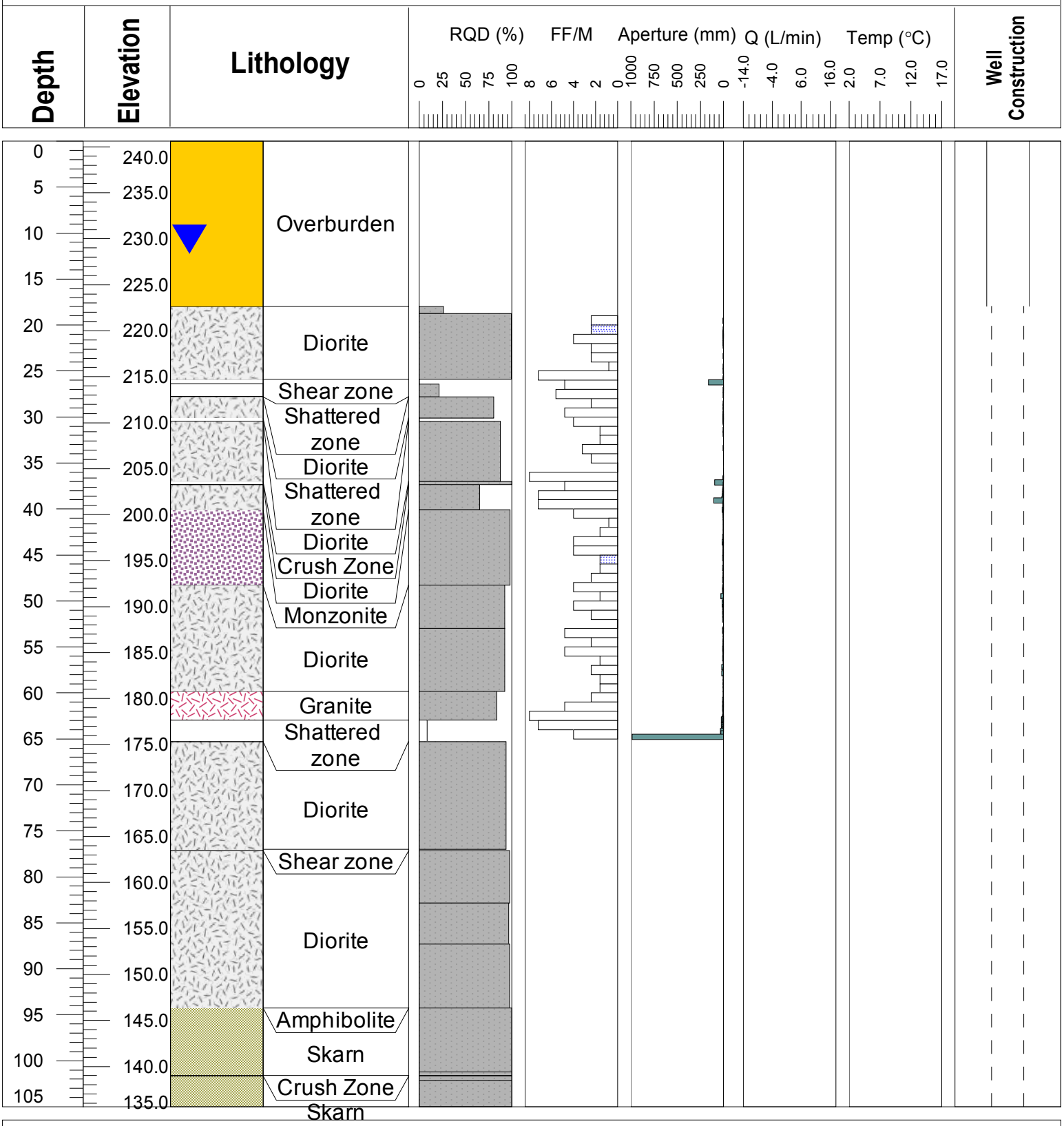
Dip (°): -55
Azi (°): 360

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: KUE11GT03

Easting: 2498487 **Northing:** 7500463



Drilling Date: 04-09/05/2011
Drilled ∅ (mm): 75.7
Filter pack: n/a
Dip (°): -65

Drilling Company: KATI OY
Casing ∅ (mm):
Stick-up (m): 0.02
Azi (°): 110

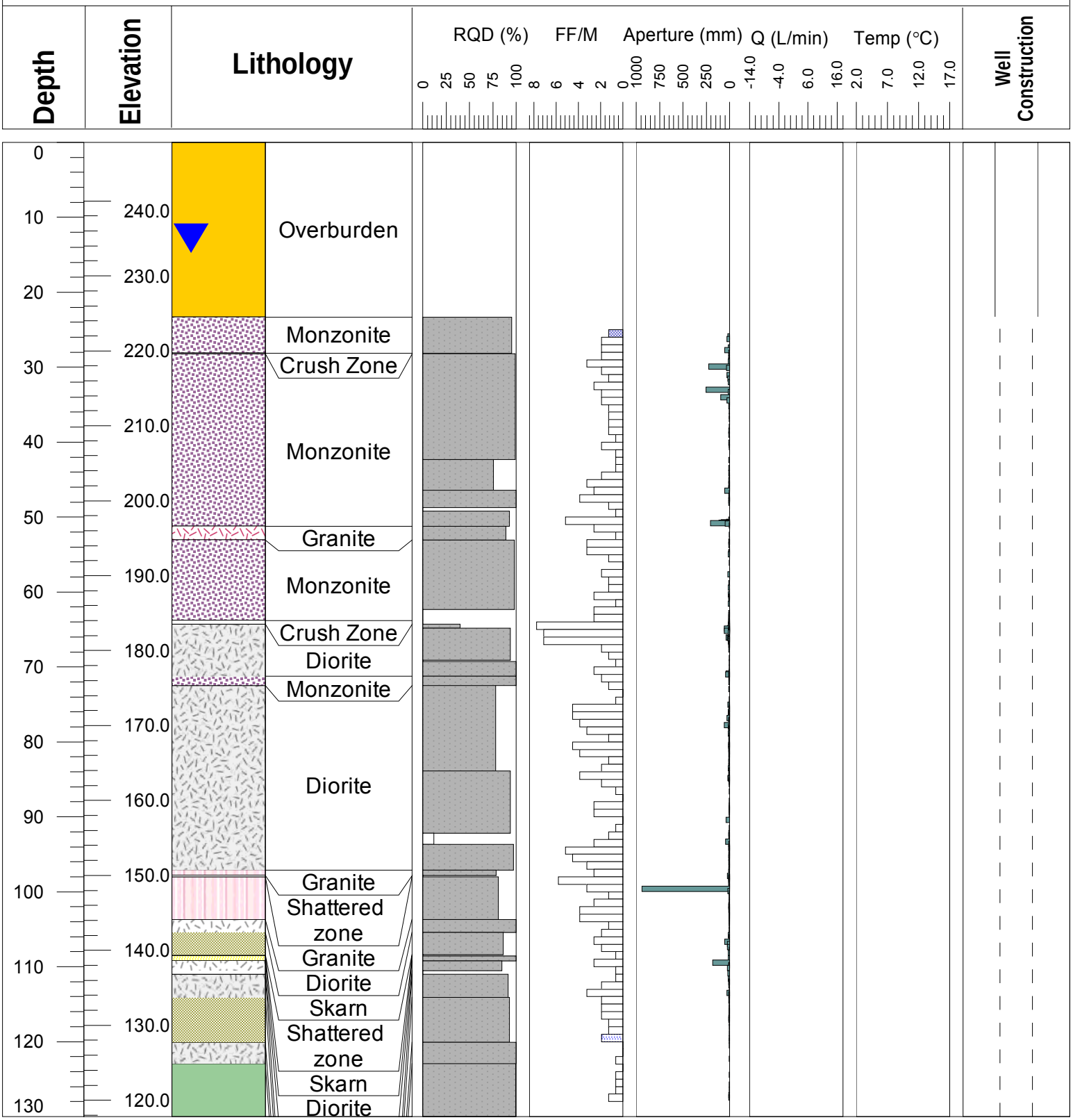
Drilling Method: DD
Slot size (mm): n/a
Hole Type: Geotechnical

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Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: KUE11GT04

Easting: 2498548 **Northing:** 7500065



Drilling Date: 10-11/05/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

Filter pack: n/a
Stick-up (m): 0.14
Hole Type: Geotechnical

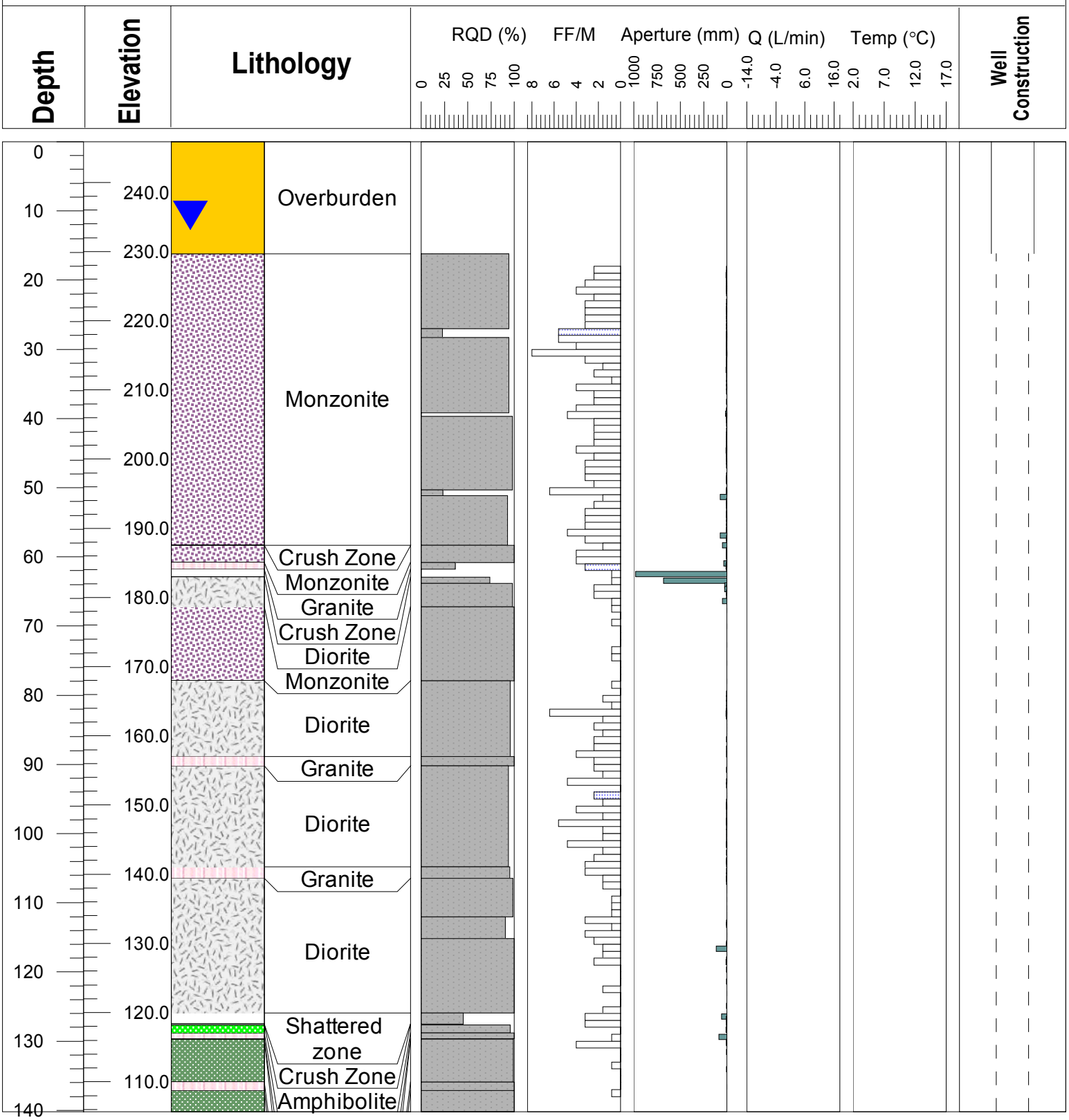
Dip (°): -80
Azi (°): 300

srk consulting

Project: U4970
Client: Northland Resources
Location: Hannukainen

Well ID: KUE11GT05

Easting: 2498515 **Northing:** 7499834



Drilling Date: 12-17/05/2011
Drilling Company: KATI OY
Drilling Method: DD

Drilled ∅ (mm): 75.7
Casing ∅ (mm):
Slot size (mm): n/a

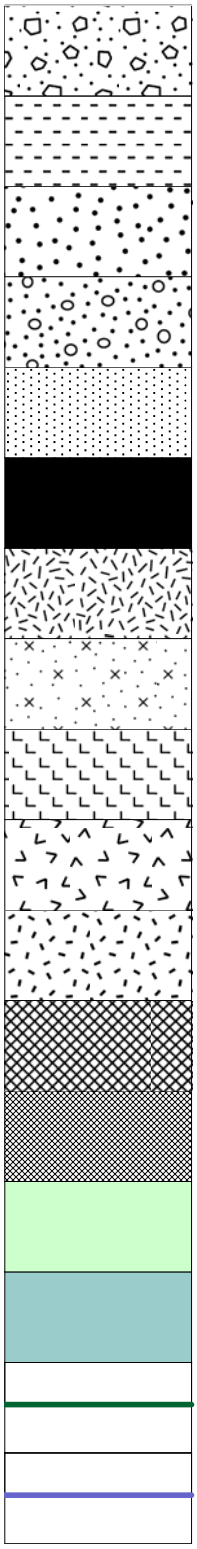
Filter pack: n/a
Stick-up (m): 0.12
Hole Type: Geotechnical

Dip (°): -50
Azi (°): 45

RAUTUVAARA BOREHOLE LOGS

LEGEND

LITHOLOGY AND WELL TESTING



Overburden

Clay

Sand

Gravel

Tailings

Peat

Diorite

Amphibole

Volcanic

Granodiorite

Monzonite

PG

Bedrock

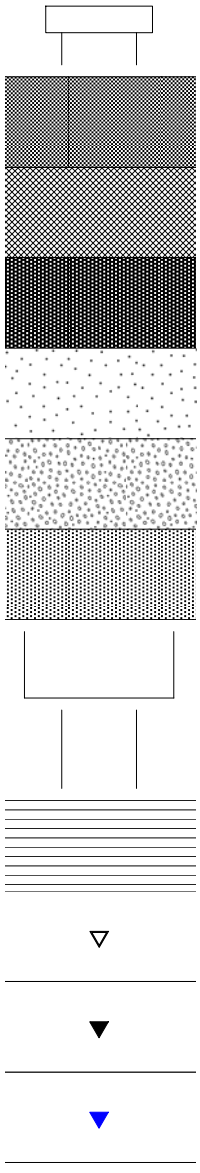
Penetration rate (min)

Blow test (l/s)

EC (µS/cm)

Temperature (°C)

WELL CONSTRUCTION



Piezometer Top Cap

Sanitary Seal

Concete

Bentonite

Backfill

Gravel

Sand

Open Hole

PVC

Screen

Groundwater Strike

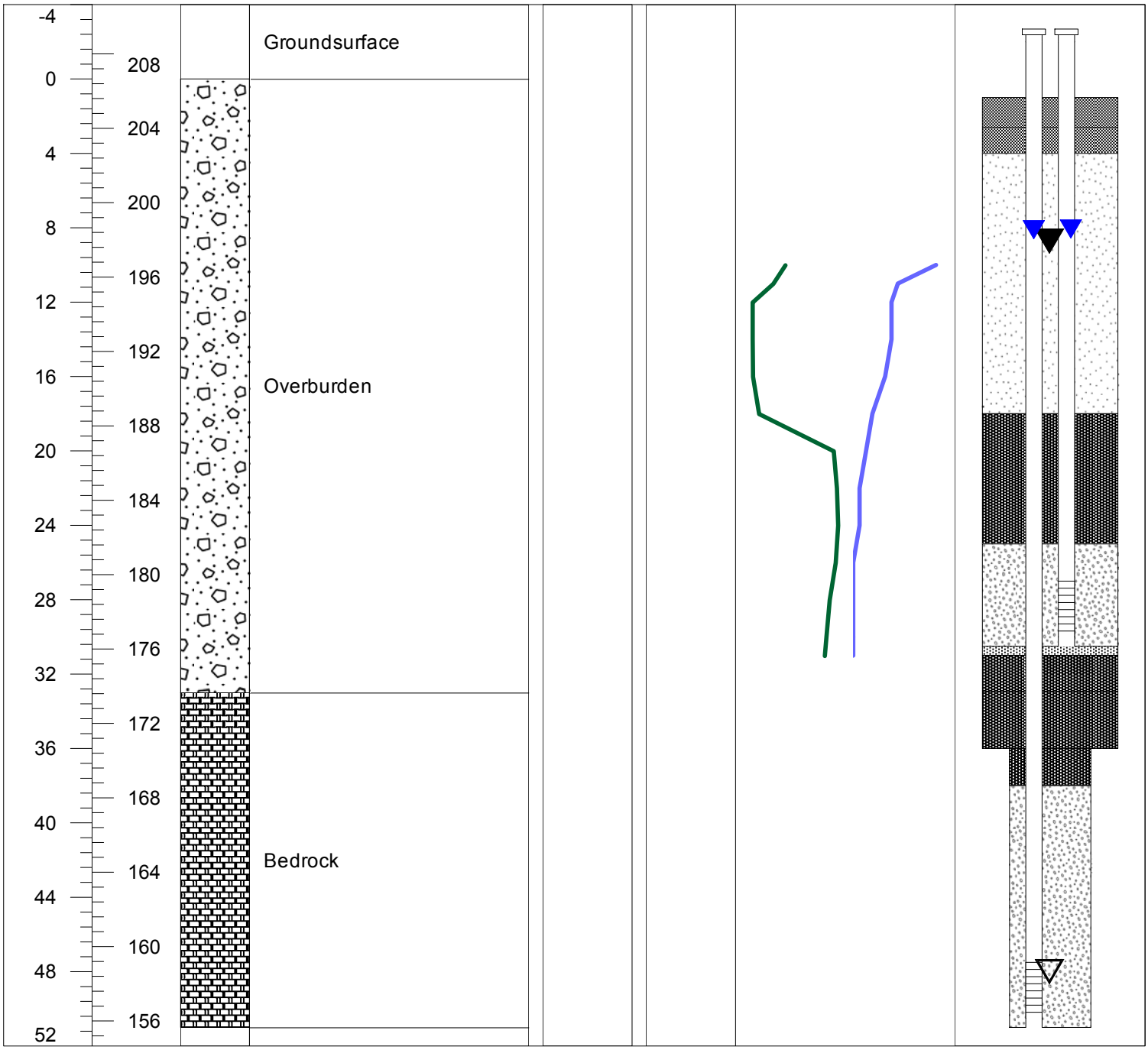
Open Hole Static Water Level

Piezometer Static Water Level

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2496723 **Northing:** 7489436

Well ID: RAU12HYD01

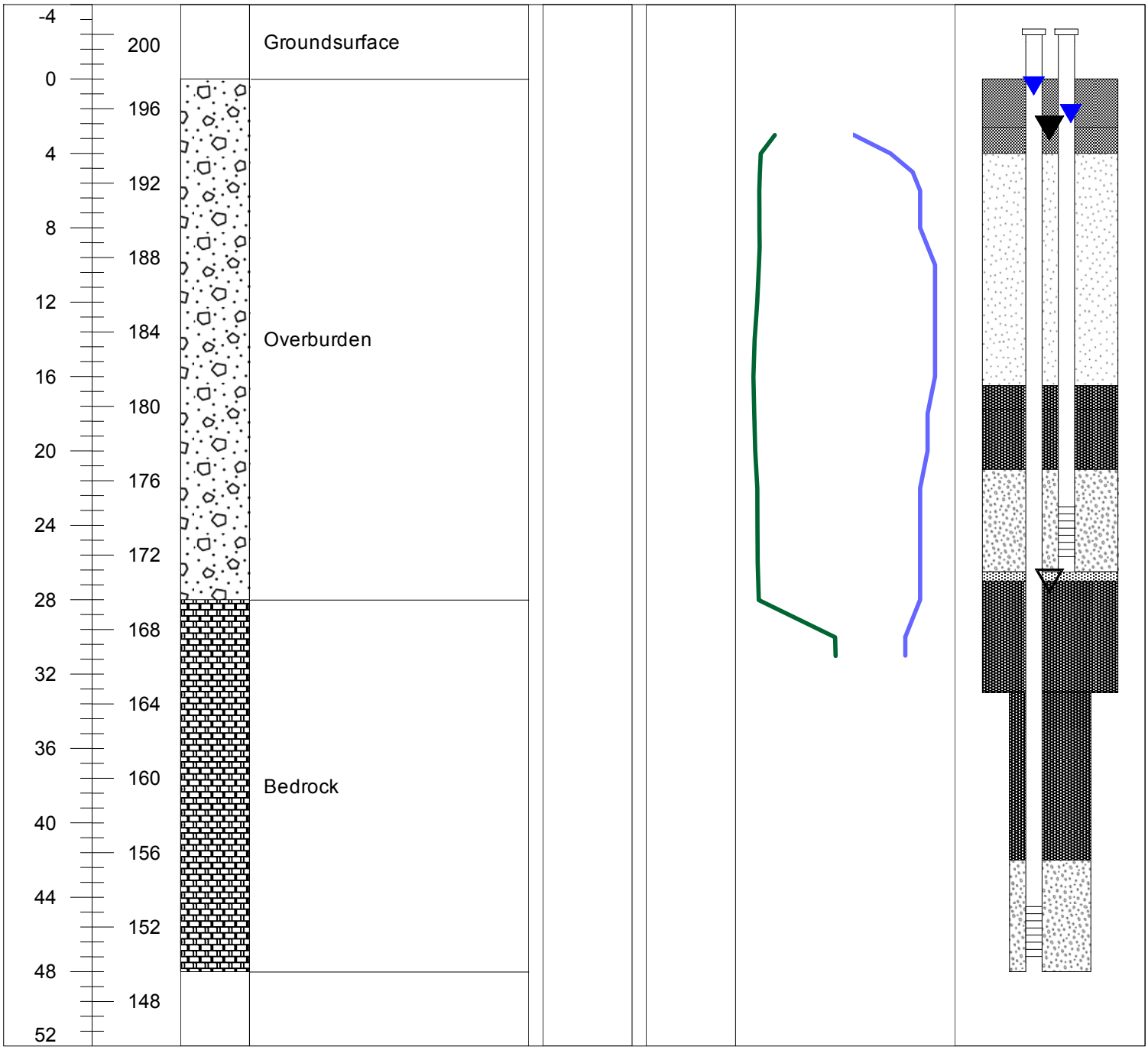


Drilling Date and ID:	3/30/12 RV116	Drilled ∅ (mm):		Filter pack:	2-6mm Gravel
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed	Stick-up:	0.79(D), 1.27 (S)
Drilling Method:	DHH with air flush	Slot size:	0.5	Comments:	Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497594 **Northing:** 7490110

Well ID: RAU12HYD02



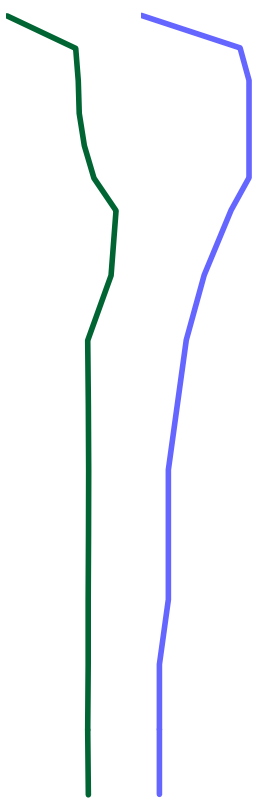
Drilling Date and ID:	3/31/12 RV117	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	0.60(D), 0.75(S)		
Comments:	Key on Pg1 of Appendix		

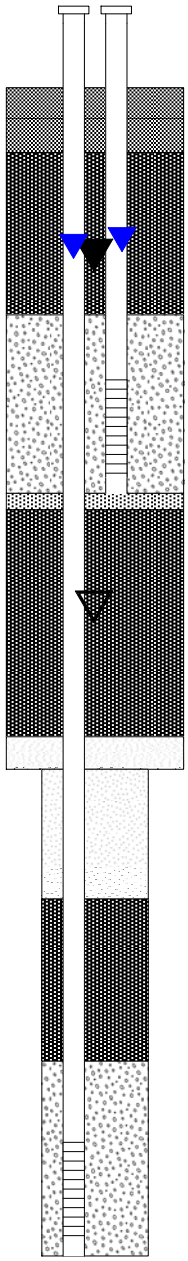
srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497702 **Northing:** 7489449

Well ID: RAU12HYD03

Depth	Elevation	Lithology	Penetration Rate (m/min)	Blow Test (l/s)	EC (µS/cm)	Temperature (°C)	Well Construction
-4	200	Groundsurface	0.0	2.0	1200	4.6	
-2	198						
0	196	dark brownish. Tailings					
2	194	brownish. Tailings					
4	192	dark brownish. Tailings					
6	190						
8	188	dark brownish, small felsic fragments. Tailings					
10	186	dark brownish, little clayey. Tailings					
12	184						
14	182	mud-like, dark brown, organic material also. ?Peat					
16	180	sandy/gravely, brownish, bt (propably from above?)					
18	178	similar, little less rock fragments					
20	176	more sandy					
22	174	similar, more rock fragments					
24	172	more sandy					
26	170						
28	168	slightly monzodioritic/granitic					
30	166						
32	164						
34	162						
36	160	similar, more mica					
38	158						



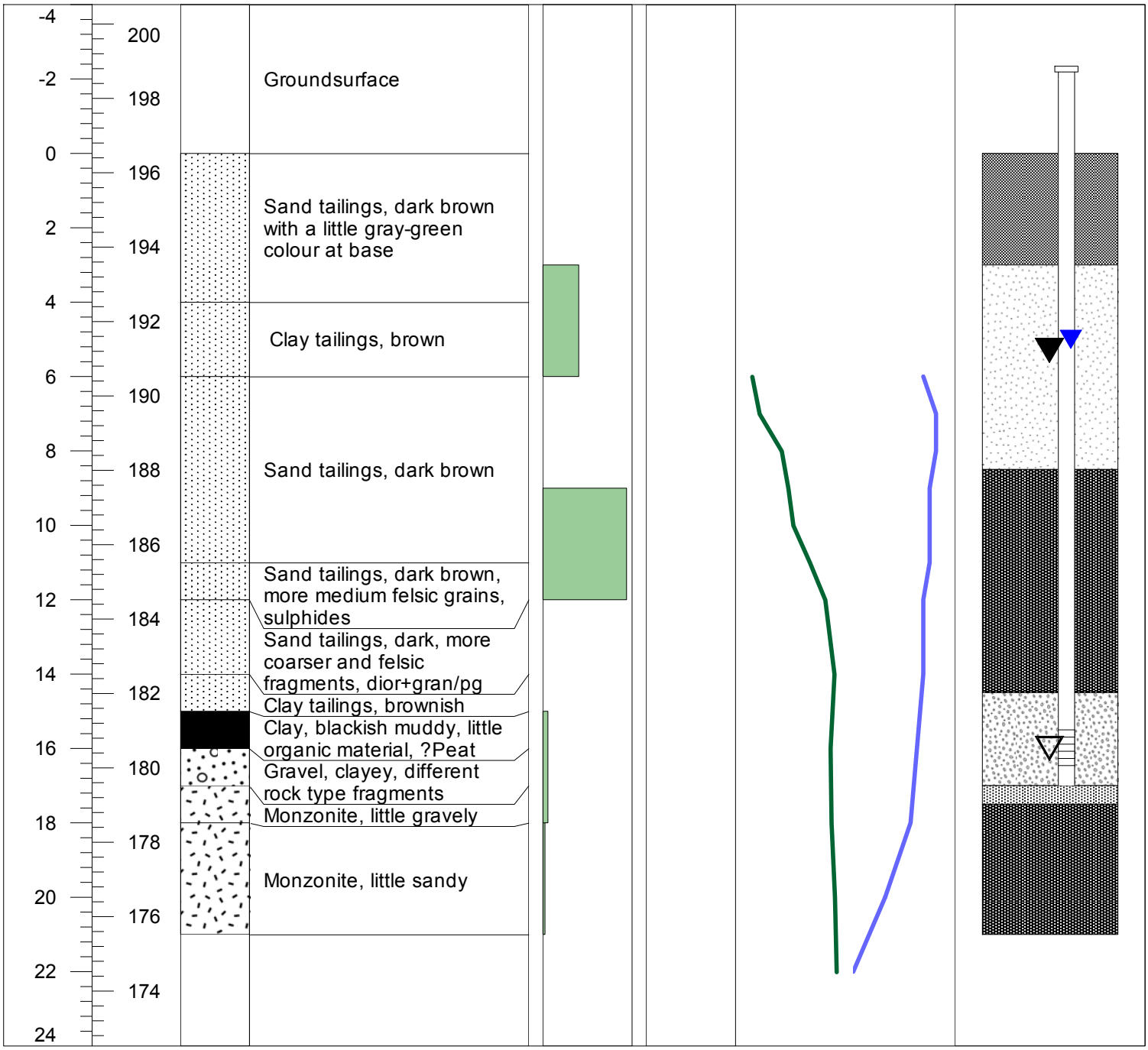


Drilling Date and ID: 4/1/12 RV37
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.20(D), 1.02(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497702 **Northing:** 7489449

Well ID: RAU12HYD03(Mid)

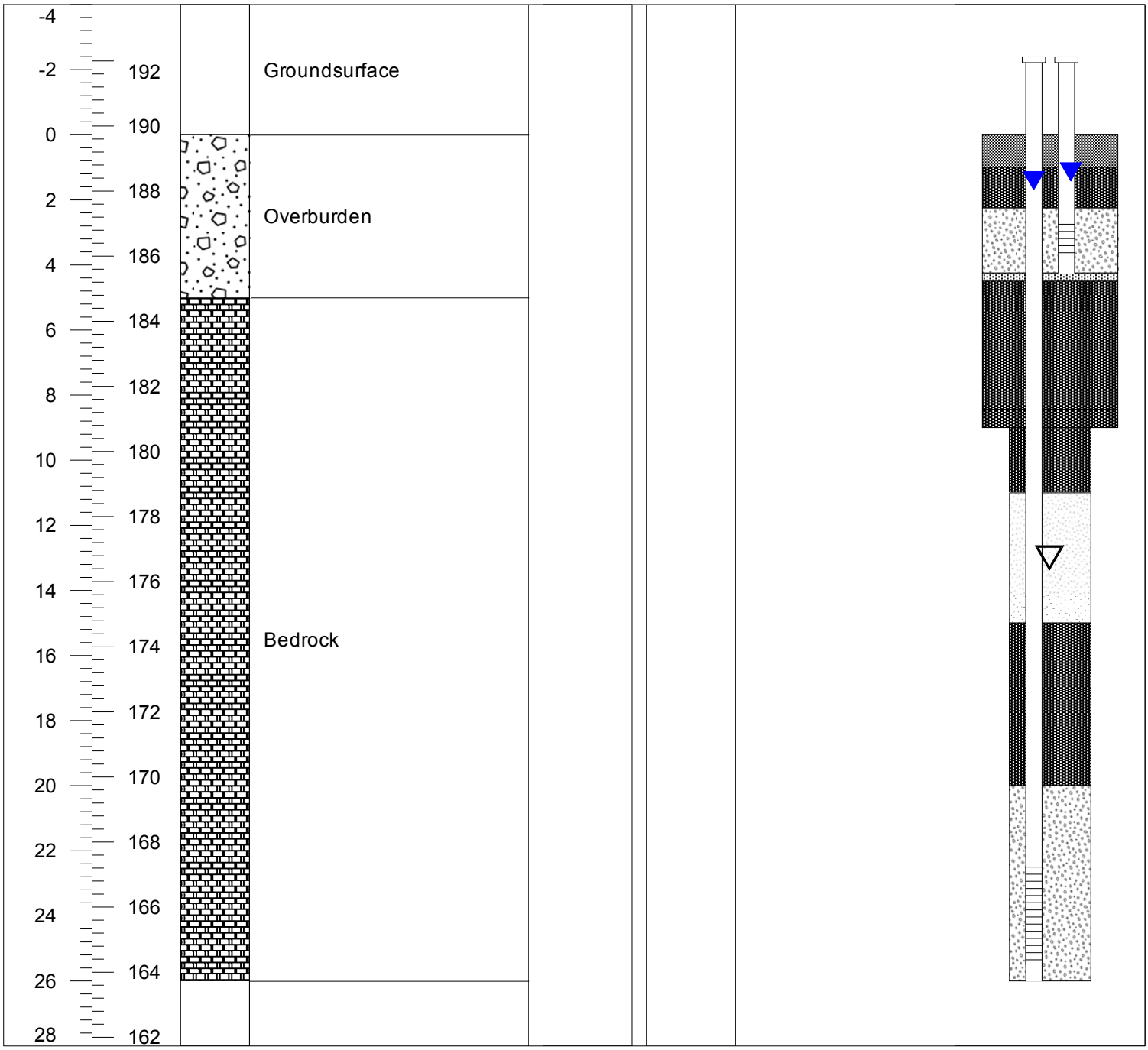


Drilling Date and ID: 4/4/12 RV38
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.24
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2500246 **Northing:** 7491790

Well ID: RAU12HYD04



Drilling Date and ID: 4/2/12 RV6
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.49(D), 1.35(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497757 **Northing:** 7490570

Well ID: RAU12HYD05

Depth	Elevation	Lithology	Penetration Rate (m/min)	Blow Test (l/s)	EC (µS/cm)	Temperature (°C)	Well Construction
-4			0.2	1.2	2.2	3.2	4.2	1.5	2.0	2.5	3.0	3.5	62	64	66	68	3.6	3.8	4.0	4.2	
-2	218	Groundsurface																			
0	216																				
2	214	Overburden																			
4	212																				
6	210																				
8	208																				
		No data																			
10	206	pale grayish, plg,bt																			
12	204																				
14	202																				
16	200	grayish, wet sample																			
18	198	grayish, coarser grinding, little kfs																			
20	196																				
22	194																				
24	192	very similar, more clayish																			
26	190																				
28	188																				
30	186																				

Drilling Date and ID: 4/3/12 RV23
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.06(D), 0.69(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497147 **Northing:** 7488641

Well ID: RAU12HYD06

Depth	Elevation	Lithology	Penetration Rate (m/min)	Blow Test (l/s)	EC (µS/cm)	Temperature (°C)	Well Construction
-4	194	Groundsurface	0.2	1.2	2.2	3.2	4.2	1.5	2.0	2.5	3.0	3.5	312	332	352	372	2.1	2.6	3.1	3.6	4.1	
-2	192																					
0	190																					
2	188																					
4	186	Tailings																				
6	184																					
8	182																					
10	180																					
12	178	Overburden																				
14	176	Bedrock																				
16	174	dark grayish																				
18	172	perhaps gran in dior, or k-altered dior. Small sample size																				
20	170																					
22	168	dark grayish. Small sample size																				
24	166	perhaps gran in dior, or k-altered dior. Small sample size																				
26	164																					
28	162																					
30	160	more like k-altered dior, small sample size																				
32	158																					
34	156																					
36																						

Drilling Date and ID: 4/3/12 RV115 Drilled ∅ (mm):
Filter pack: 2-6mm Gravel

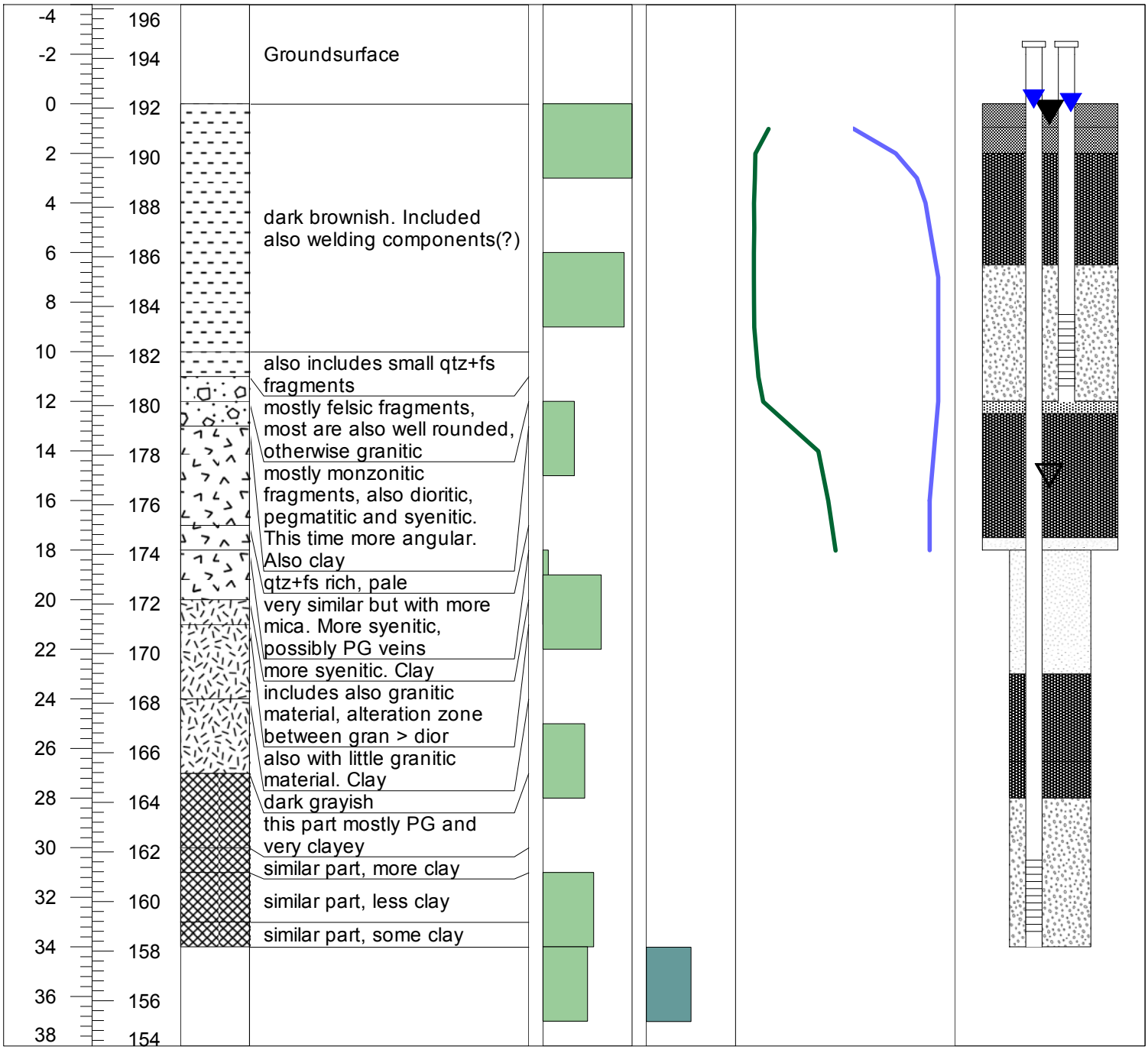
Drilling Company: MINEREC OY Casing: 50mm PVC screw jointed
Stick-up: 1.96(D), 1.90(S)

Drilling Method: DHH with air flush Slot size: 0.5
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497278 **Northing:** 7488956

Well ID: RAU12HYD07

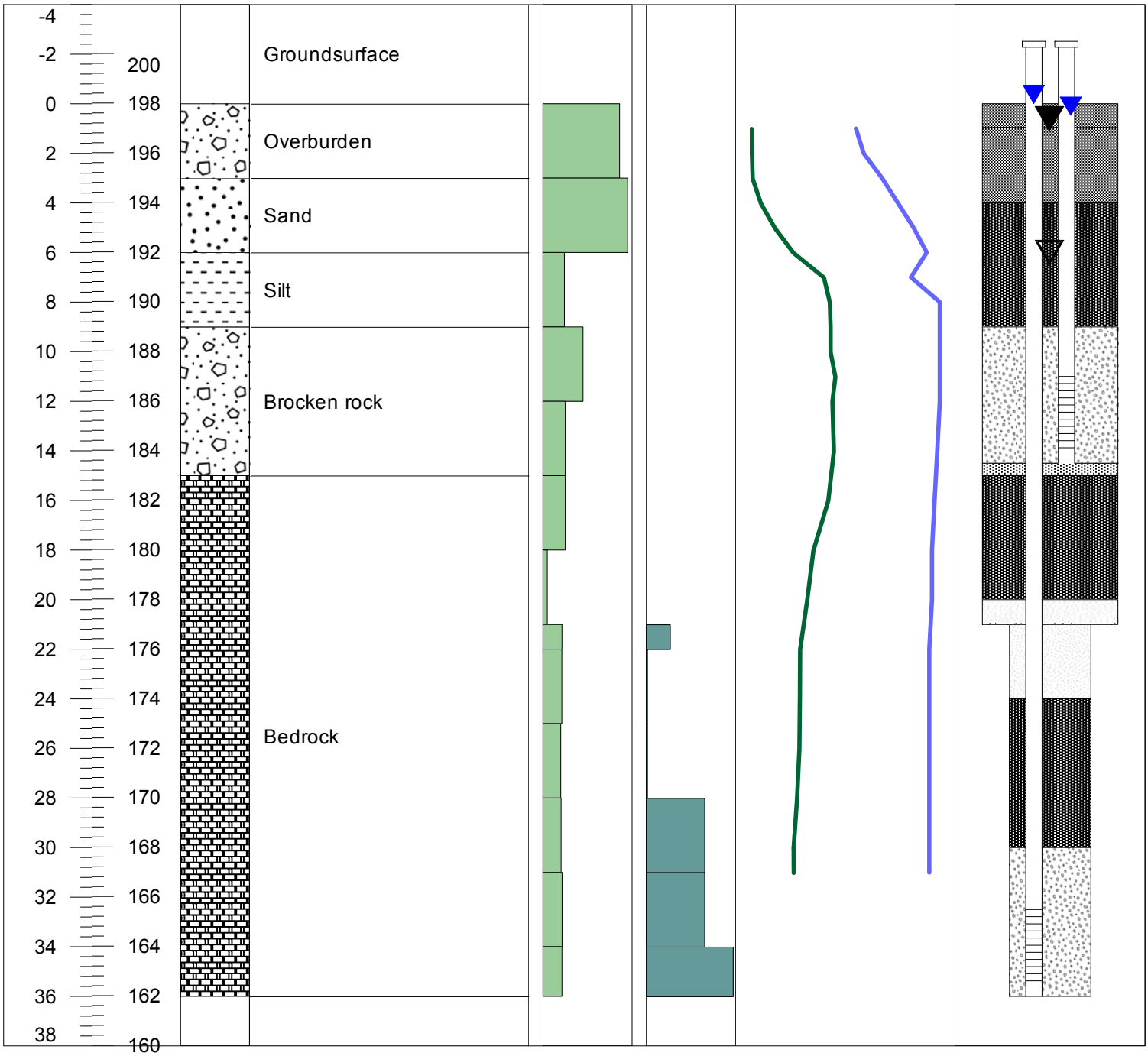


Drilling Date and ID: 4/23/12 RV114
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.38(D), 1.92(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2496221 **Northing:** 7488412

Well ID: RAU12HYD08

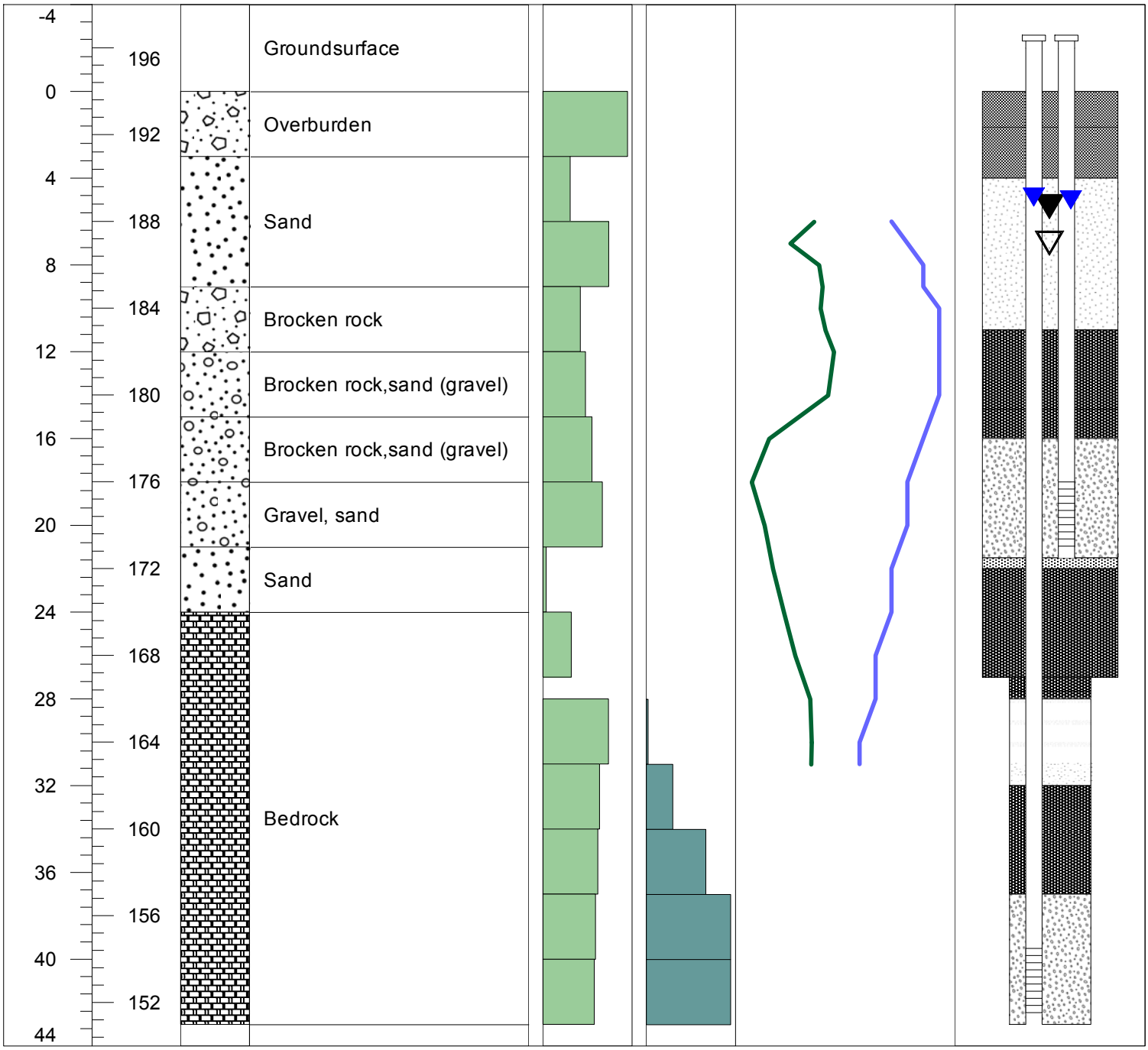


Drilling Date and ID:	4/12/12 RV69	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.44(D), 1.16(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497006 **Northing:** 7487815

Well ID: RAU12HYD09

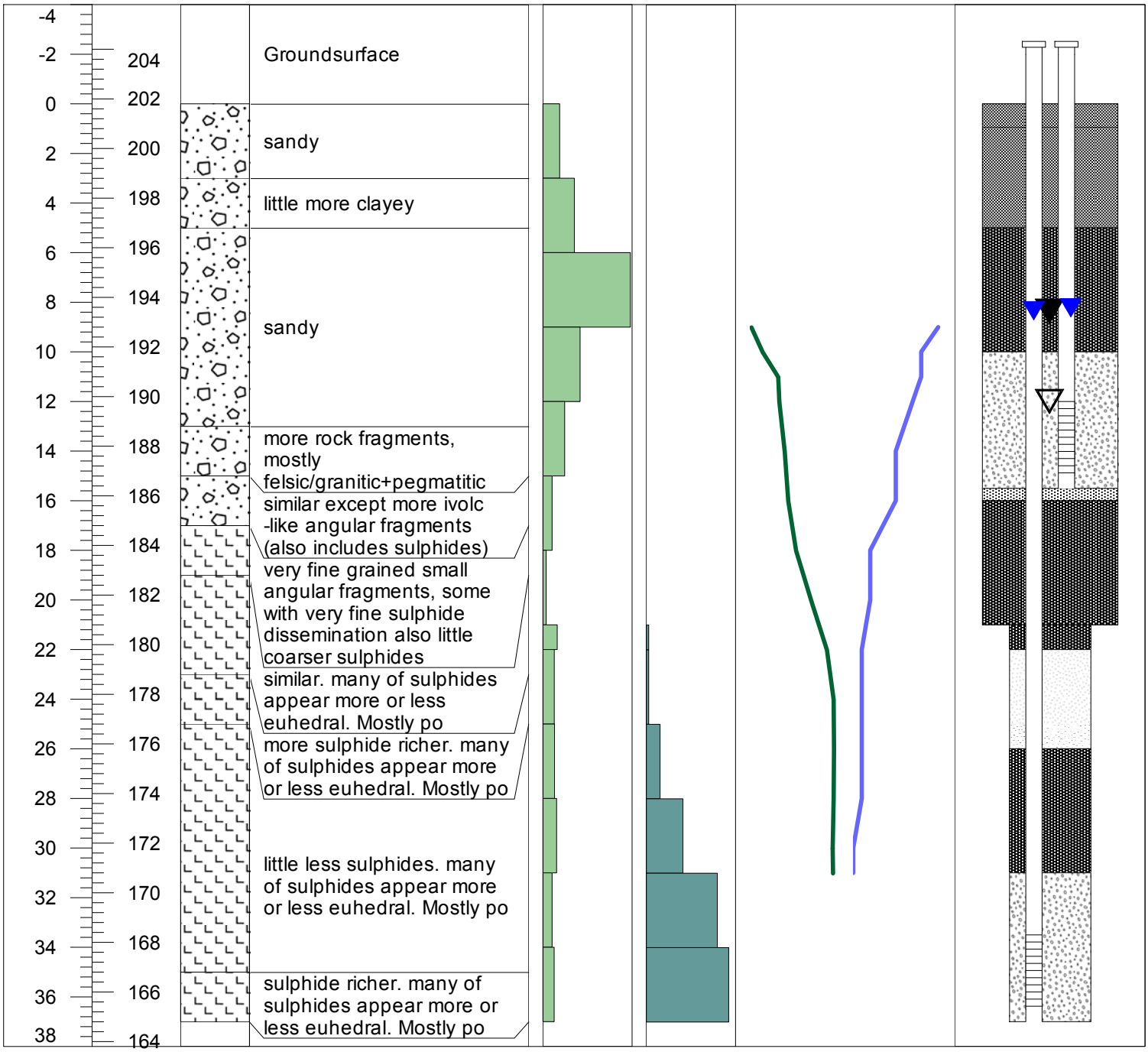


Drilling Date and ID:	4/13/12 RV50	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.37(D), 1.31(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497891 **Northing:** 7487612

Well ID: RAU12HYD10

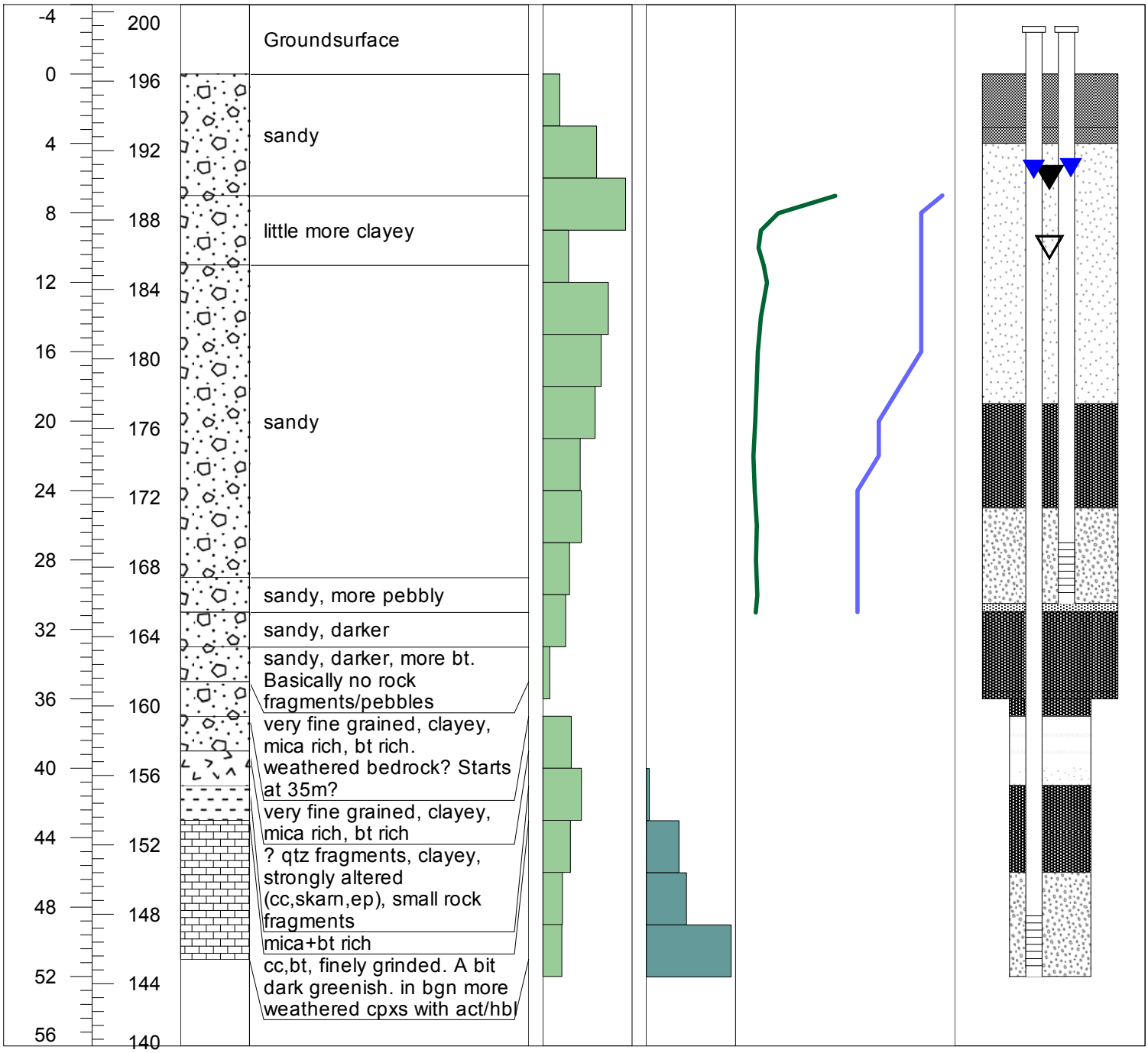


Drilling Date and ID: 4/15/12 RV49
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.30(D), 1.10(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2497580 **Northing:** 7487075

Well ID: RAU12HYD11



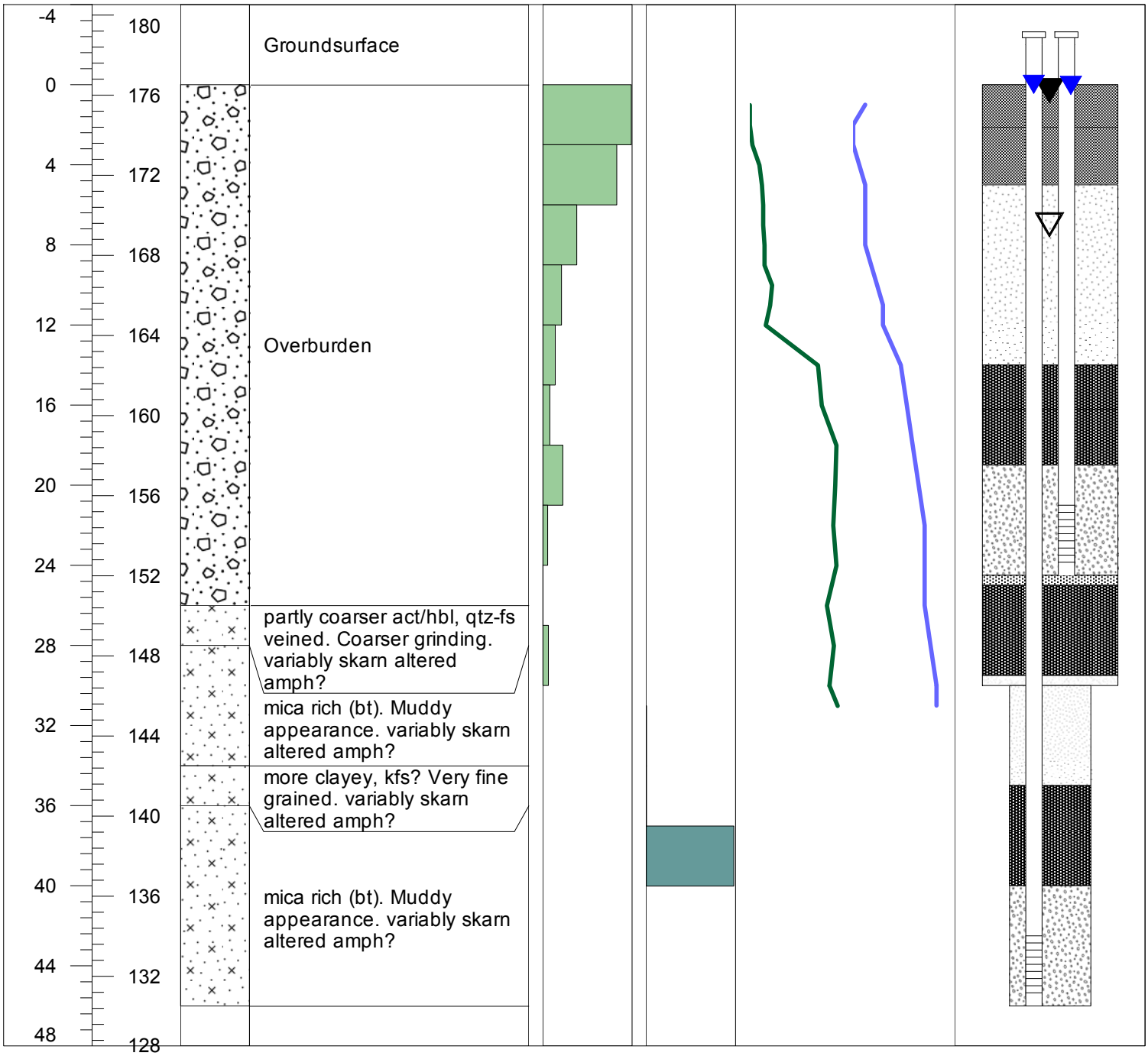
Drilling Date and ID:	4/16/12 RV58	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing: 50mm PVC screw jointed	
Drilling Method:	DHH with air flush	Slot size: 0.5	

Filter pack:	2-6mm Gravel
Stick-up:	1.45(D), 1.28(S)
Comments:	Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2496607 **Northing:** 7485775

Well ID: RAU12HYD12

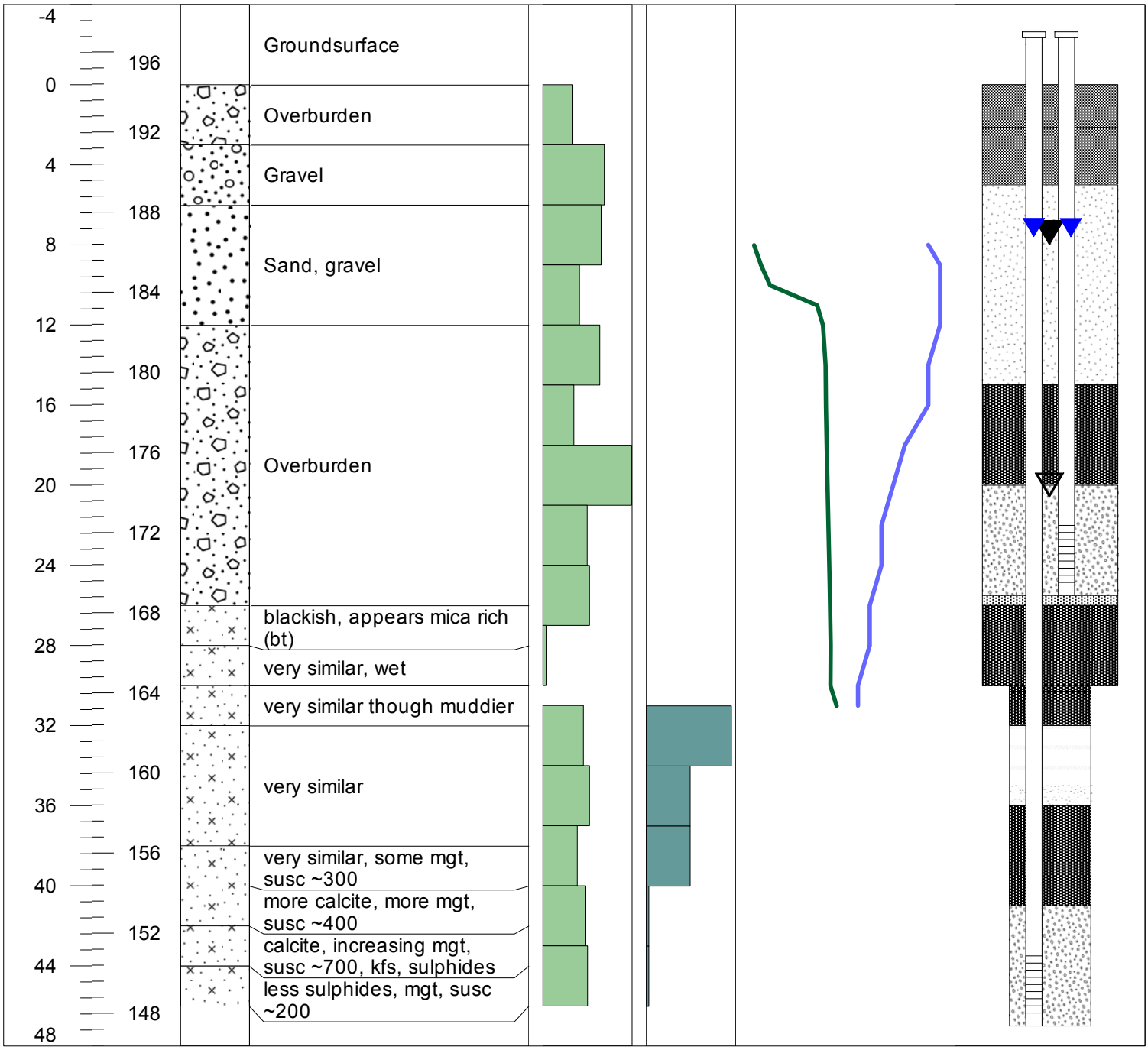


Drilling Date and ID:	4/18/12 RV121	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.80(D),1.94(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2496908 **Northing:** 7487703

Well ID: RAU12HYD13

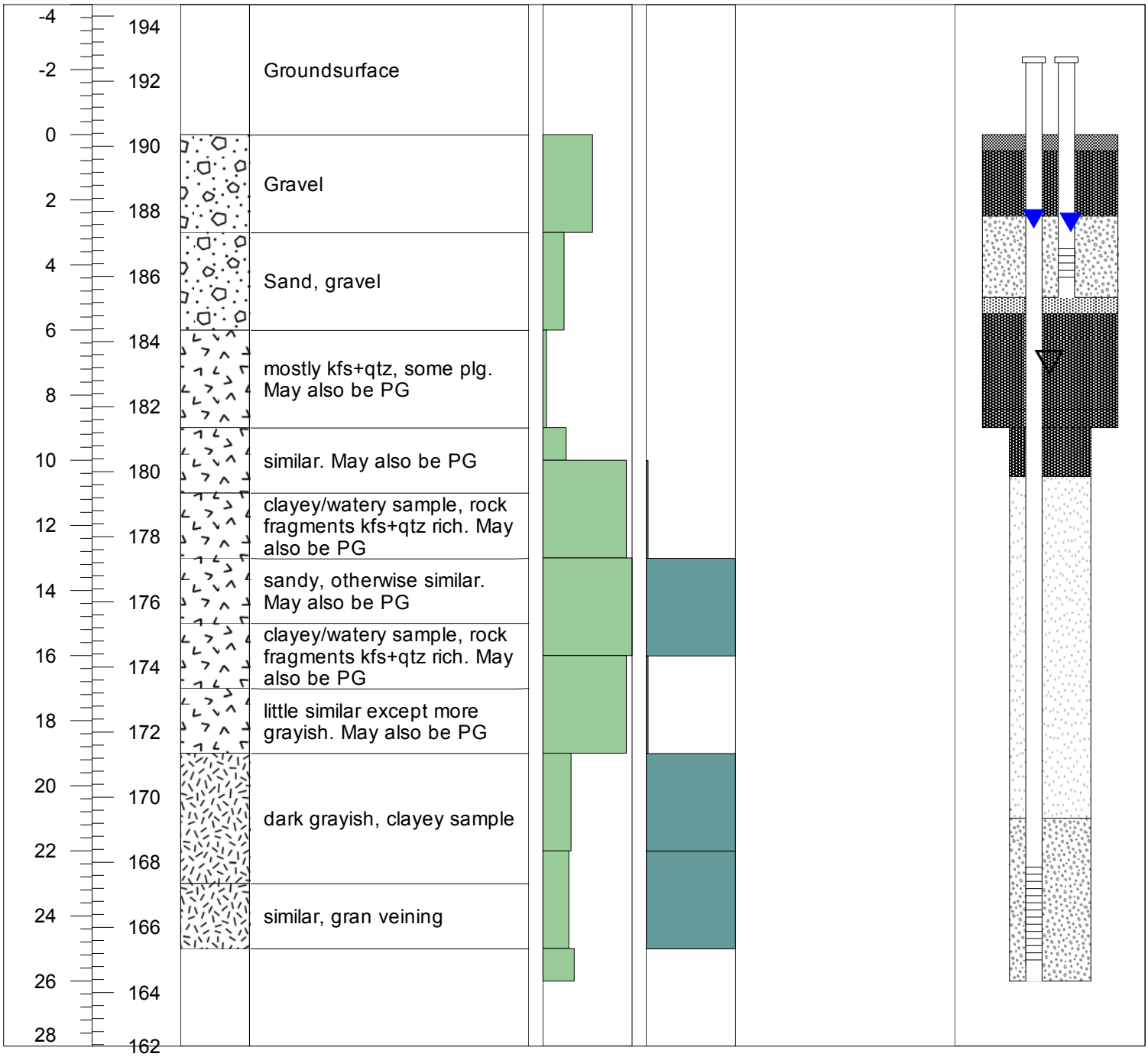


Drilling Date and ID: 4/18/12 RV128
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 0.84(D), 0.75(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2500604 **Northing:** 7492299

Well ID: RAU12HYD14

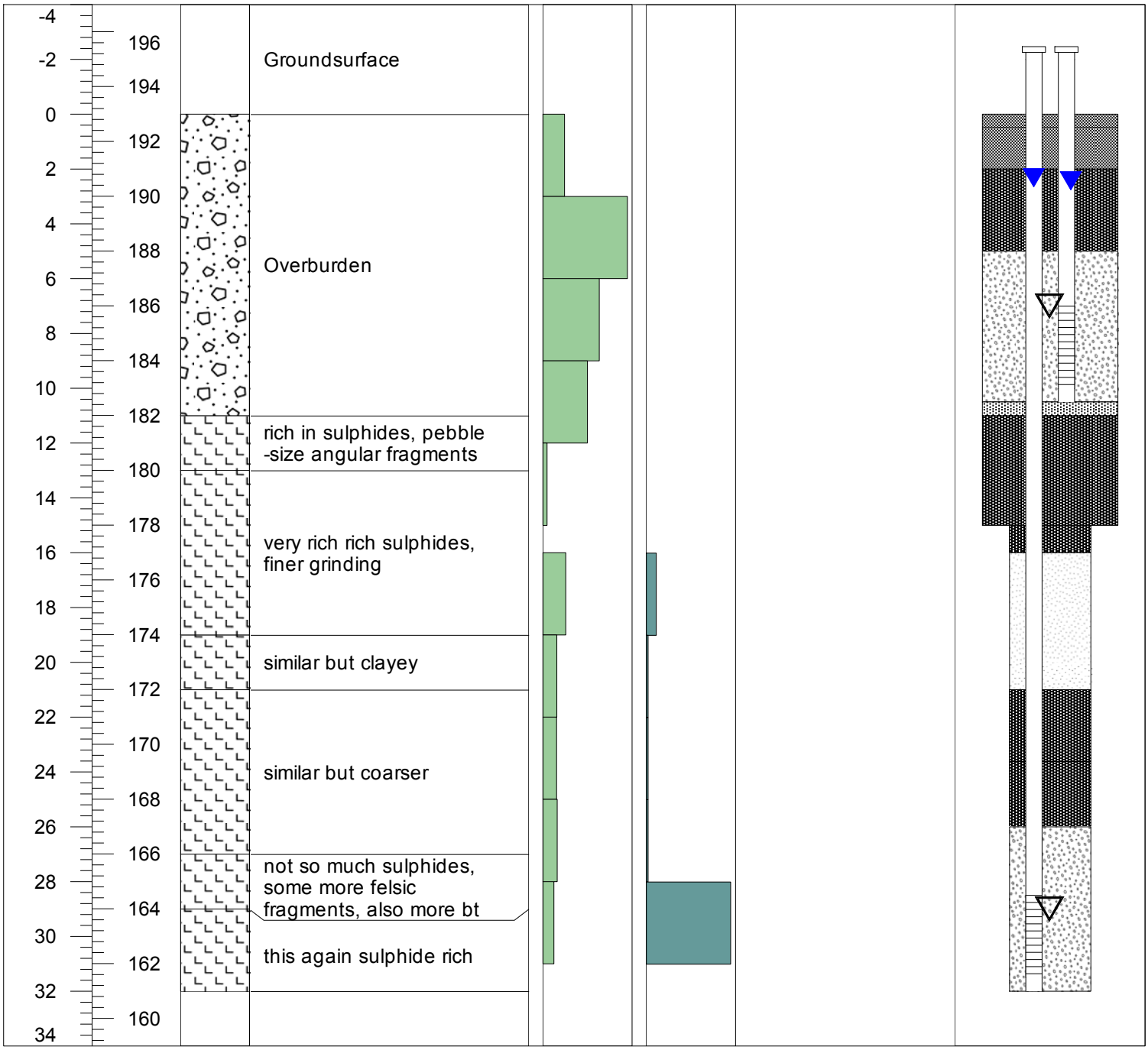


Drilling Date and ID:	4/19/12 RV1	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.07(D), 1.18(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2500698 **Northing:** 7491694

Well ID: RAU12HYD15

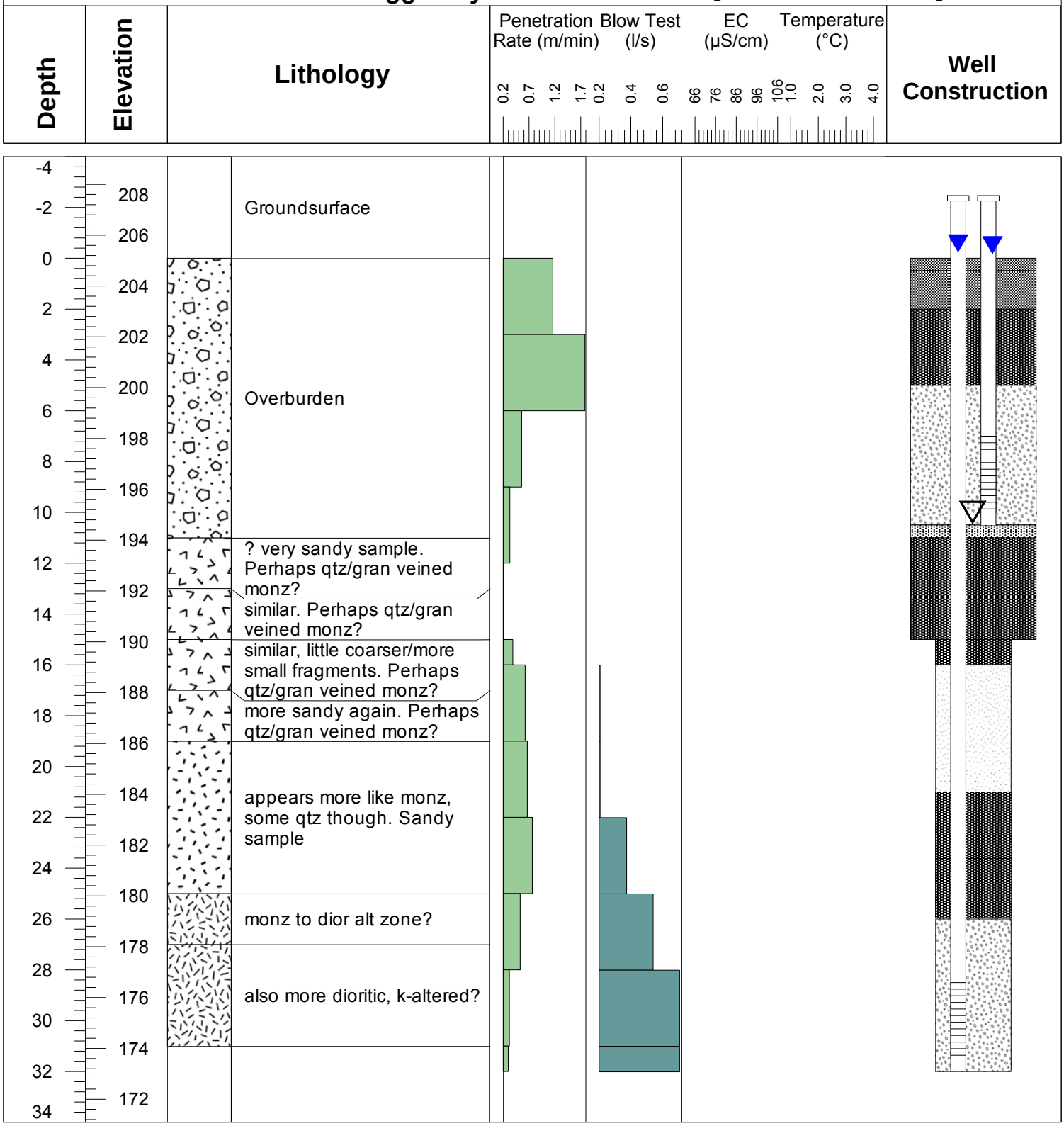


Drilling Date and ID: 4/20/12 RV4
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.30(D), 1.40(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2499159 **Northing:** 7491477

Well ID: RAU12HYD16

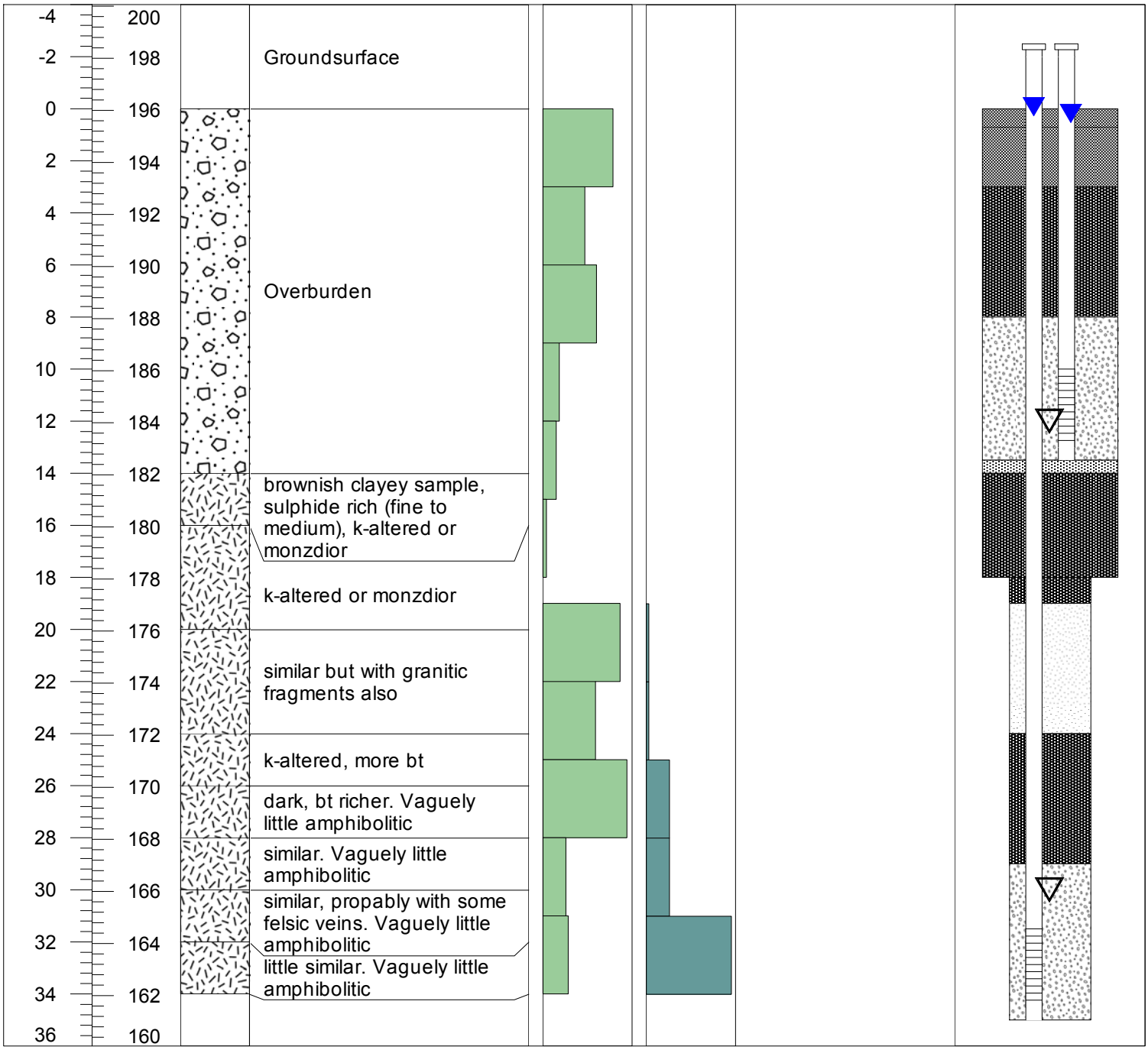


Drilling Date and ID:	4/20/12 RV8	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.30(D), 0.93(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2498832 **Northing:** 7491057

Well ID: RAU12HYD17

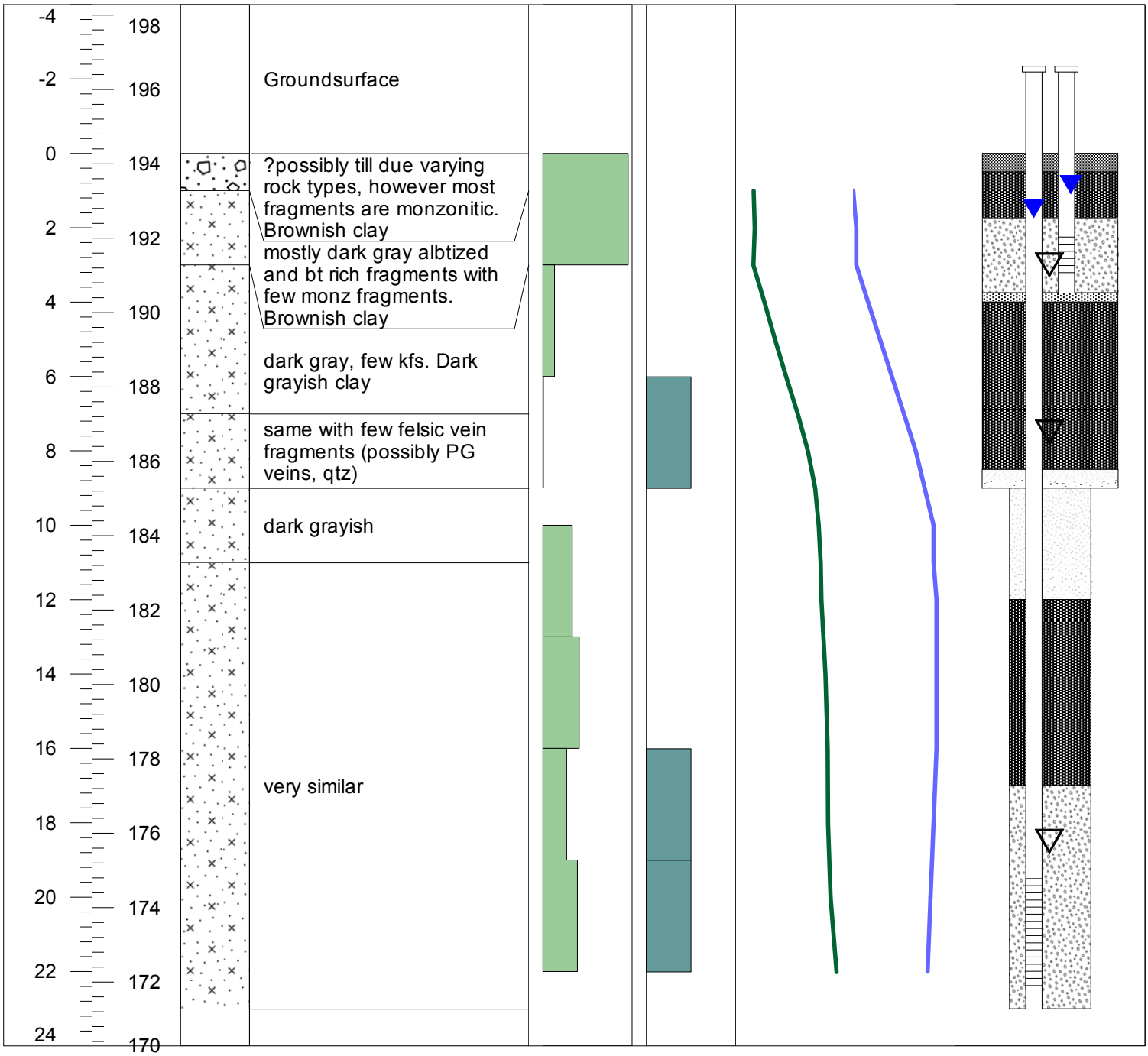


Drilling Date and ID:	4/21/12 RV14	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.27(D), 1.65(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2498009 **Northing:** 7489134

Well ID: RAU12HYD18

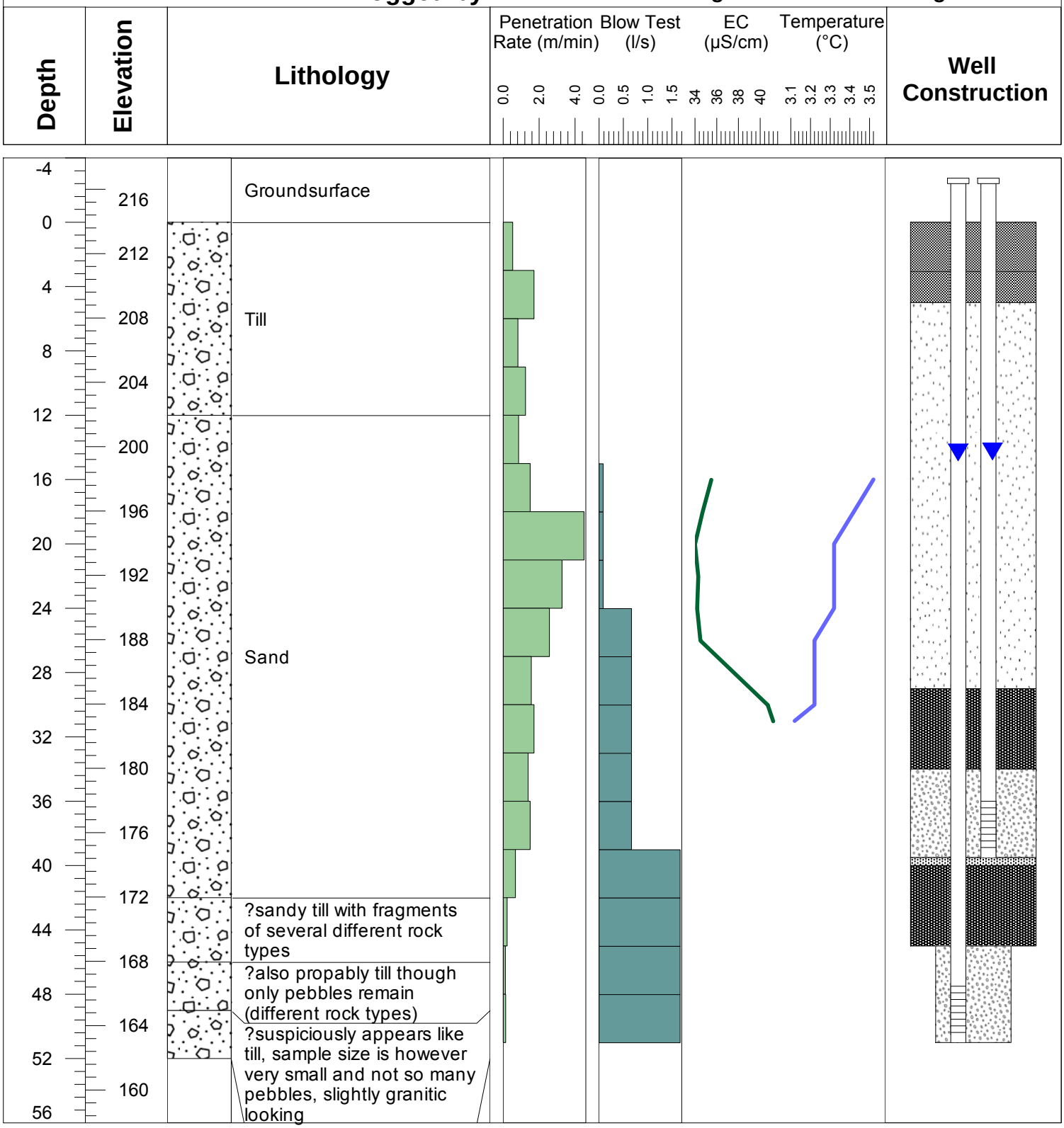


Drilling Date and ID:	4/22/12 RV39	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.00(D), 1.16(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2498535 **Northing:** 7488601

Well ID: RAU12HYD19

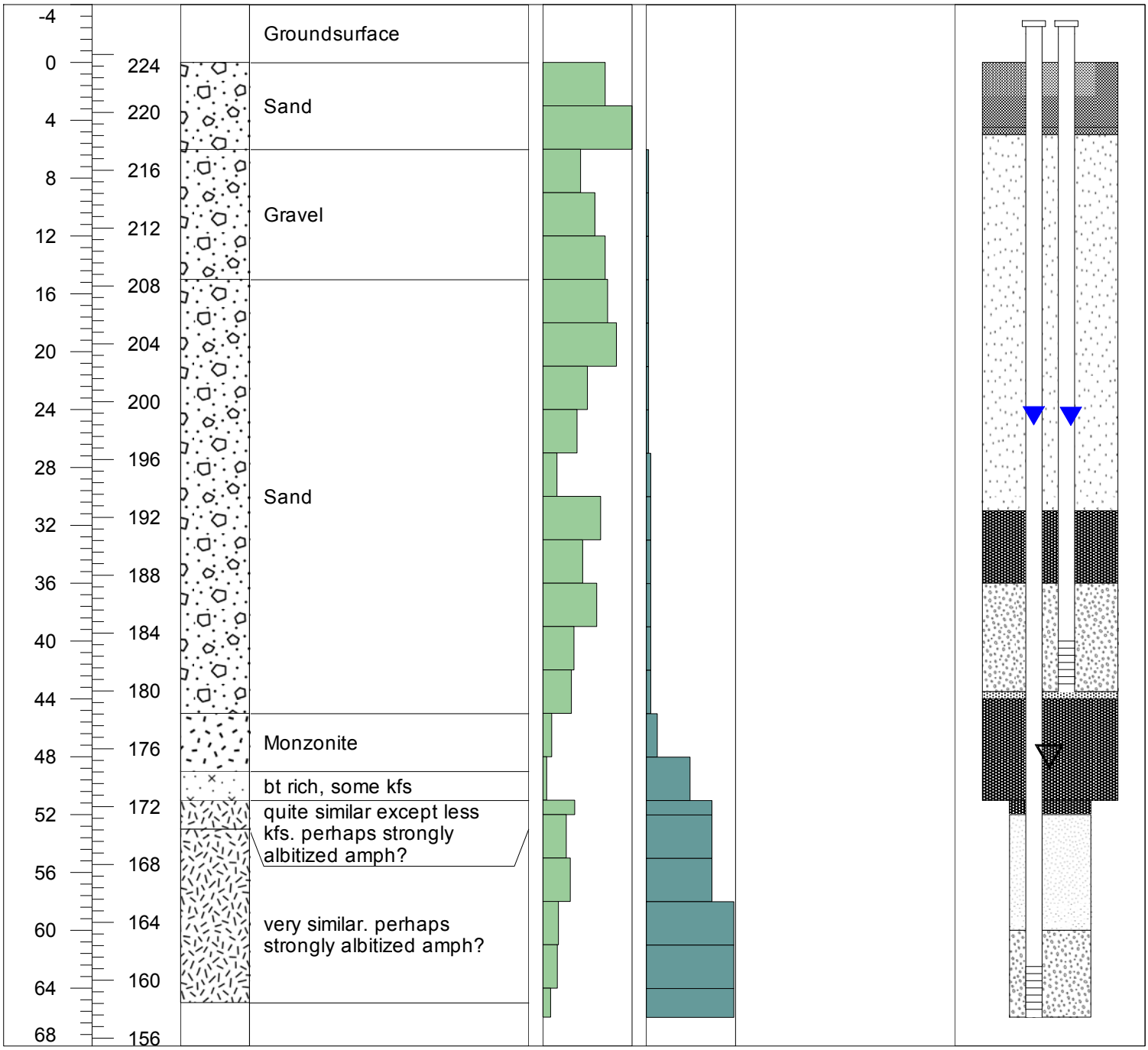


Drilling Date and ID:	4/24/12 RV41	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.10(D), 1.10(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2498843 **Northing:** 7489433

Well ID: RAU12HYD20

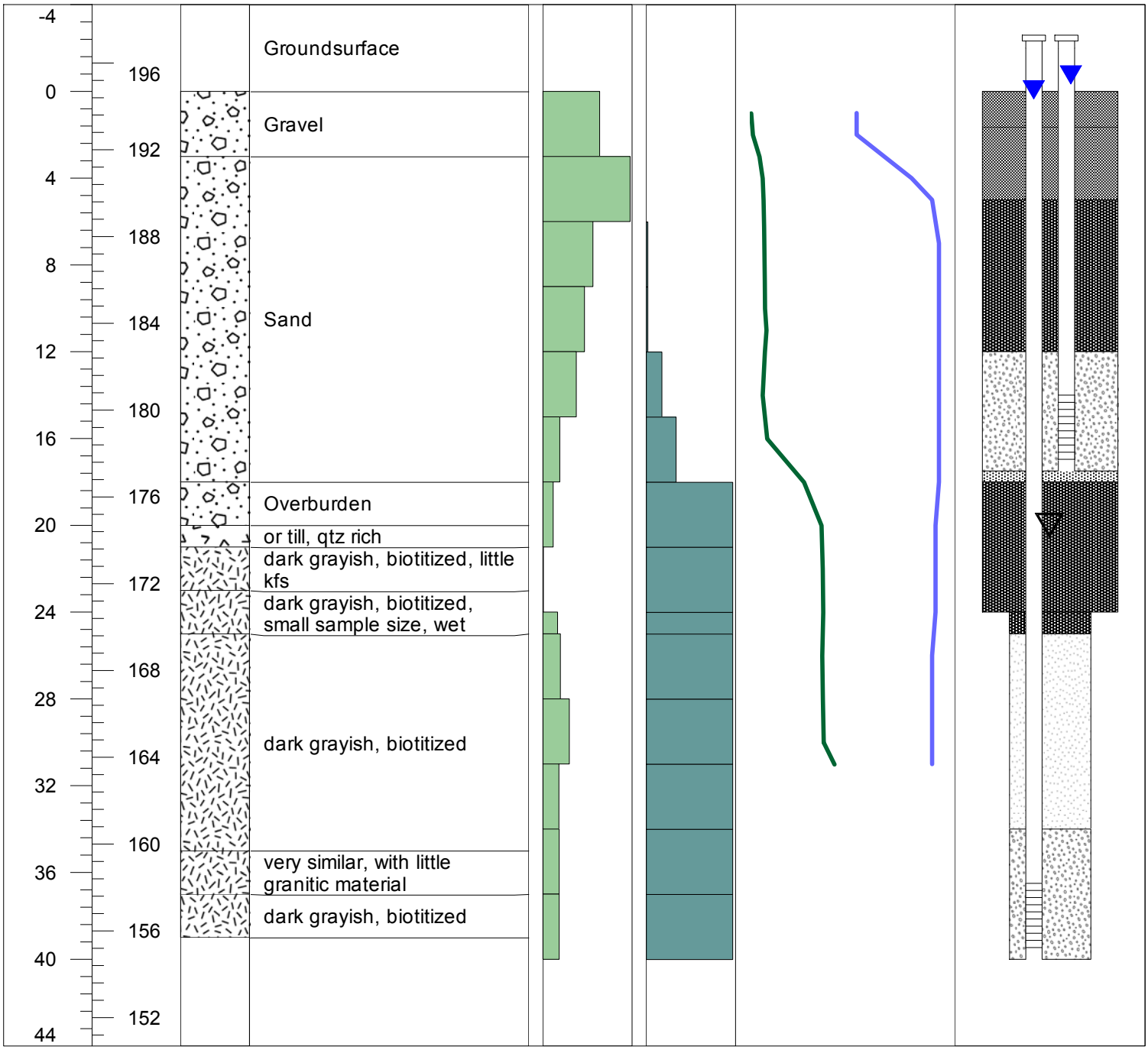


Drilling Date and ID: 4/28/12 RV118
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.25(D), 1.27(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2498465 **Northing:** 7489613

Well ID: RAU12HYD21

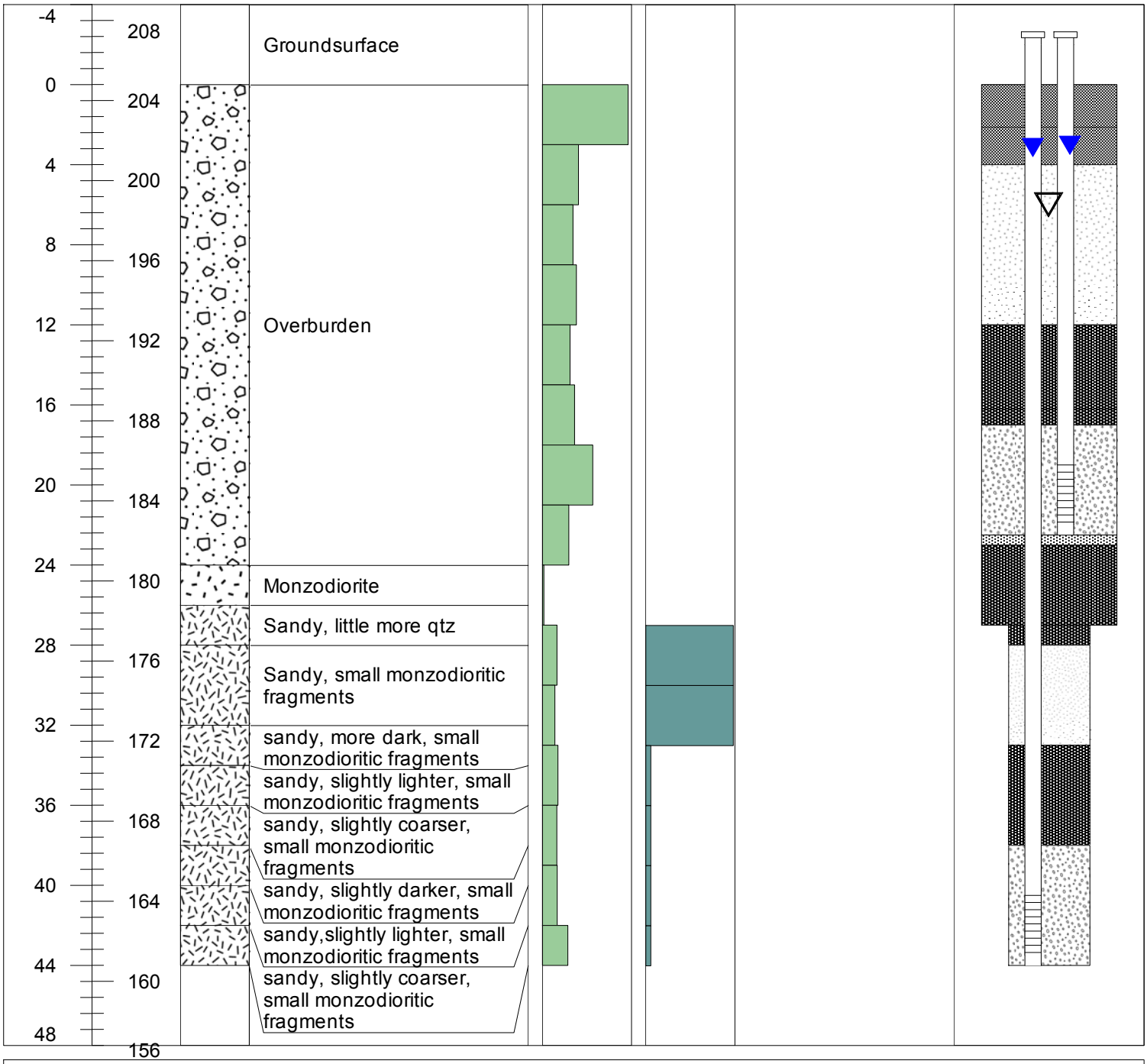


Drilling Date and ID:	4/30/12 RV30	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	1.14(D), 1.24(S)		
Comments:	Key on Pg1 of Appendix		

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2495560 **Northing:** 7488316

Well ID: RAU12HYD22

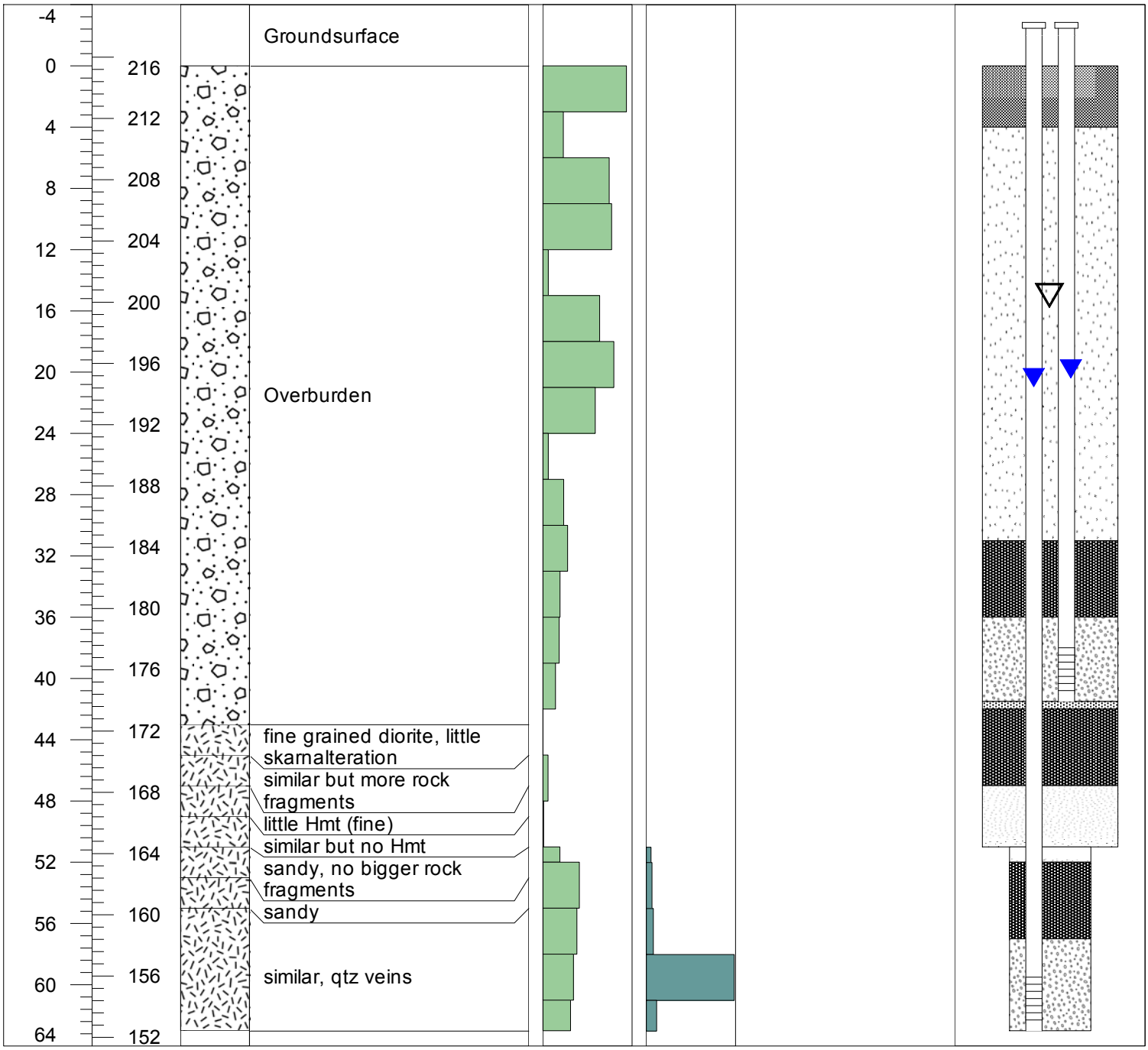


Drilling Date and ID: 5/14/12 RV62
Drilling Company: MINEREC OY
Drilling Method: DHH with air flush
Drilled ∅ (mm):
Casing: 50mm PVC screw jointed
Slot size: 0.5
Filter pack: 2-6mm Gravel
Stick-up: 1.00(D), 1.22(S)
Comments: Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2499409 **Northing:** 7490429

Well ID: RAU12HYD23

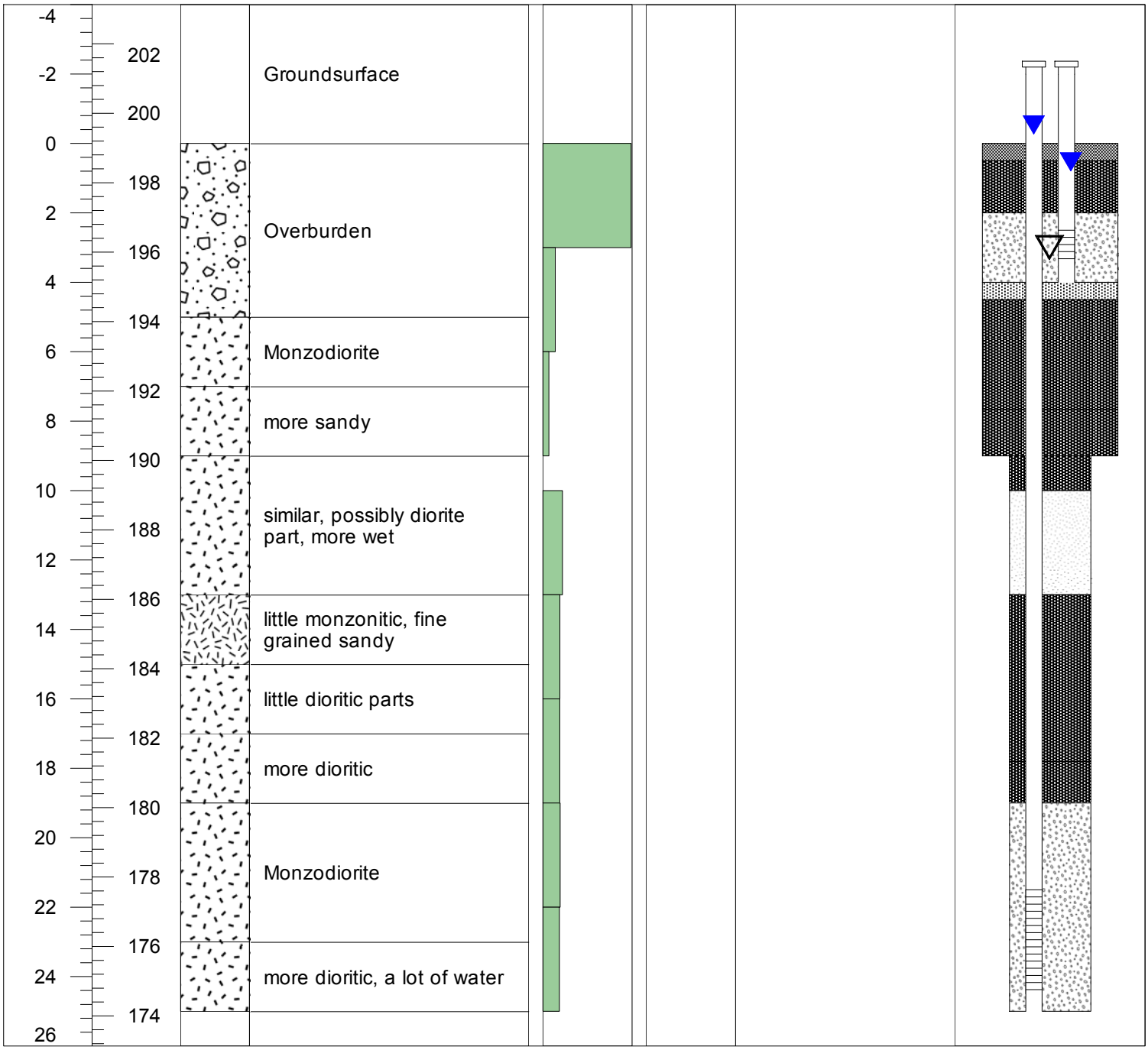


Drilling Date and ID:	5/15/12 RV17	Drilled ∅ (mm):		Filter pack:	2-6mm Gravel
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed	Stick-up:	0.85(D), 1.00(S)
Drilling Method:	DHH with air flush	Slot size:	0.5	Comments:	Key on Pg1 of Appendix

srk consulting

Project: U4970, Rautuvaara
Client: Northland
Logged by: Jari Mannila **Easting:** 2495594 **Northing:** 7486760

Well ID: RAU12HYD24



Drilling Date and ID:	5/22/12 RV56	Drilled ∅ (mm):	
Drilling Company:	MINEREC OY	Casing:	50mm PVC screw jointed
Drilling Method:	DHH with air flush	Slot size:	0.5
Filter pack:	2-6mm Gravel		
Stick-up:	0.54(D), 0.90(S)		
Comments:	Key on Pg1 of Appendix		

APPENDIX

E SLUG TEST ANALYSIS

1.1 Summary of Hydraulic Testwork

A total of 40no. slug tests, 2no. rising head tests and 57no. falling head tests were performed in the shallow and deep piezometers of RAU12HYD01 to RAU12HYD24.

Water levels recorded during each test are shown in Annex 1 of this appendix.

Hydraulic conductivity was estimated from this data using AQTESOLV, an industry standard software for analysis of hydraulic tests. All data was analysed using the Cooper et al. (1967) straight line method, followed by either the Bower-Rice (1976), KGS (1994), Hvorslev (1951), Springer-Gelhar (1991) or Butler-Zhan (2004) methods as appropriate. In some cases it was not possible to match all of the data to a single curve. In these cases data within the recommended range for normalized head (estimated using the Butler (1998) method) was used to match the solution. The analysis of each test is shown in Annex 2 of this appendix.

Estimated hydraulic conductivity for each test is given in Annex 3 of this appendix and is summarised below in Table 1-1. The tests are split in to 'reliable' and 'unreliable' based on the quality of the curve matching and considering the analysis described below in Section 1.2.

Table 1-1: Summary of Hydraulic Tests

	Reliable tests	**Unreliable tests**
Hydraulic conductivity (m/d)		
Minimum	1.64E-04	5.11E-01
Maximum	26.97	22.93
median	0.67	6.13
average	2.17	7.92
Aquifer		
Shallow	54	17
Deep	52	3
Tailings	4	5
Total	110	25

1.2 Slug Test Quality

It was important to filter the data to remove poor quality test results. Figure 1-1 summarises the slug test data collected at Rautuvaara. The chart shows:

- The initial displacement recorded in each piezometer plotted against the time for 95% recovery;
- Where the volume displaced is equal for introduction / removal of the slug, the marker gives the average displacement and no error bars are shown;
- Where displacement caused by introduction / removal of the slug is not equal error bars show the head change for introduction / removal. The marker bisects the line to show the relative proportions of head change during introduction / removal[1]; and
- The equivalent diameter of the casing given the initial displacement.

[1] *For example, the point circled in blue in Figure 4-20 had an initial displacement of 1.69 m when the slug was introduced and only 0.60 m when it was removed. The top and bottom of the bars give the absolute displacement in each case and the position of the marker three quarters of the way down the line provides a quick visual demonstration of the disparity.*

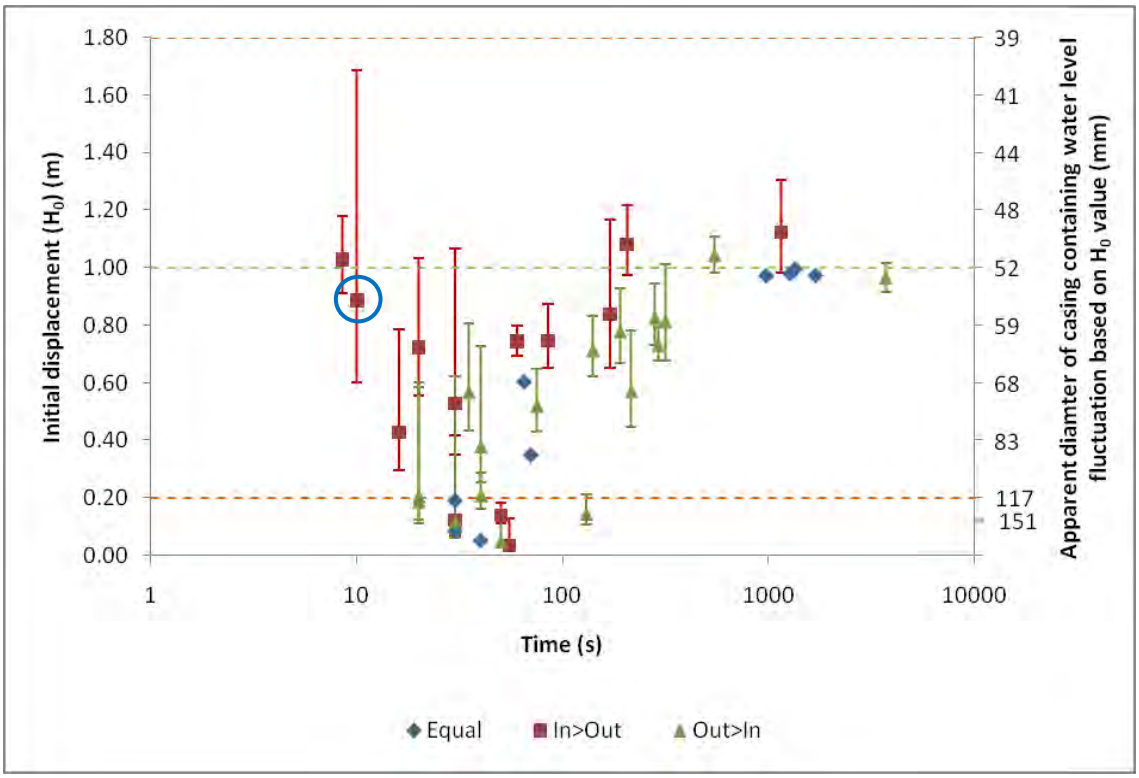


Figure 1-1: Summary of Slug Test Quality Control

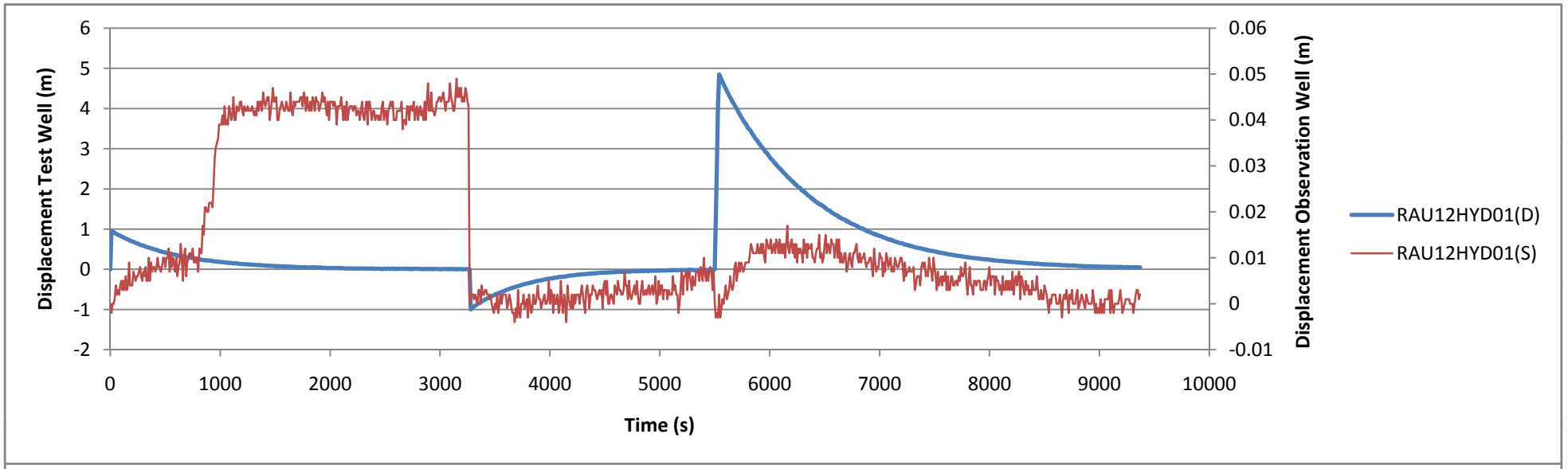
In a perfect test the upward and downward displacement are equal and maximum displacement is achieved (in this case 1 m), indicating that there is no interaction between the water in the piezometer and the surrounding aquifer during the introduction / removal of the slug.

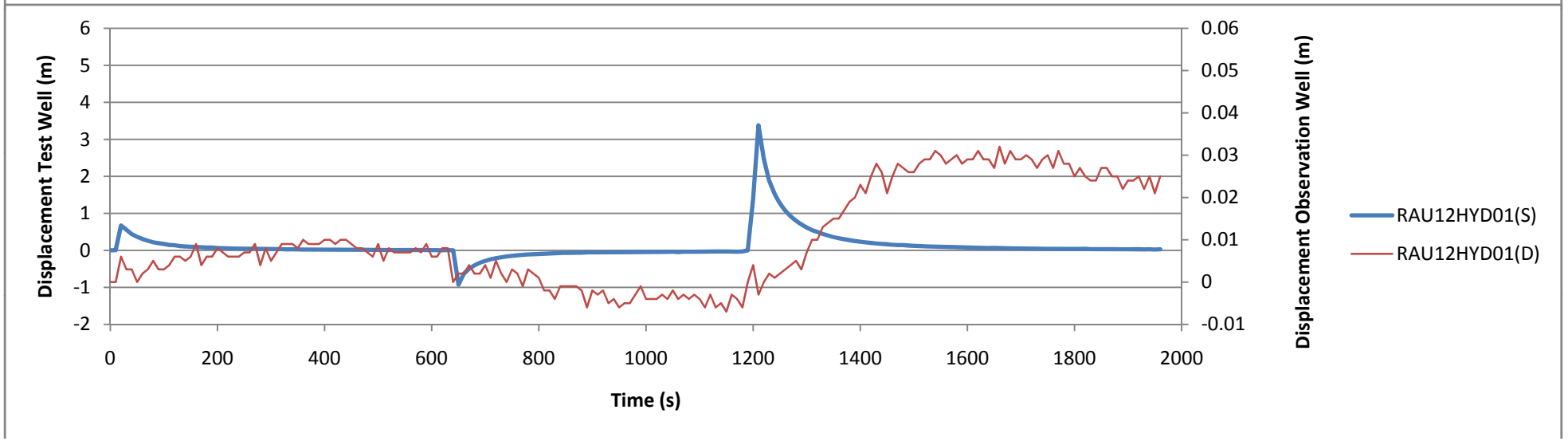
It is shown in Figure 1-1 that:

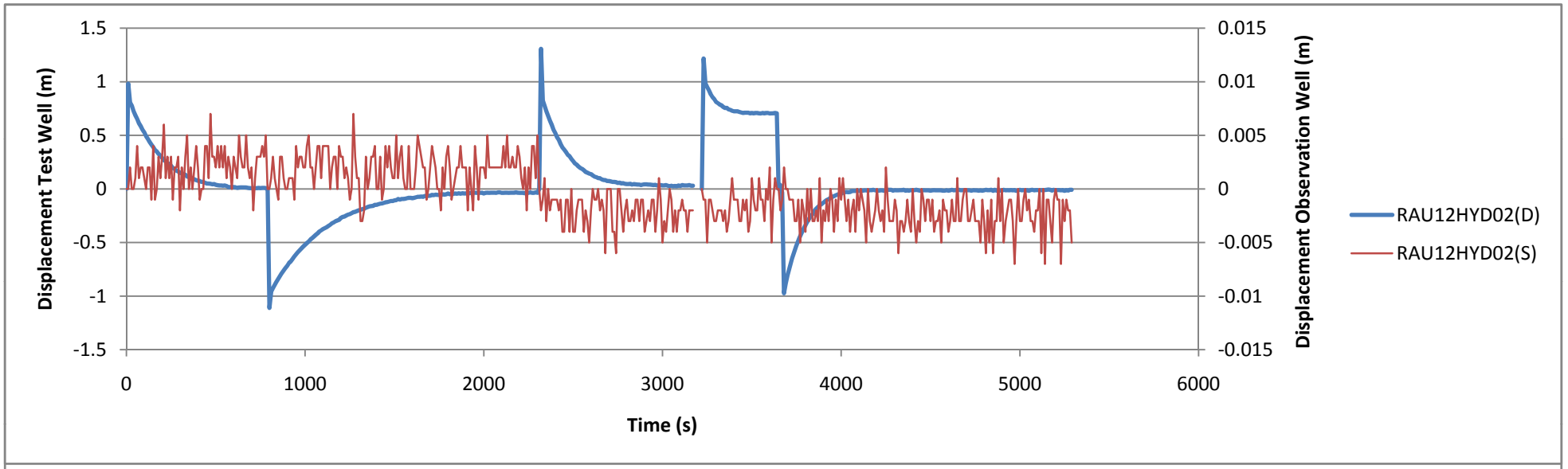
- Generally the quality of the slug tests increases as the recovery time increases;
- Horizontal, orange, dashed lines show where the displacement is less than 0.2 m. As can be seen on the scale on the right of the chart, this corresponds to a casing diameter of about 120 mm. Since the drilled diameter is about 140 mm this suggests that the slug may be inducing a change in the water level of the annular space as well as the 50 mm (ID) casing and so tests inducing less than 0.2 m change should be discarded.
- Of the 31no. tests with more than 0.2 m displacement, 23% record equal displacement, 35% greater displacement with introduction and 42% with removal of the slug.

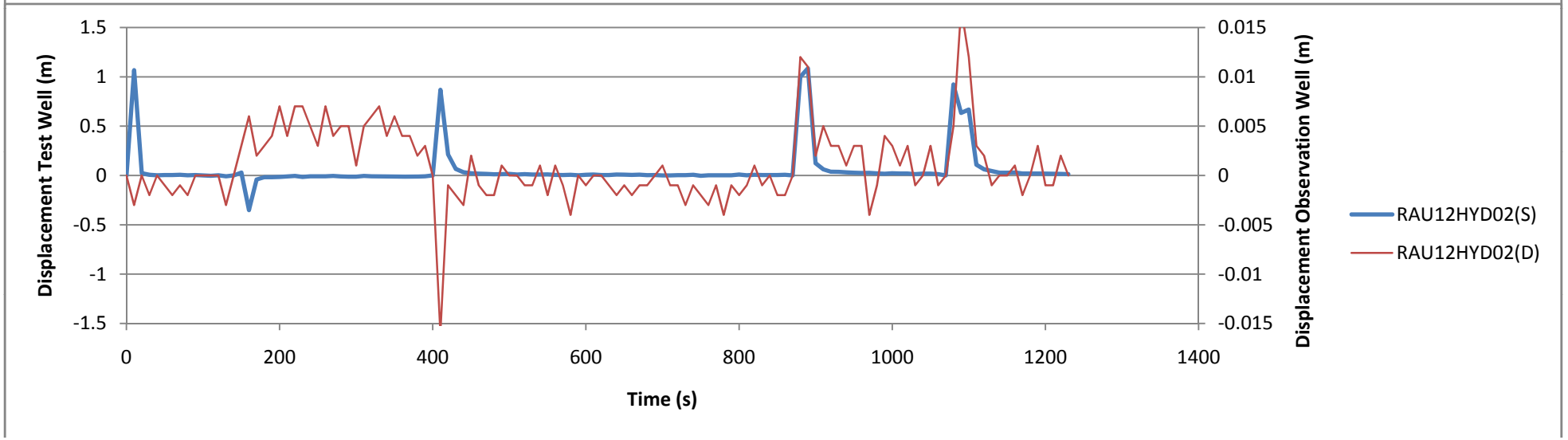
Nine of the forty slug tests conducted at Rautuvaara were deemed unreliable (less than 0.2 m change in head).

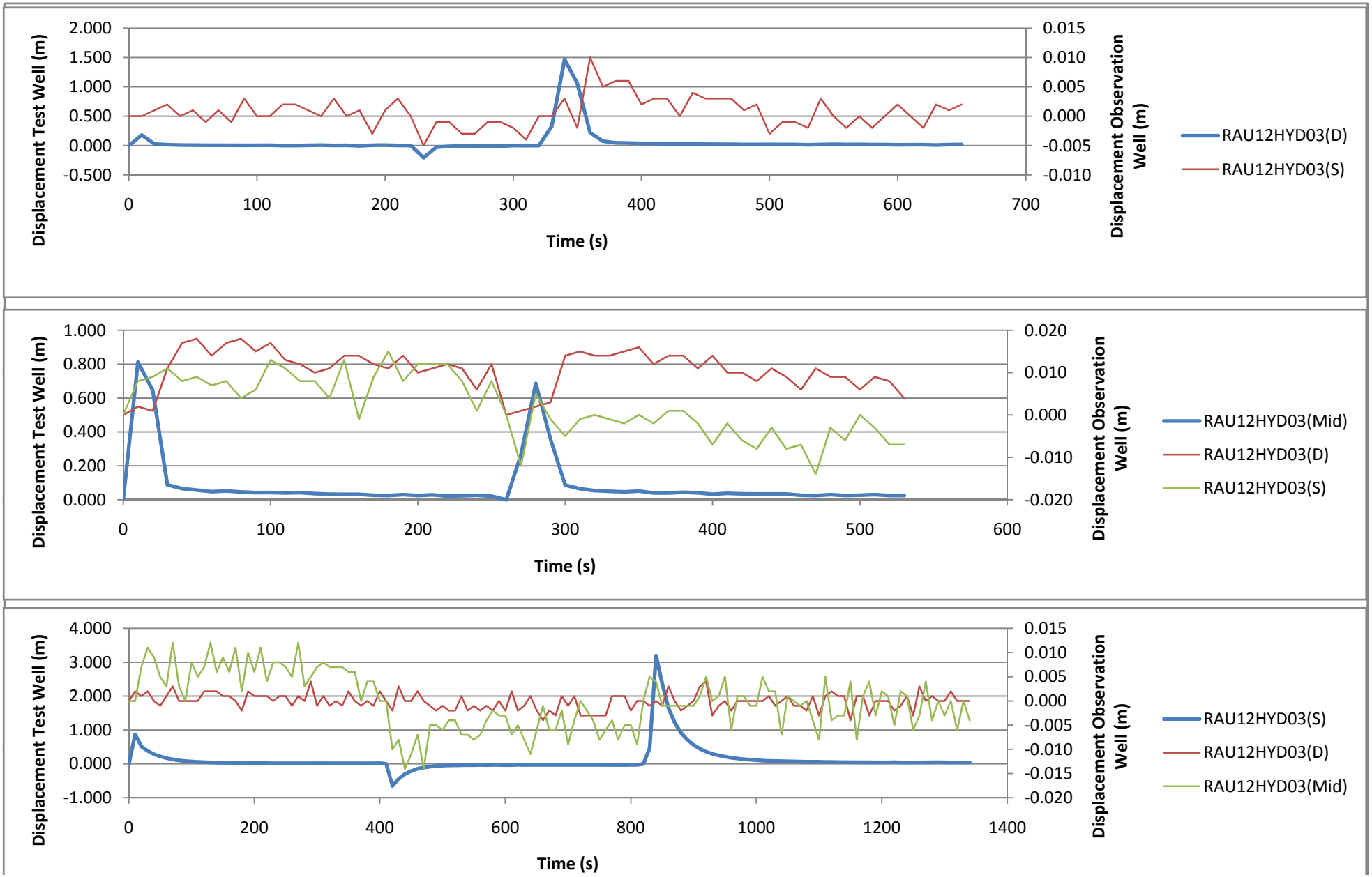
Annex 1 – Hydraulic Test Charts

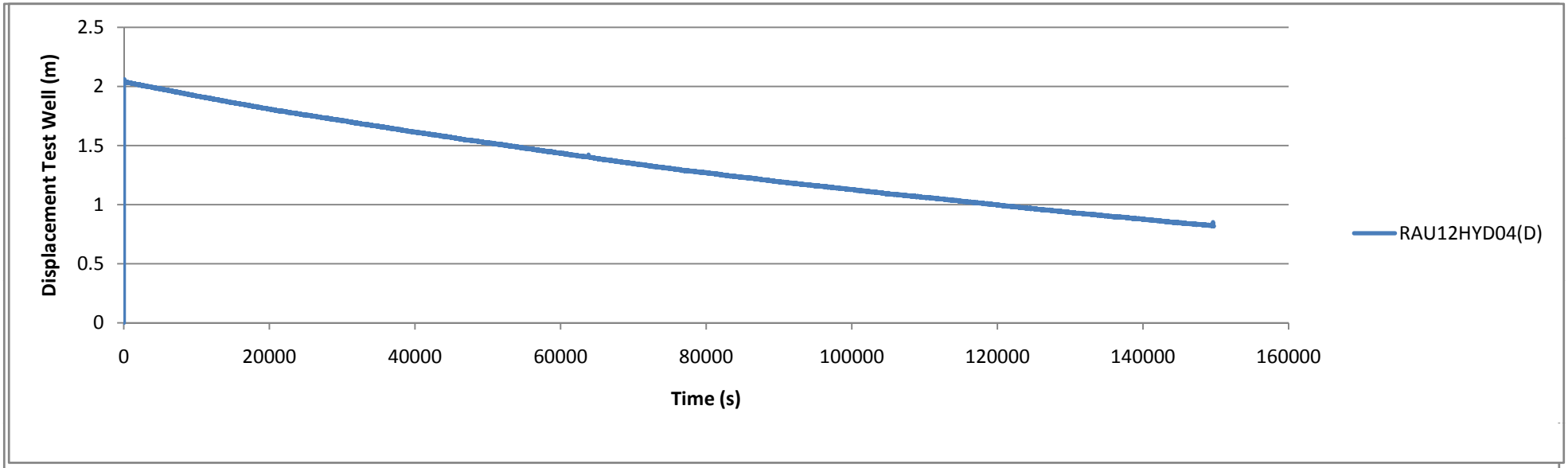

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD01(D)
RAU12HYD01(S)

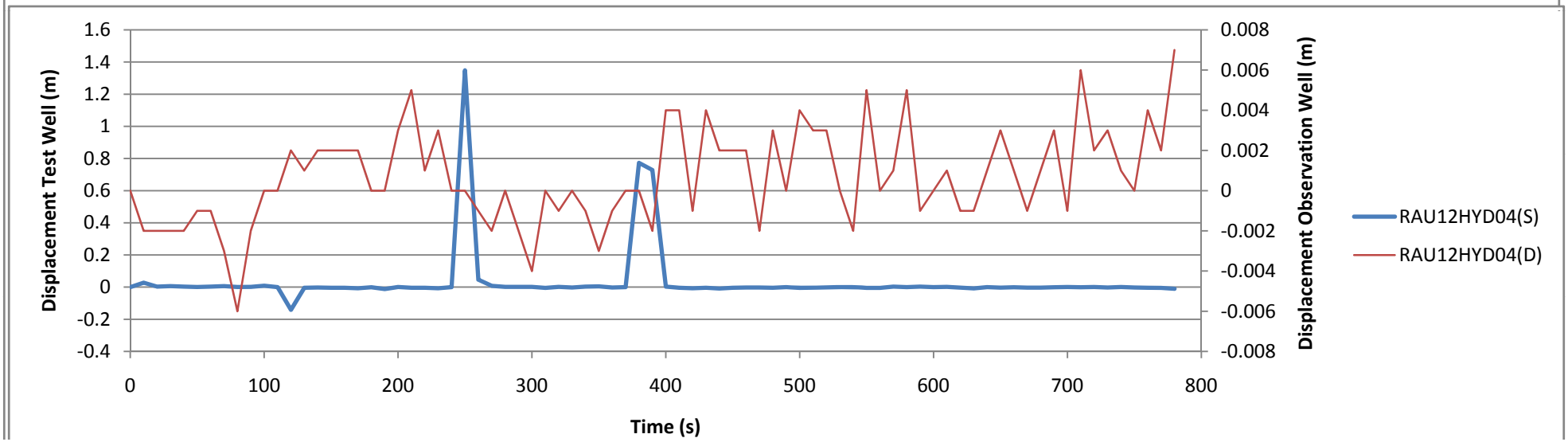

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD01(S)
RAU12HYD01(D)

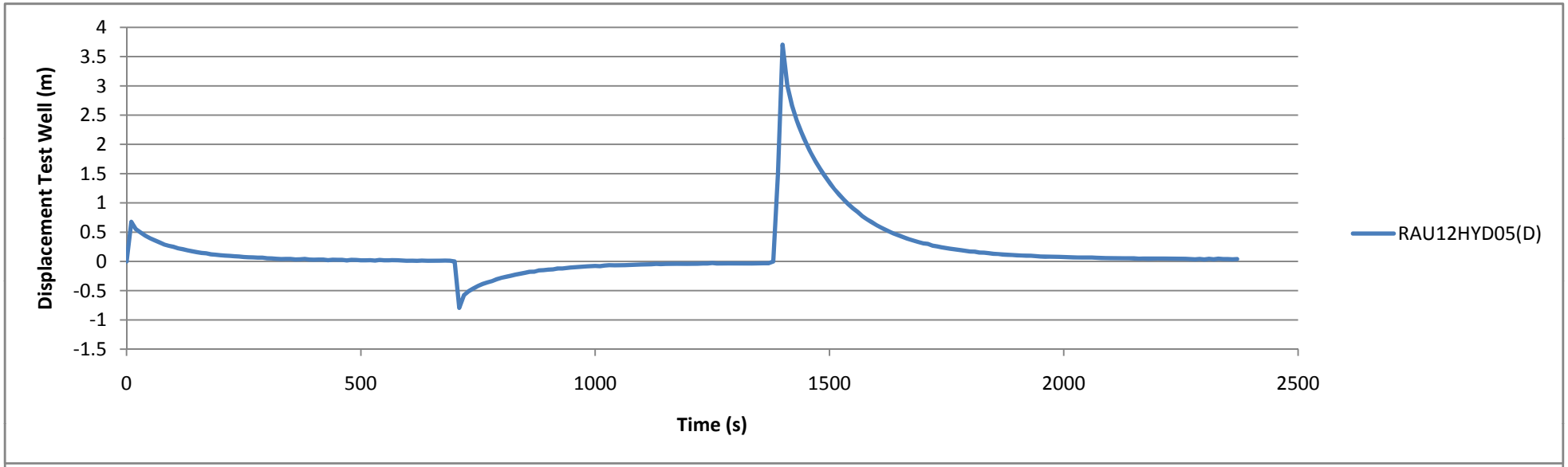

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
1.5
1
0.5
0
-0.5
-1
-1.5
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
1000
2000
3000
4000
5000
6000
RAU12HYD02(D)
RAU12HYD02(S)

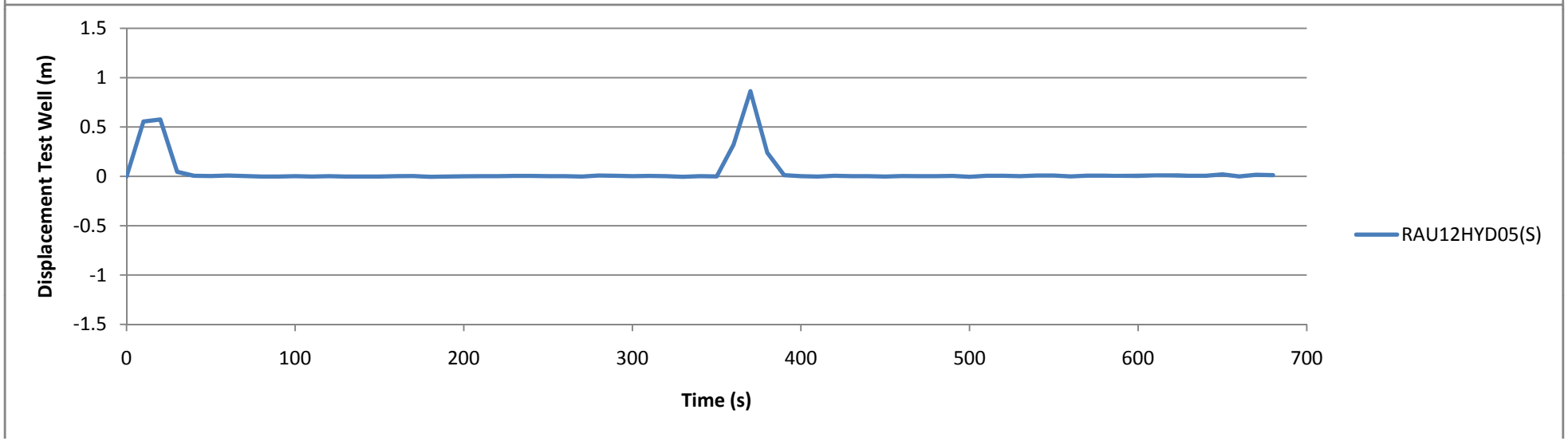

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
1.5
1
0.5
0
-0.5
-1
-1.5
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
200
400
600
800
1000
1200
1400
RAU12HYD02(S)
RAU12HYD02(D)

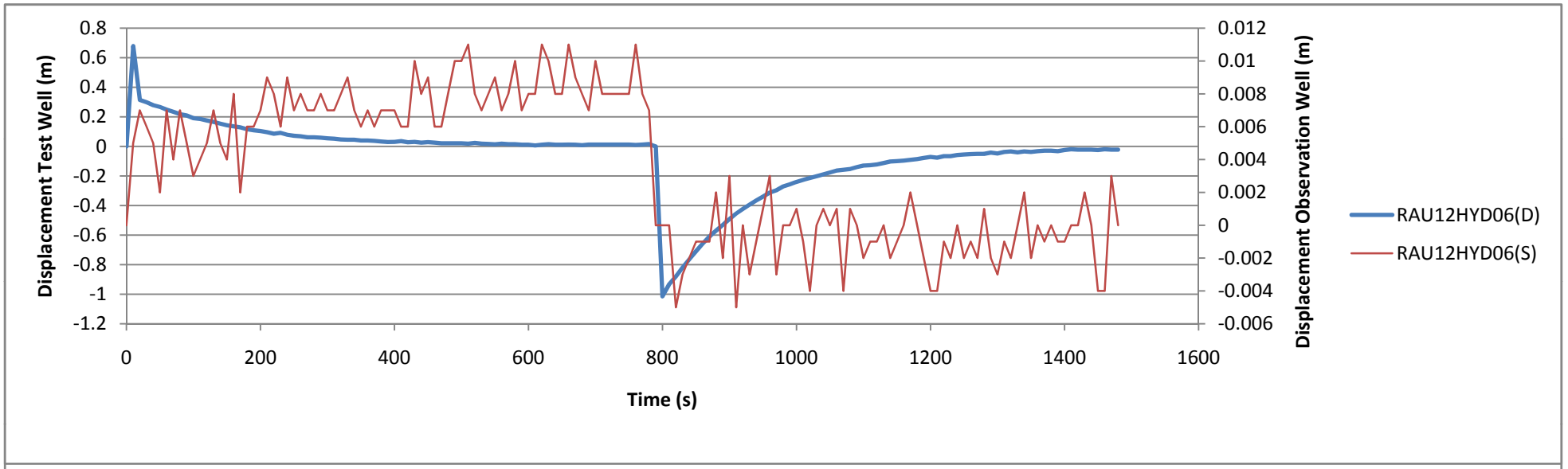

Displacement Test Well (m)
2.000
1.500
1.000
0.500
0.000
-0.500
0
100
200
300
400
500
600
700
Time (s)
Displacement Observation Well (m)
0.015
0.010
0.005
0.000
-0.005
-0.010
RAU12HYD03(D)
RAU12HYD03(S)
Displacement Test Well (m)
1.000
0.800
0.600
0.400
0.200
0.000
0
100
200
300
400
500
600
Time (s)
Displacement Observation Well (m)
0.020
0.010
0.000
-0.010
-0.020
RAU12HYD03(Mid)
RAU12HYD03(D)
RAU12HYD03(S)
Displacement Test Well (m)
4.000
3.000
2.000
1.000
0.000
-1.000
0
200
400
600
800
1000
1200
1400
Time (s)
Displacement Observation Well (m)
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
RAU12HYD03(S)
RAU12HYD03(D)
RAU12HYD03(Mid)

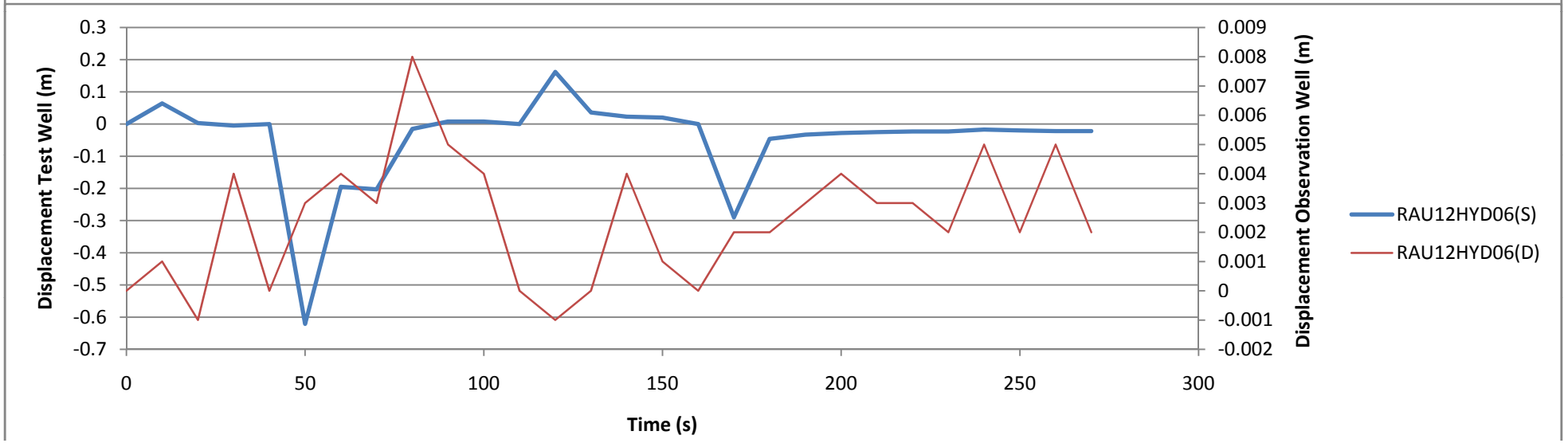

Displacement Test Well (m)
2.5
2
1.5
1
0.5
0
0
20000
40000
60000
80000
100000
120000
140000
160000
Time (s)
RAU12HYD04(D)

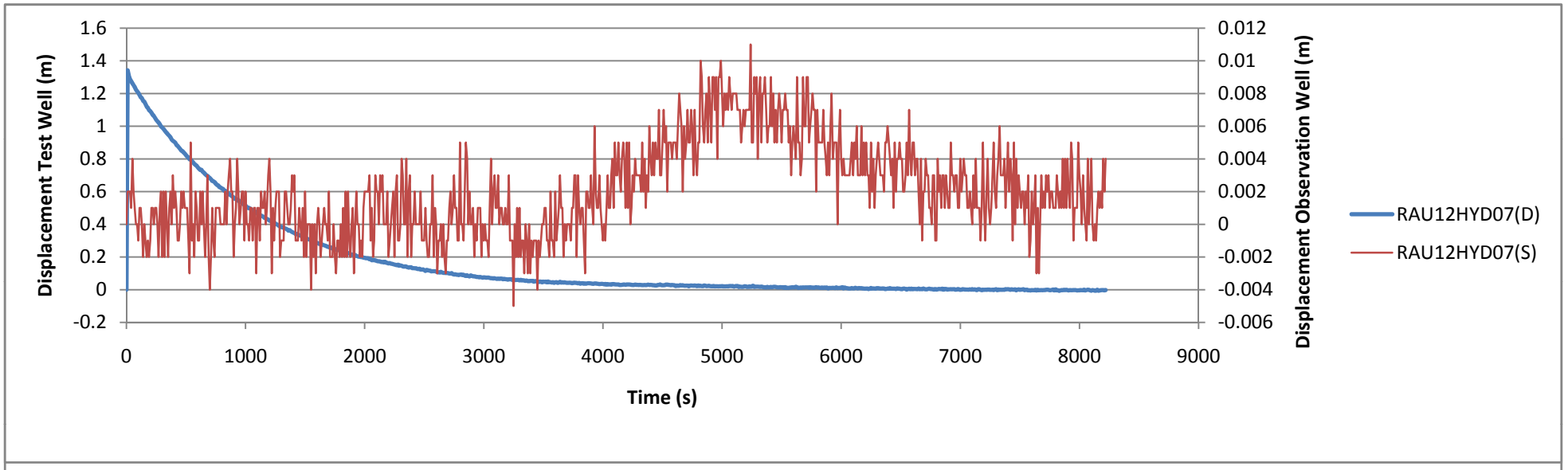

Displacement Test Well (m)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
Time (s)
Displacement Observation Well (m)
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
RAU12HYD04(S)
RAU12HYD04(D)

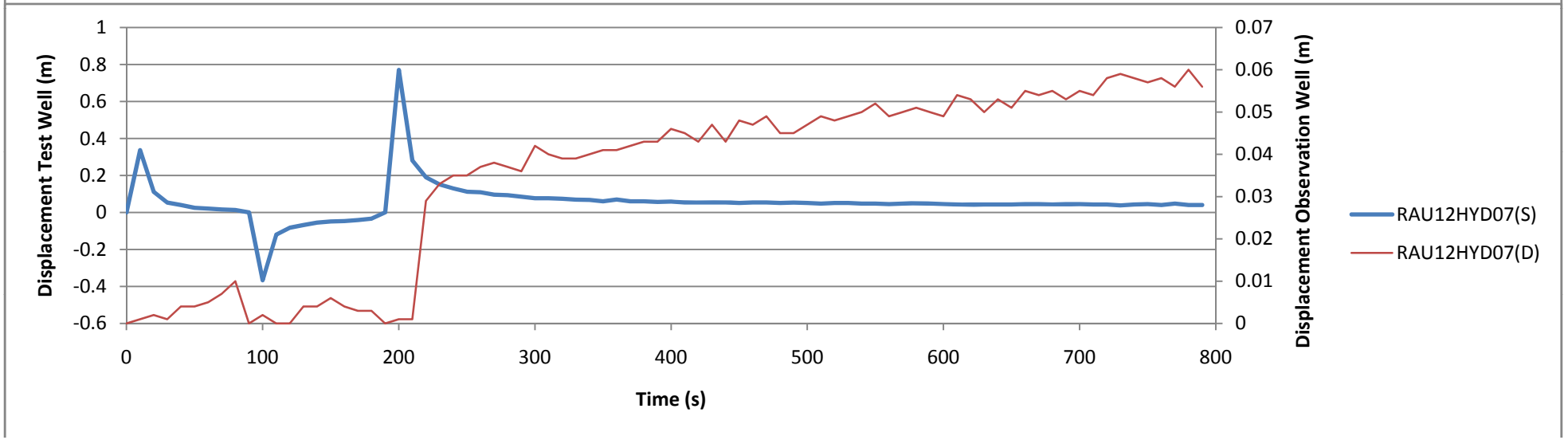

Displacement Test Well (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
500
1000
1500
2000
2500
Time (s)
RAU12HYD05(D)

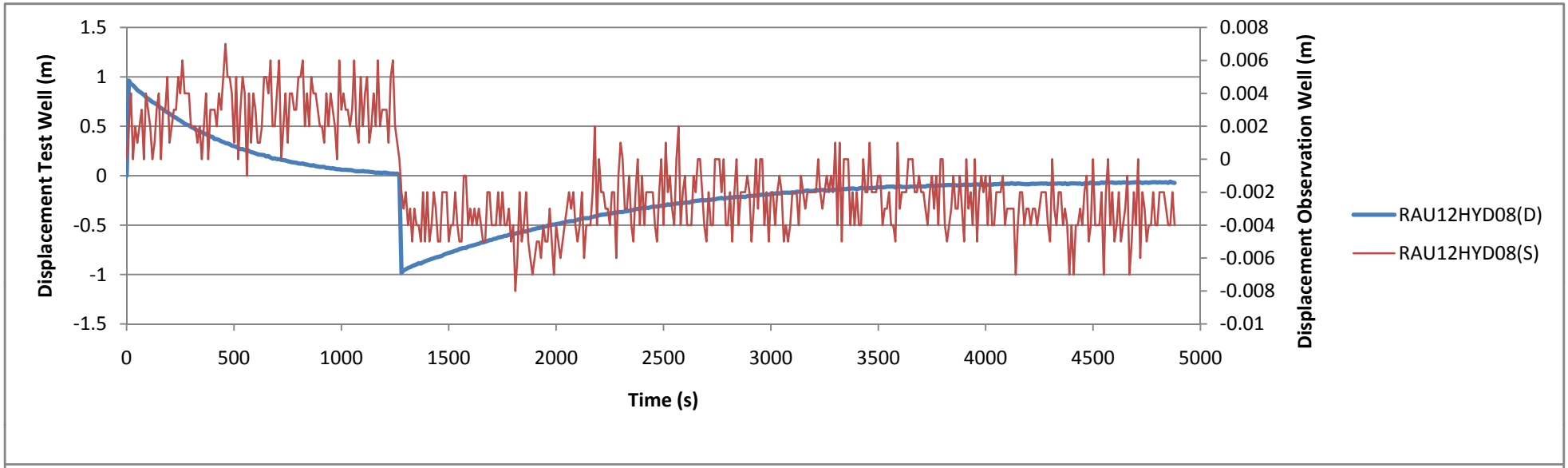

Displacement Test Well (m)
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400
500
600
700
Time (s)
RAU12HYD05(S)

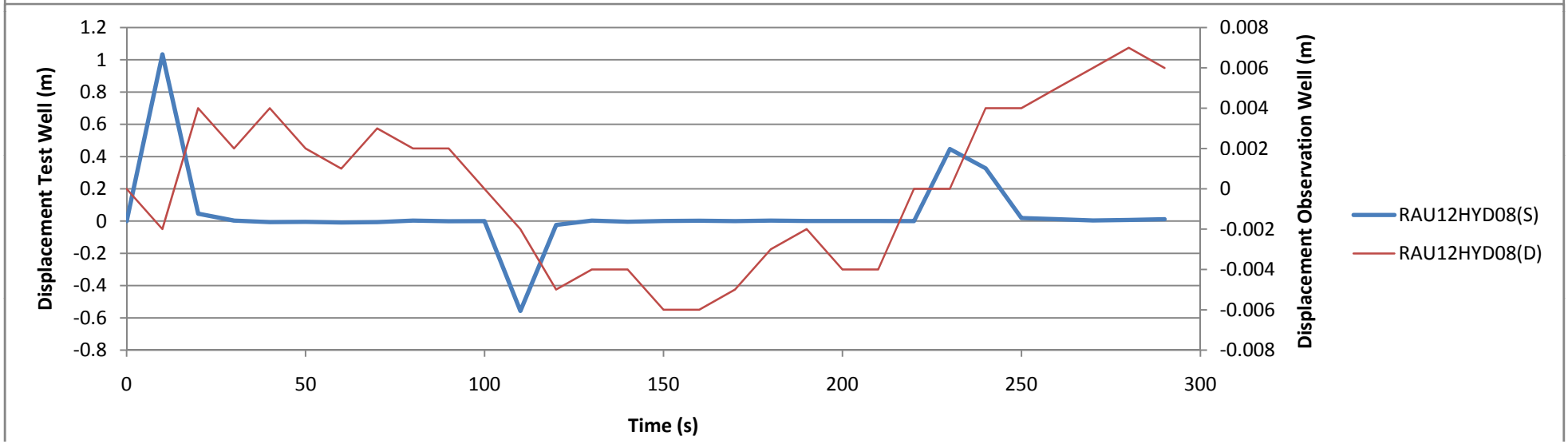

Displacement Test Well (m)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
200
400
600
800
1000
1200
1400
1600
Time (s)
Displacement Observation Well (m)
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
RAU12HYD06(D)
RAU12HYD06(S)

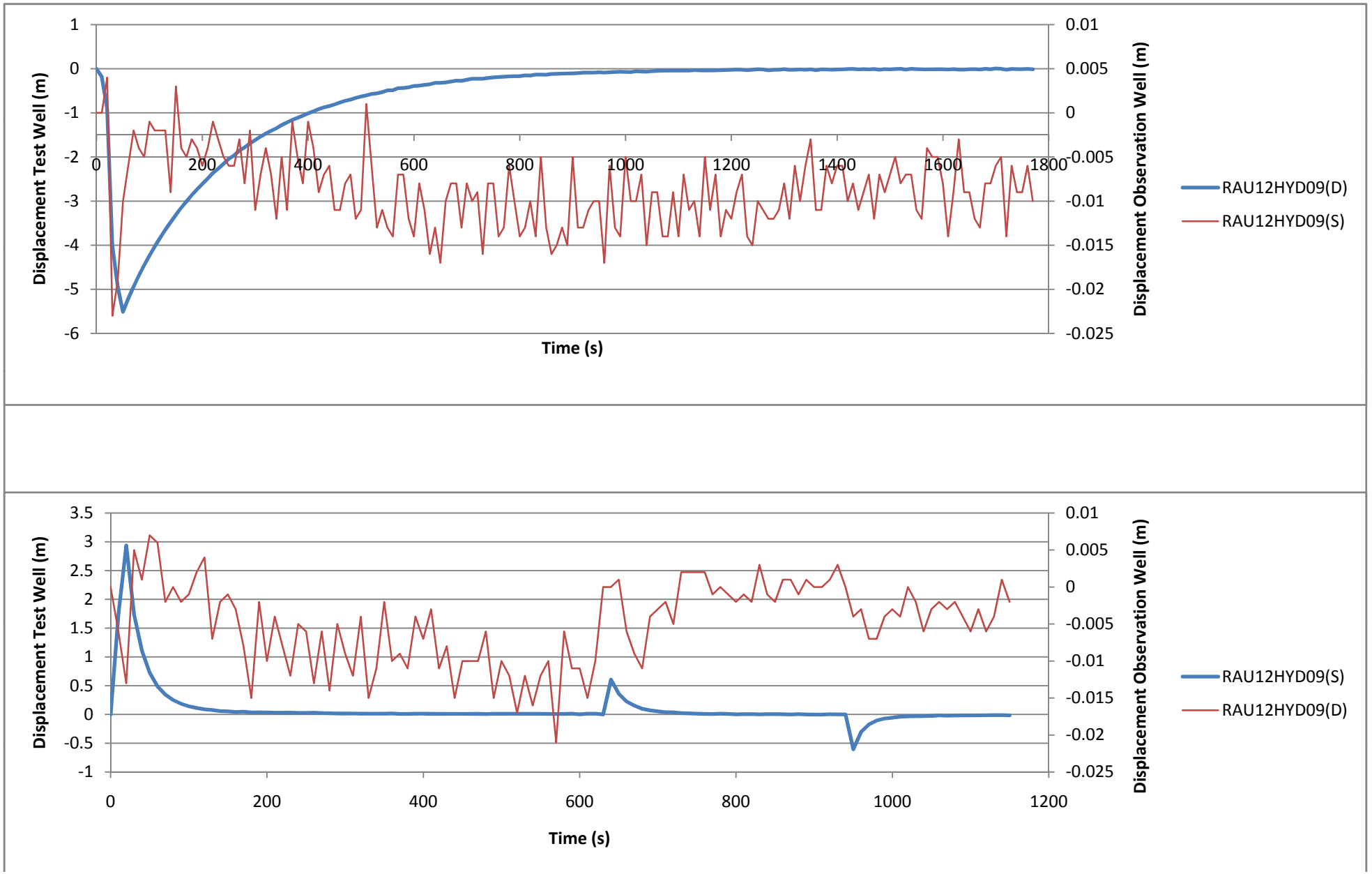

Displacement Test Well (m)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0
50
100
150
200
250
300
Time (s)
Displacement Observation Well (m)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
RAU12HYD06(S)
RAU12HYD06(D)

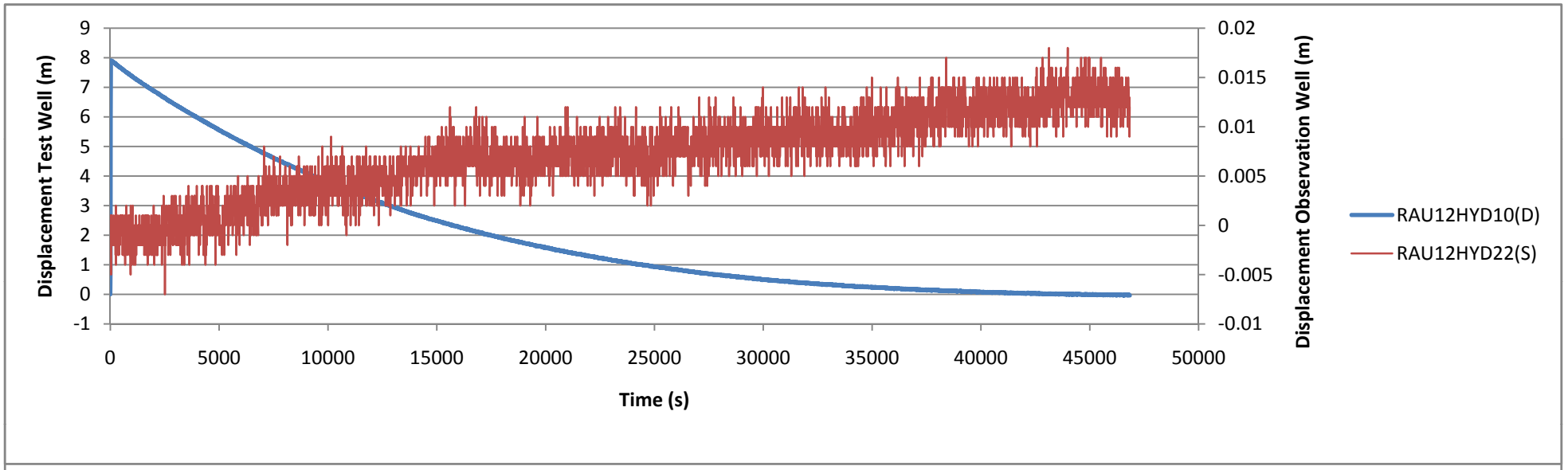

Displacement Test Well (m)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Time (s)
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
Displacement Observation Well (m)
RAU12HYD07(D)
RAU12HYD07(S)

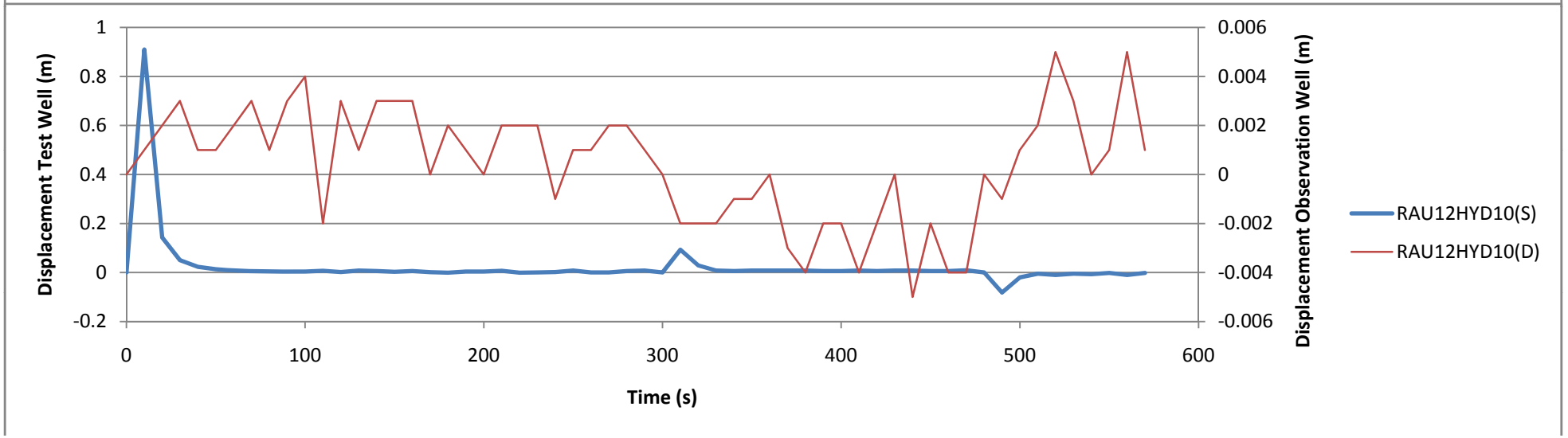

Displacement Test Well (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
Time (s)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Displacement Observation Well (m)
RAU12HYD07(S)
RAU12HYD07(D)

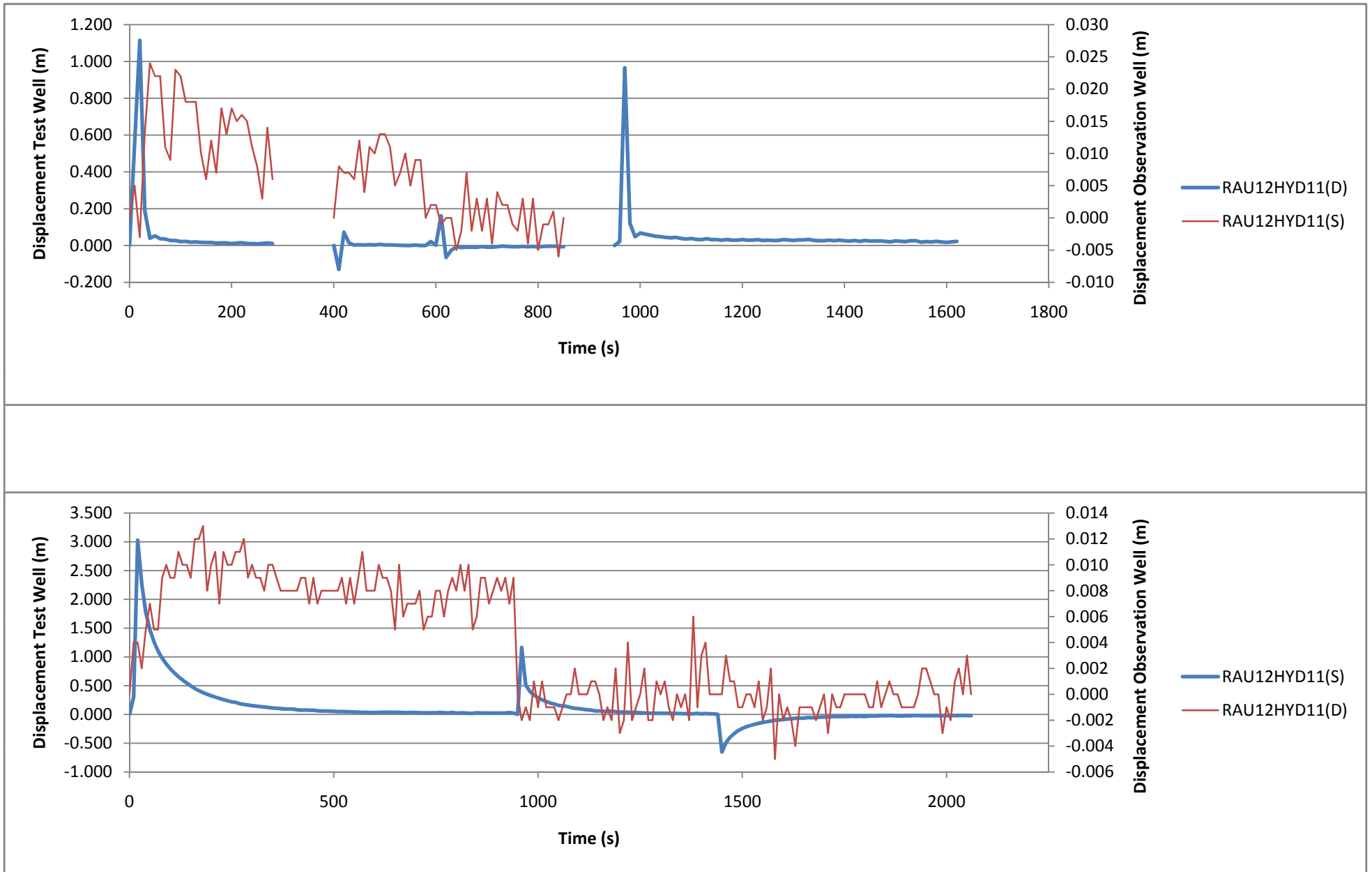

Displacement Test Well (m)
1.5
1
0.5
0
-0.5
-1
-1.5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (s)
Displacement Observation Well (m)
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
RAU12HYD08(D)
RAU12HYD08(S)

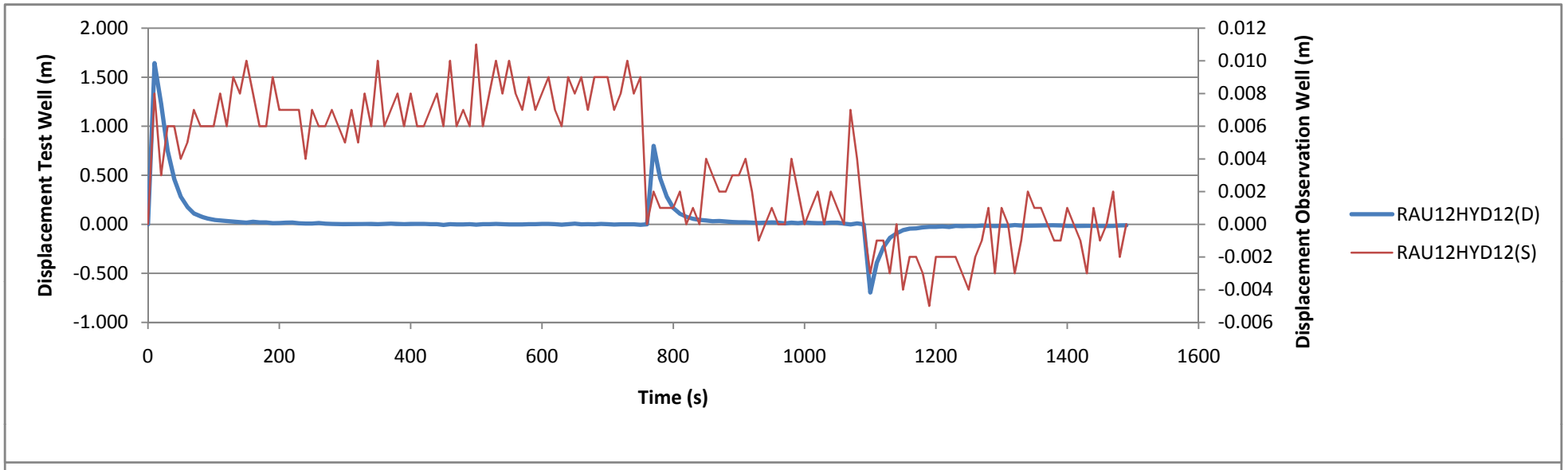

Displacement Test Well (m)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
50
100
150
200
250
300
Time (s)
Displacement Observation Well (m)
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
RAU12HYD08(S)
RAU12HYD08(D)

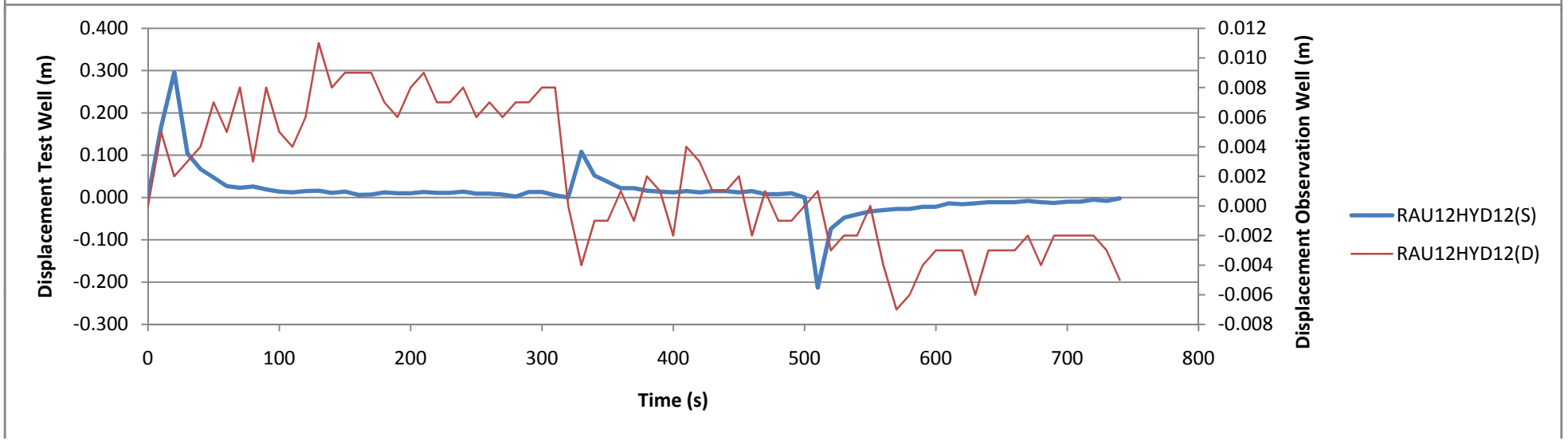

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD09(D)
RAU12HYD09(S)
Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD09(S)
RAU12HYD09(D)

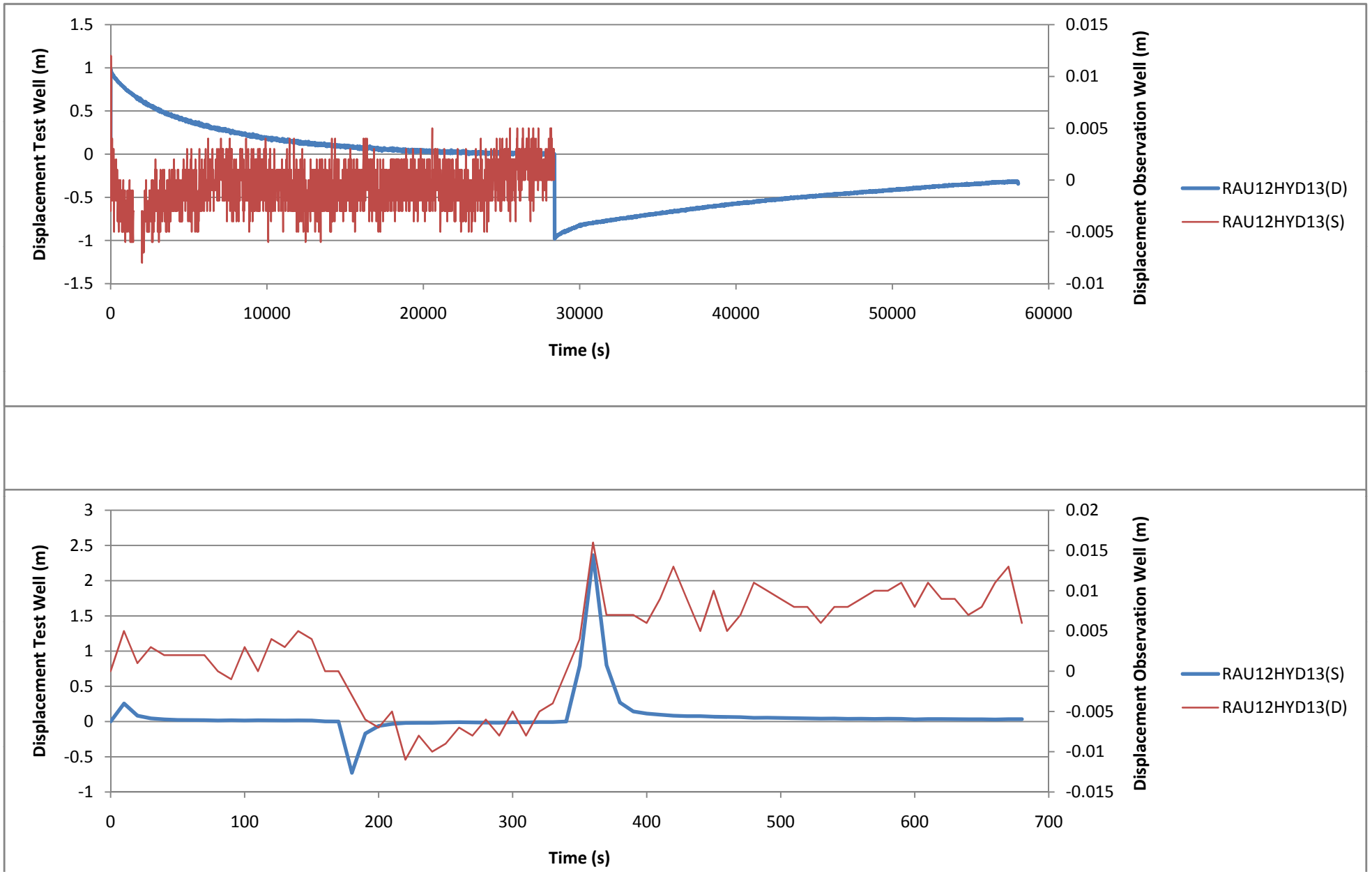

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD10(D)
RAU12HYD22(S)

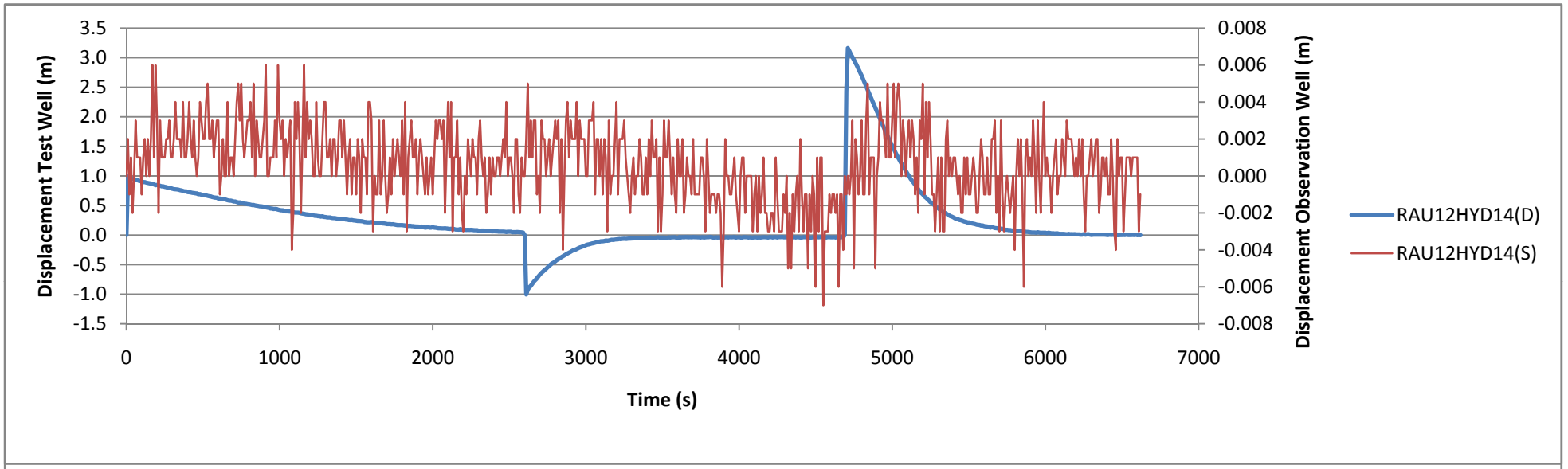

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD10(S)
RAU12HYD10(D)

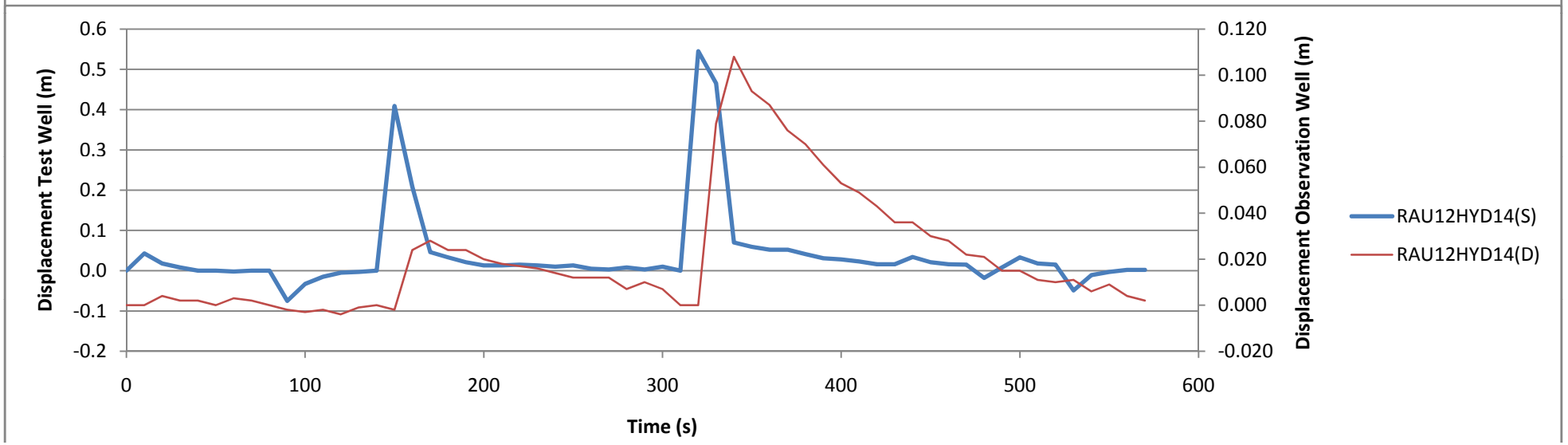

Displacement Test Well (m)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)
Displacement Observation Well (m)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
RAU12HYD11(D)
RAU12HYD11(S)
Displacement Test Well (m)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
0
500
1000
1500
2000
Time (s)
Displacement Observation Well (m)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
RAU12HYD11(S)
RAU12HYD11(D)

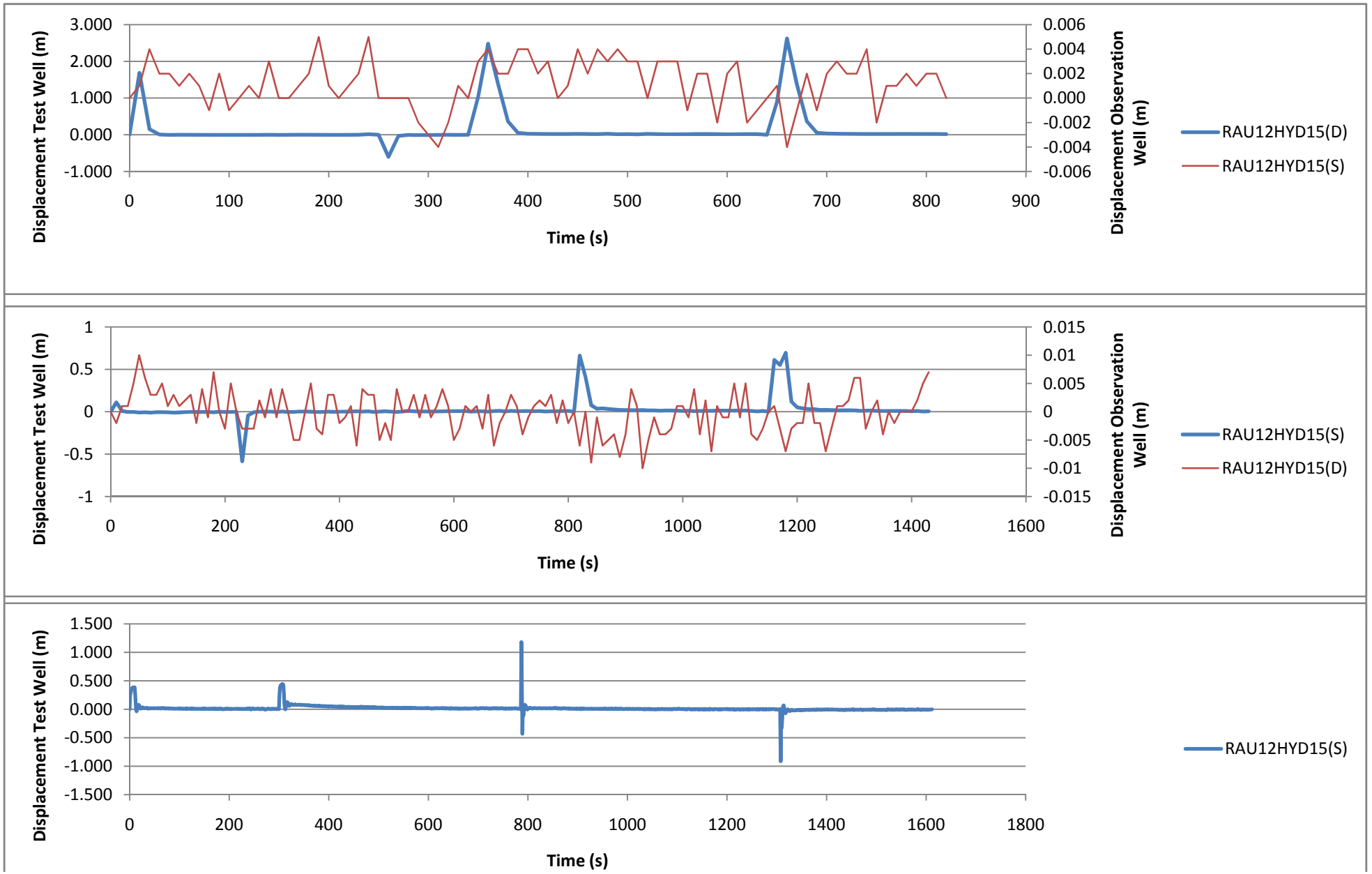

Displacement Test Well (m)
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
0
200
400
600
800
1000
1200
1400
1600
Time (s)
Displacement Observation Well (m)
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
RAU12HYD12(D)
RAU12HYD12(S)

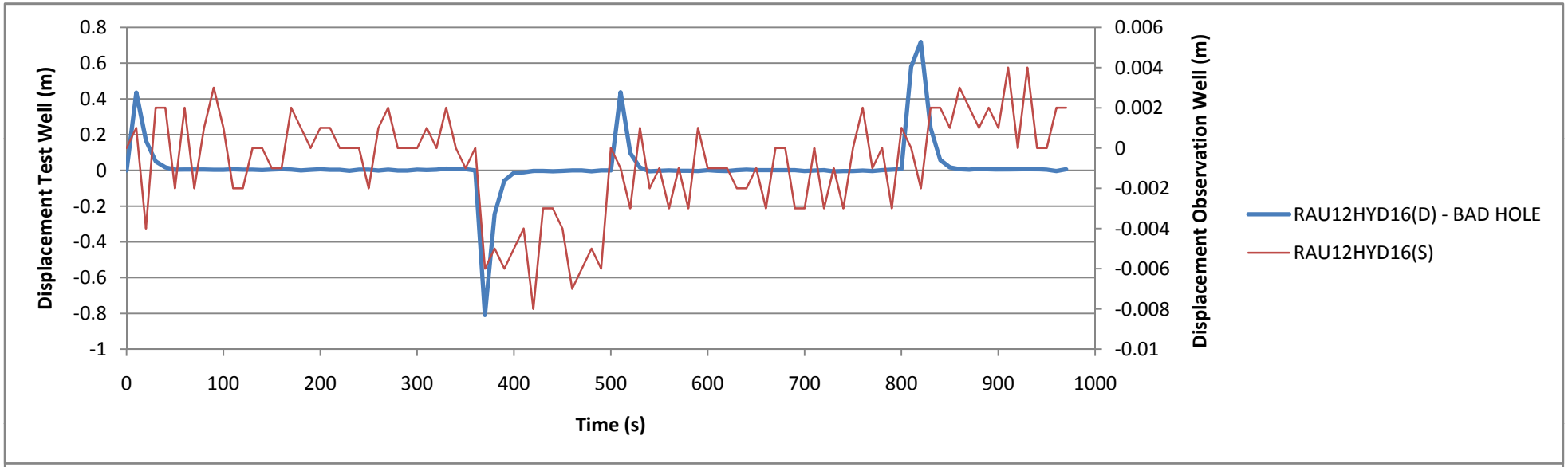

Displacement Test Well (m)
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
0
100
200
300
400
500
600
700
800
Time (s)
Displacement Observation Well (m)
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
RAU12HYD12(S)
RAU12HYD12(D)

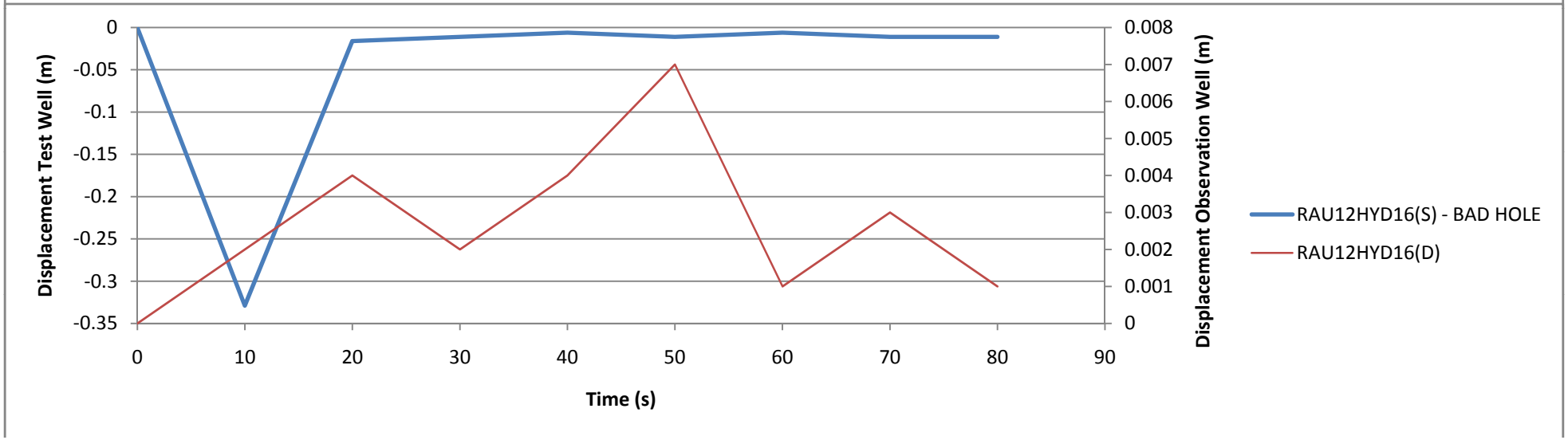

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD13(D)
RAU12HYD13(S)
1.5
1
0.5
0
-0.5
-1
-1.5
0.015
0.01
0.005
0
-0.005
-0.01
0
10000
20000
30000
40000
50000
60000
Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD13(S)
RAU12HYD13(D)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
100
200
300
400
500
600
700

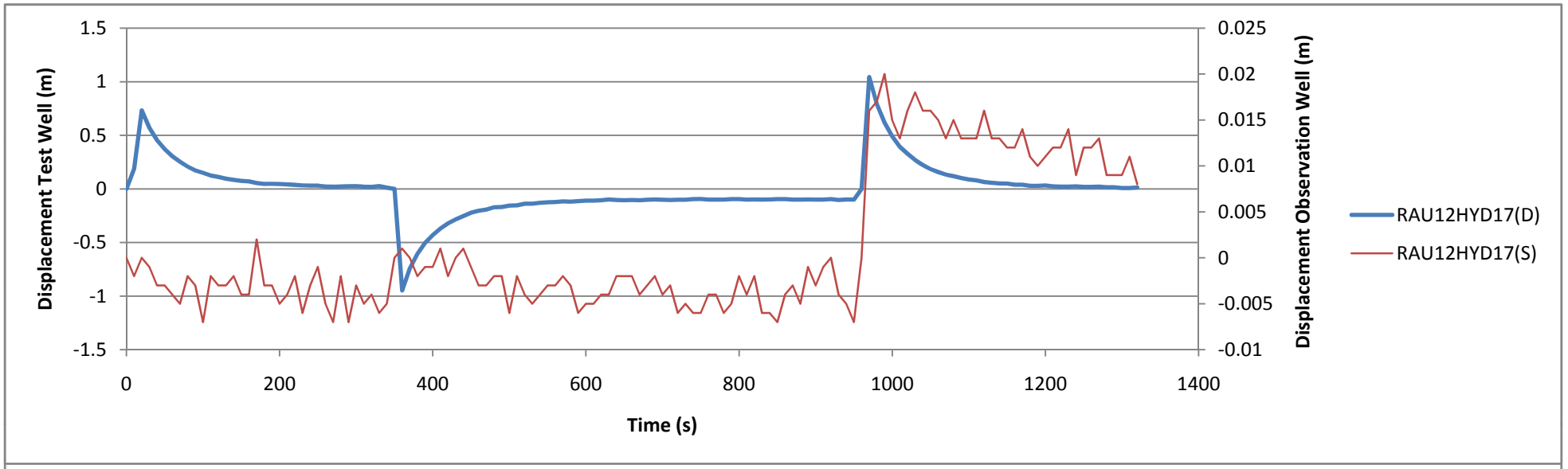

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD14(D)
RAU12HYD14(S)

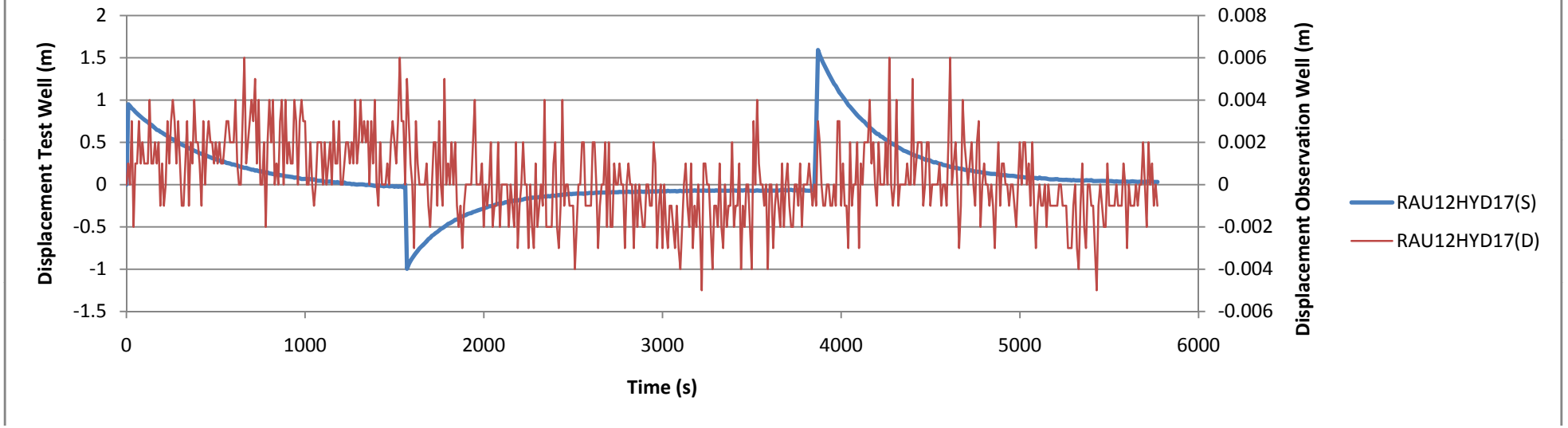

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD14(S)
RAU12HYD14(D)

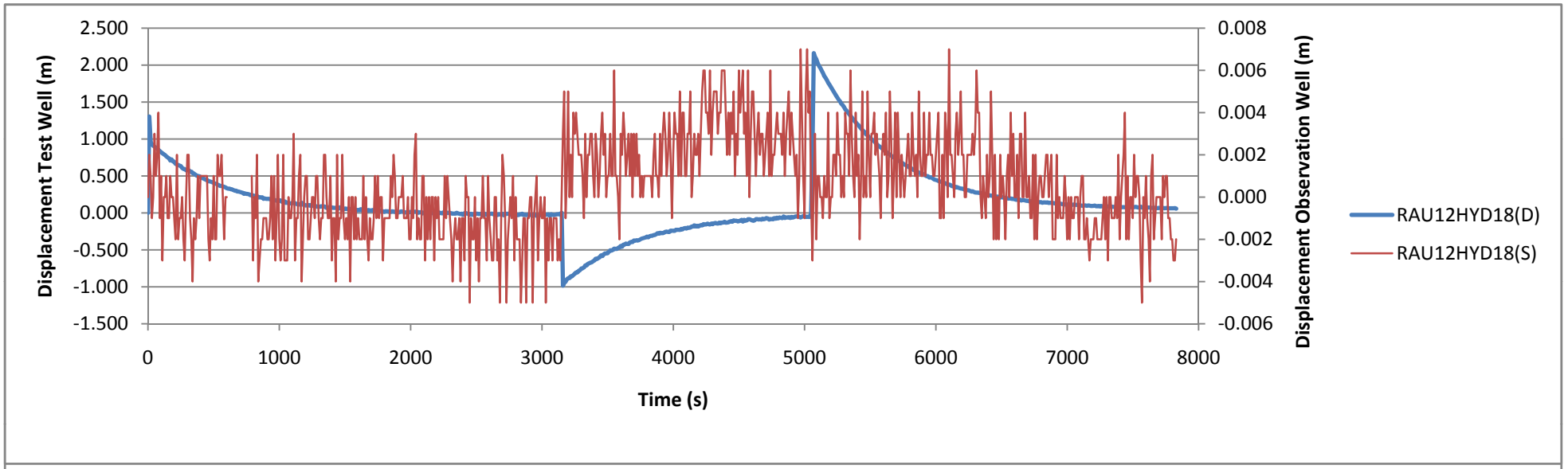

Displacement Test Well (m)
3.000
2.000
1.000
0.000
-1.000
0
100
200
300
400
500
600
700
800
900
Time (s)
Displacement Observation Well (m)
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
RAU12HYD15(D)
RAU12HYD15(S)
Displacement Test Well (m)
1
0.5
0
-0.5
-1
0
200
400
600
800
1000
1200
1400
1600
Time (s)
Displacement Observation Well (m)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
RAU12HYD15(S)
RAU12HYD15(D)
Displacement Test Well (m)
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)
RAU12HYD15(S)

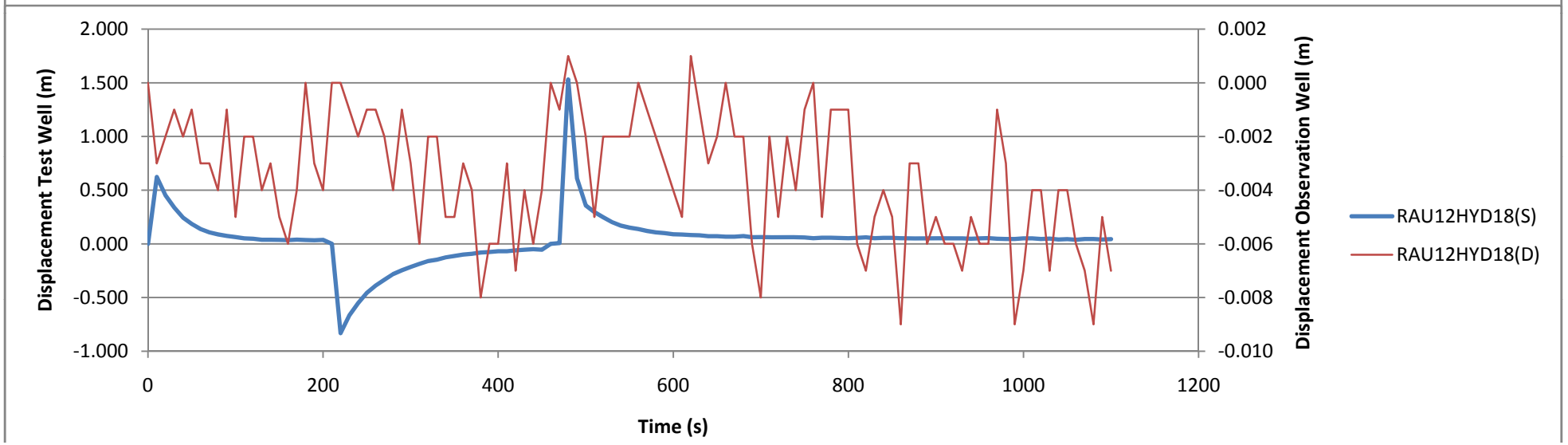

Displacement Test Well (m)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
Displacement Observation Well (m)
0
100
200
300
400
500
600
700
800
900
1000
Time (s)
RAU12HYD16(D) - BAD HOLE
RAU12HYD16(S)

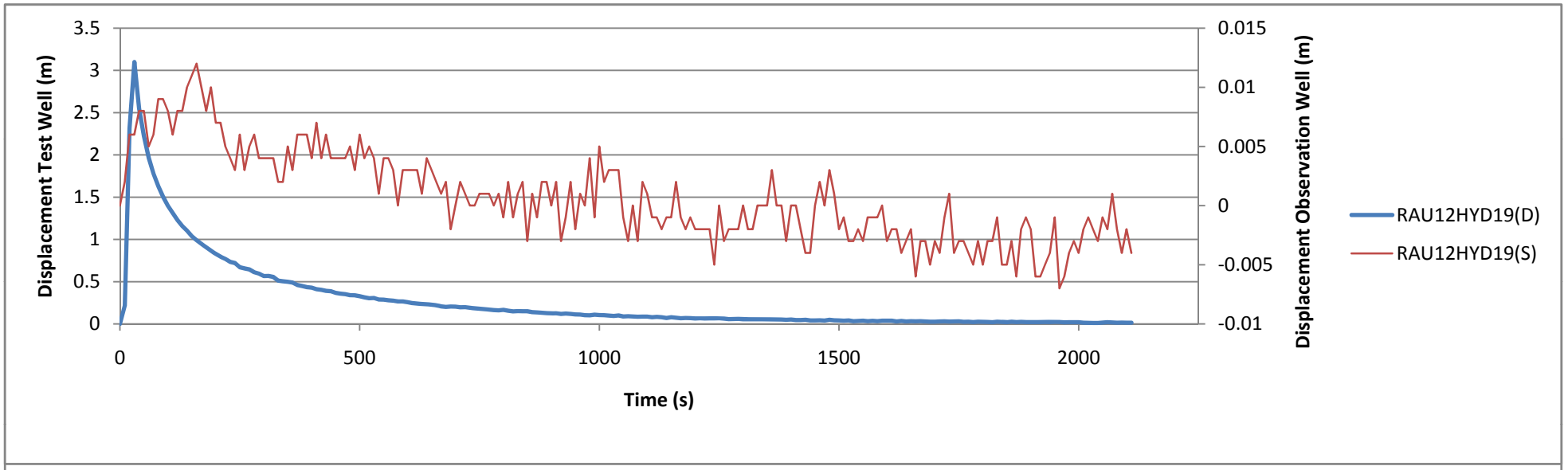

Displacement Test Well (m)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Displacement Observation Well (m)
0
10
20
30
40
50
60
70
80
90
Time (s)
RAU12HYD16(S) - BAD HOLE
RAU12HYD16(D)

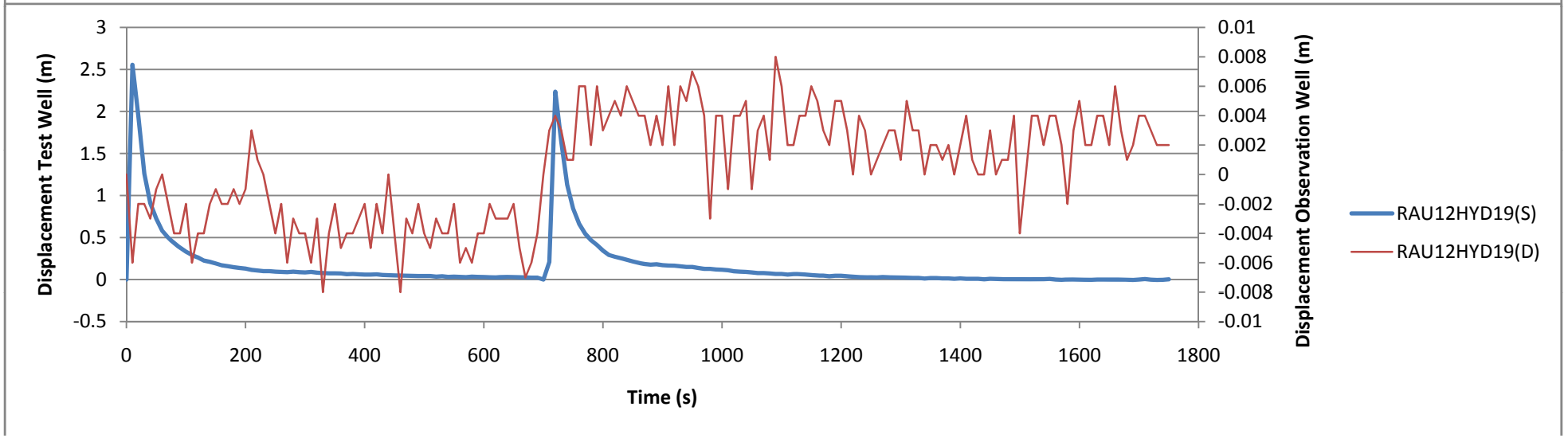

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD17(D)
RAU12HYD17(S)
1.5
1
0.5
0
-0.5
-1
-1.5
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
0
200
400
600
800
1000
1200
1400

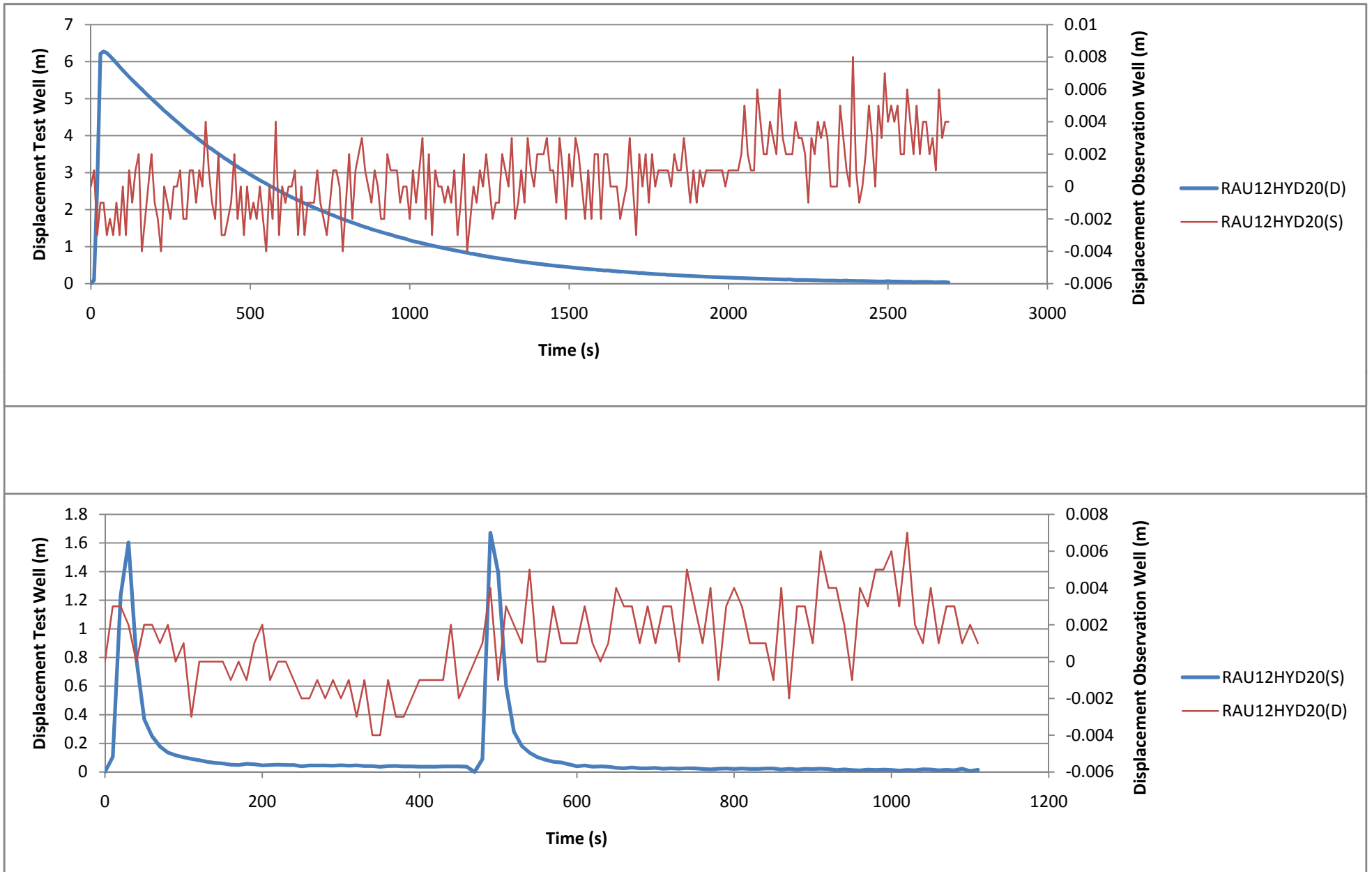

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD17(S)
RAU12HYD17(D)
2
1.5
1
0.5
0
-0.5
-1
-1.5
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
0
1000
2000
3000
4000
5000
6000

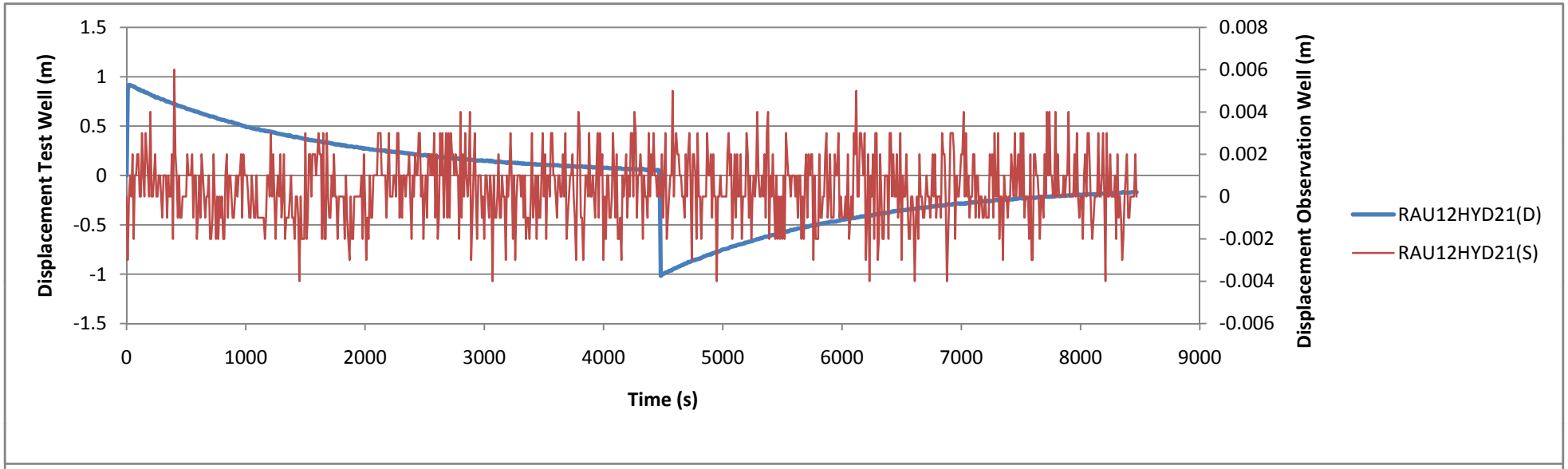

Displacement Test Well (m)
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
1000
2000
3000
4000
5000
6000
7000
8000
Time (s)
Displacement Observation Well (m)
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
RAU12HYD18(D)
RAU12HYD18(S)

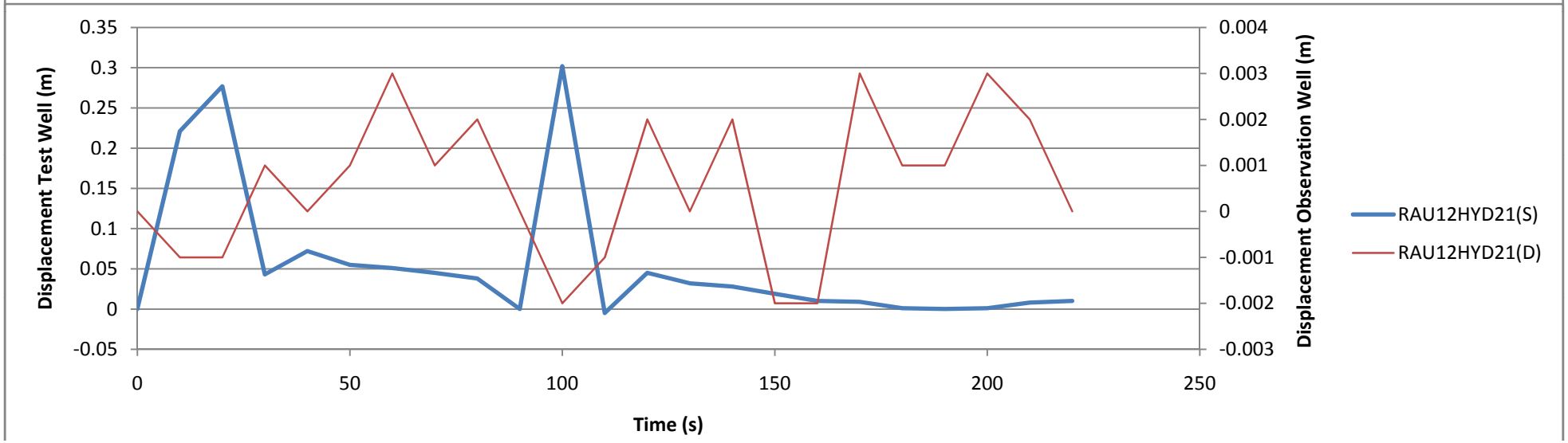

Displacement Test Well (m)
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
0
200
400
600
800
1000
1200
Time (s)
Displacement Observation Well (m)
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
RAU12HYD18(S)
RAU12HYD18(D)

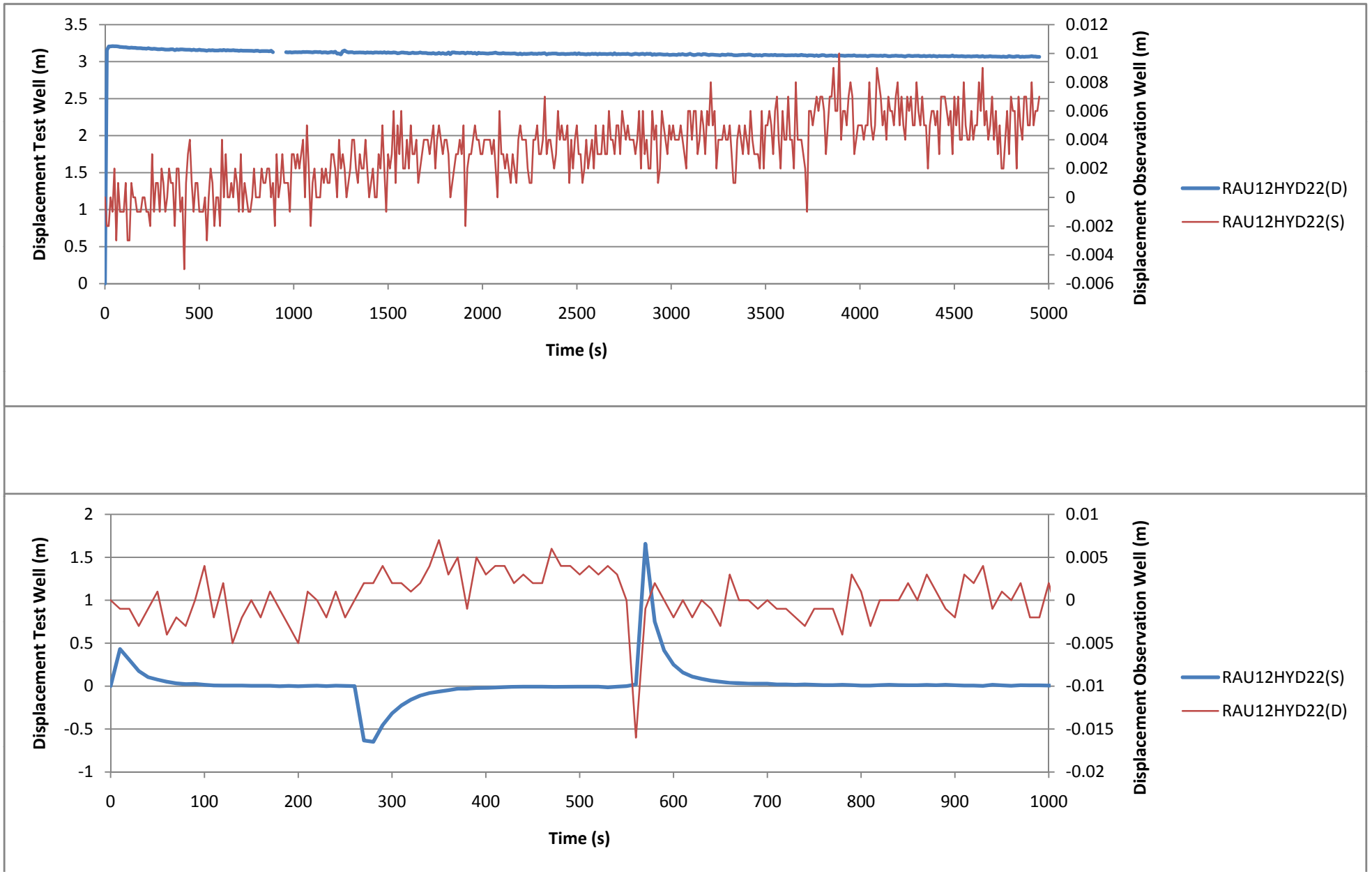

Displacement Test Well (m)
3.5
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
Time (s)
0.015
0.01
0.005
0
-0.005
-0.01
Displacement Observation Well (m)
RAU12HYD19(D)
RAU12HYD19(S)

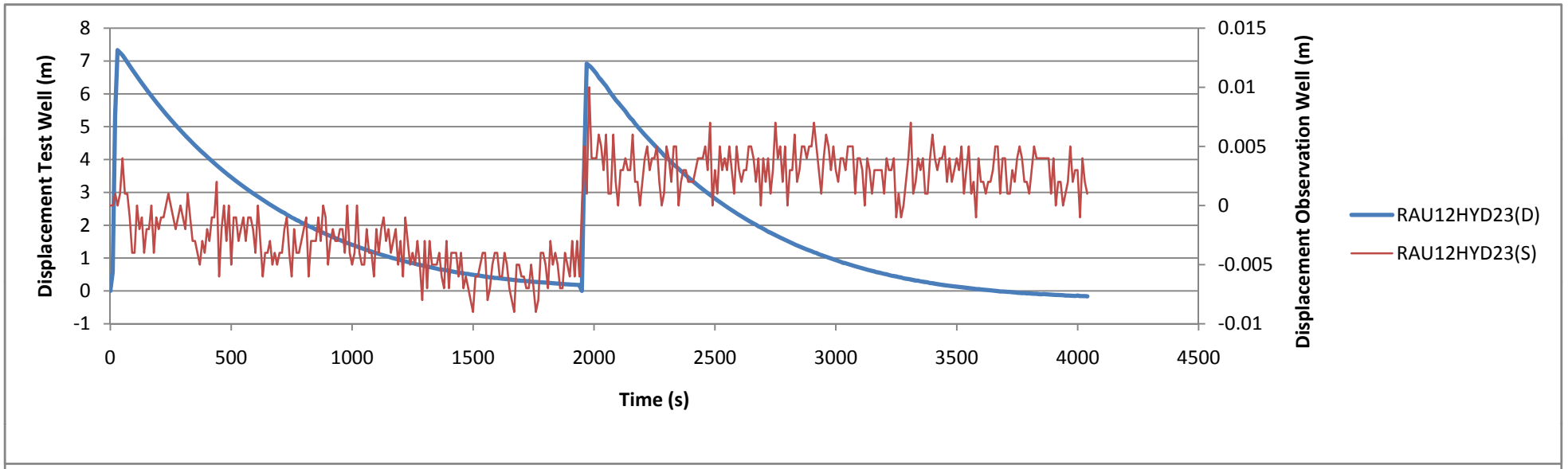

Displacement Test Well (m)
3
2.5
2
1.5
1
0.5
0
-0.5
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
Displacement Observation Well (m)
RAU12HYD19(S)
RAU12HYD19(D)

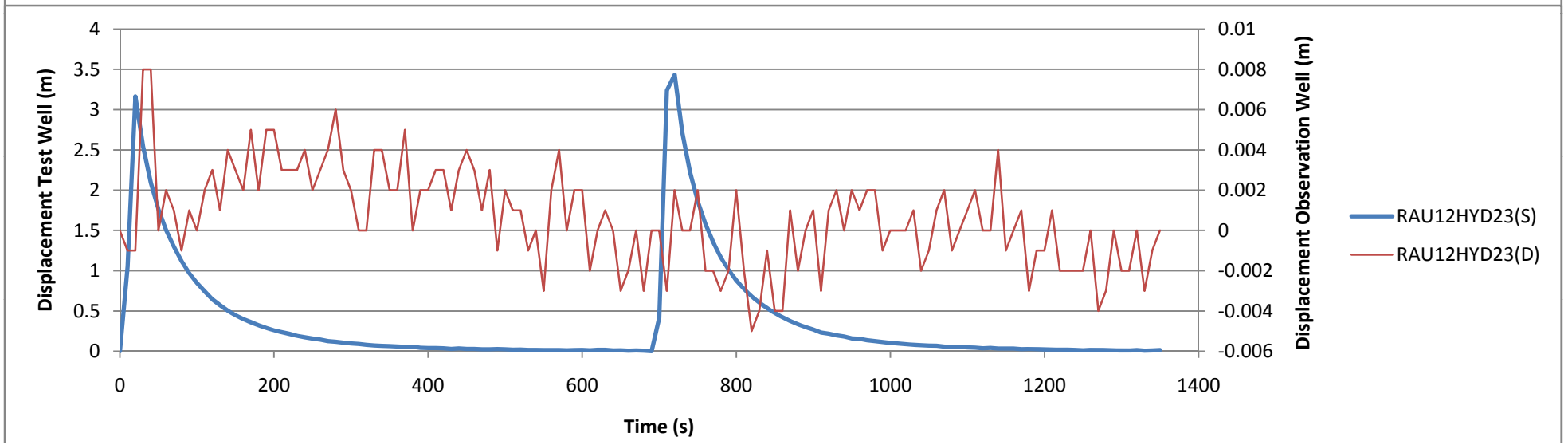

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD20(D)
RAU12HYD20(S)
0
1
2
3
4
5
6
7
0.01
0.008
0.006
0.004
0.002
-0.002
-0.004
-0.006
0
500
1000
1500
2000
2500
3000
Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD20(S)
RAU12HYD20(D)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0.008
0.006
0.004
0.002
-0.002
-0.004
-0.006
0
200
400
600
800
1000
1200

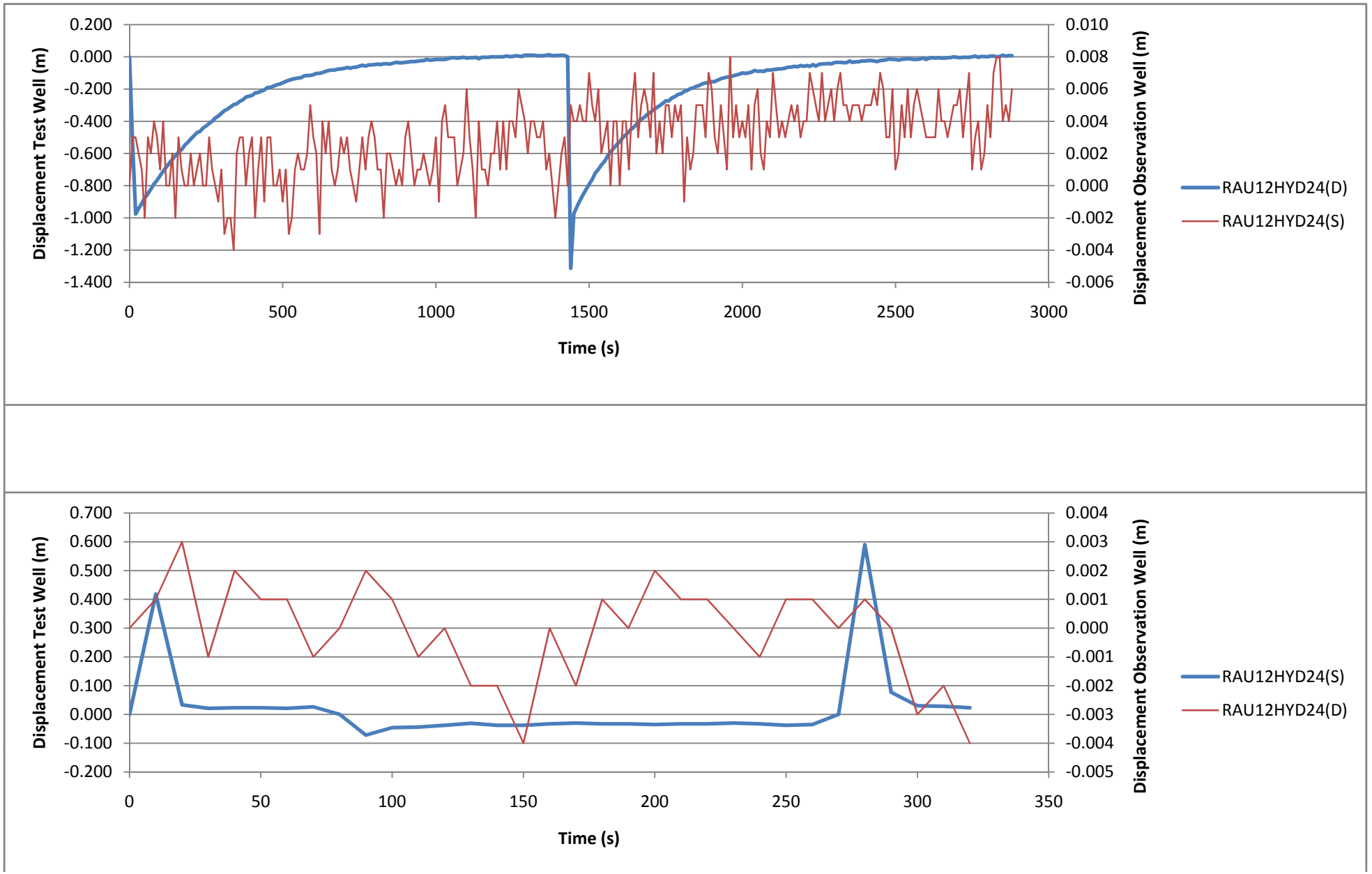

Displacement Test Well (m)
1.5
1
0.5
0
-0.5
-1
-1.5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Time (s)
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
Displacement Observation Well (m)
RAU12HYD21(D)
RAU12HYD21(S)

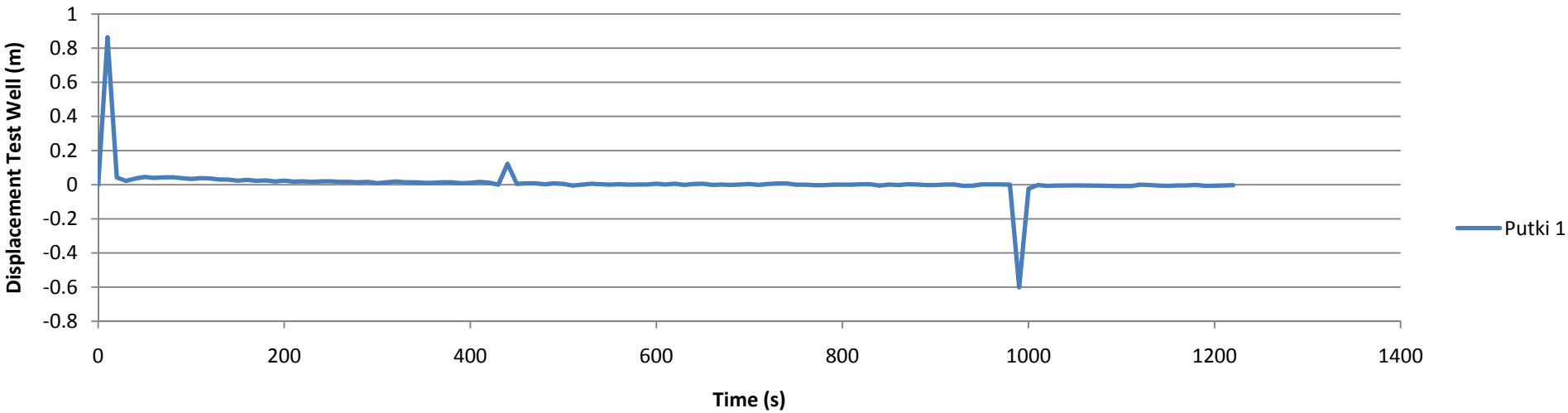

Displacement Test Well (m)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
50
100
150
200
250
Time (s)
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
Displacement Observation Well (m)
RAU12HYD21(S)
RAU12HYD21(D)

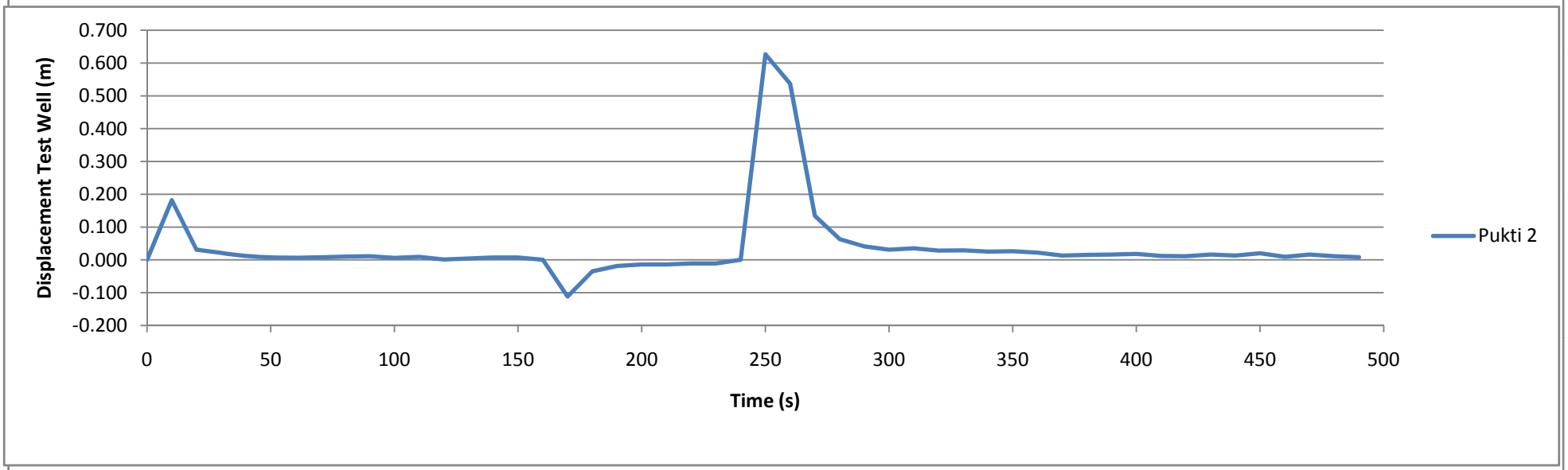

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD22(D)
RAU12HYD22(S)
Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD22(S)
RAU12HYD22(D)

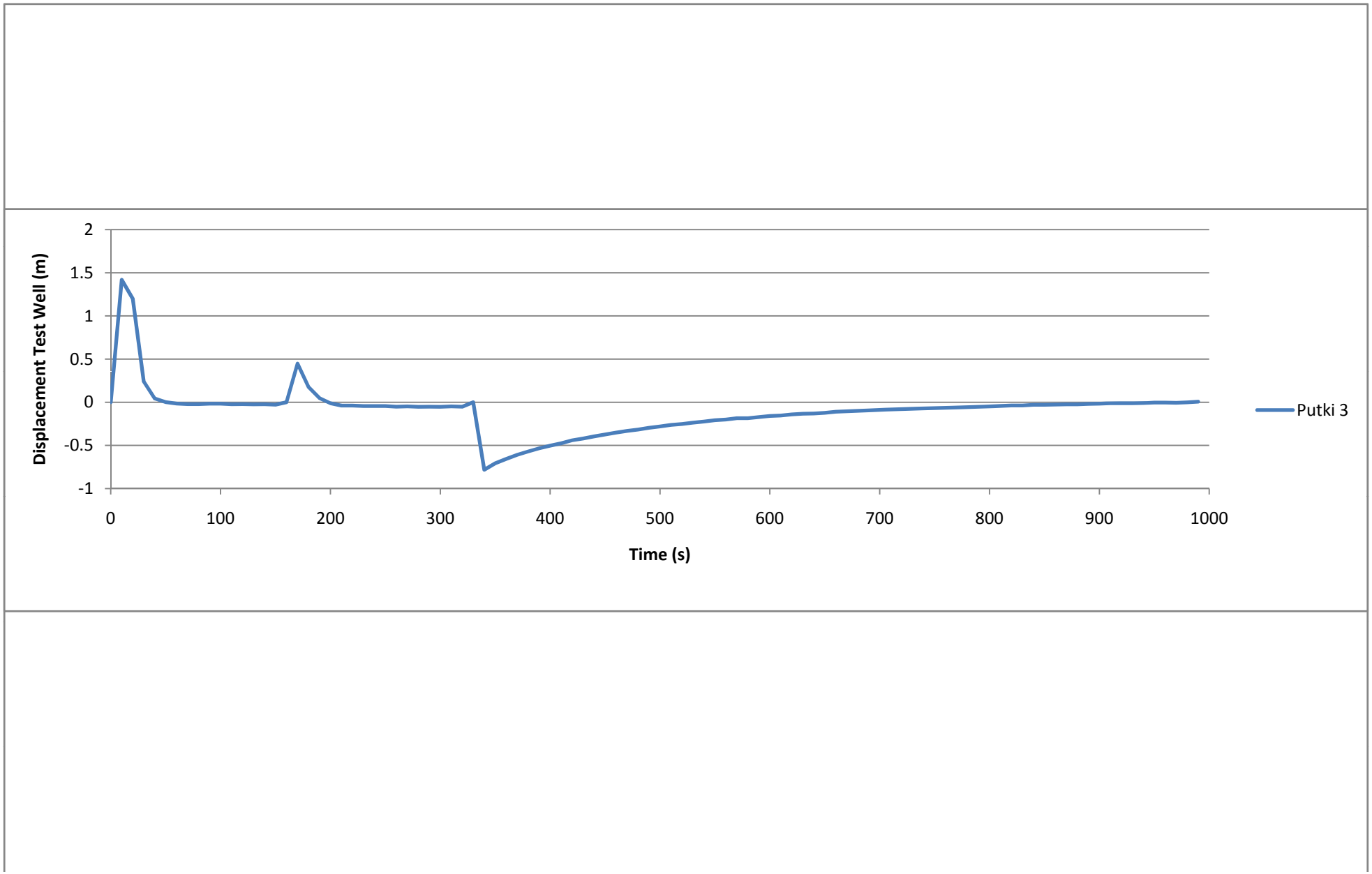

Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD23(D)
RAU12HYD23(S)


Displacement Test Well (m)
Displacement Observation Well (m)
Time (s)
RAU12HYD23(S)
RAU12HYD23(D)

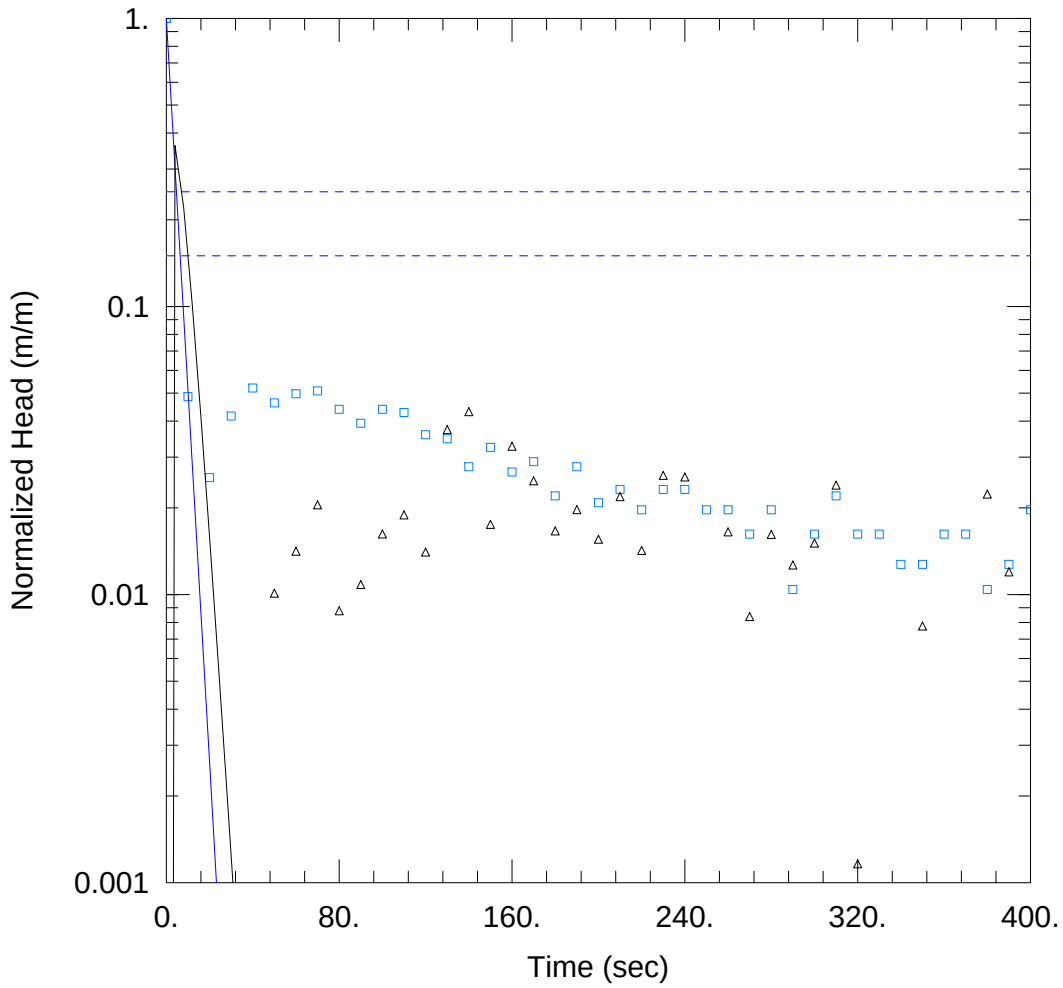

Displacement Test Well (m)
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-1.400
0
500
1000
1500
2000
2500
3000
Time (s)
Displacement Observation Well (m)
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
RAU12HYD24(D)
RAU12HYD24(S)
Displacement Test Well (m)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
0
50
100
150
200
250
300
350
Time (s)
Displacement Observation Well (m)
0.004
0.003
0.002
0.001
0.000
-0.001
-0.002
-0.003
-0.004
-0.005
RAU12HYD24(S)
RAU12HYD24(D)


Displacement Test Well (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
200
400
600
800
1000
1200
1400
Time (s)
Putki 1


Displacement Test Well (m)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
0
50
100
150
200
250
300
350
400
450
500
Time (s)
Pukti 2


Displacement Test Well (m)
2
1.5
1
0.5
0
-0.5
-1
0
100
200
300
400
500
600
700
800
900
1000
Time (s)
Putki 3

Annex 2 – AQTESOLV Analysis



WELL TEST ANALYSIS

Data Set: E:\...\Pukti1_FHT.aqt
Date: 10/22/12 Time: 13:51:09

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

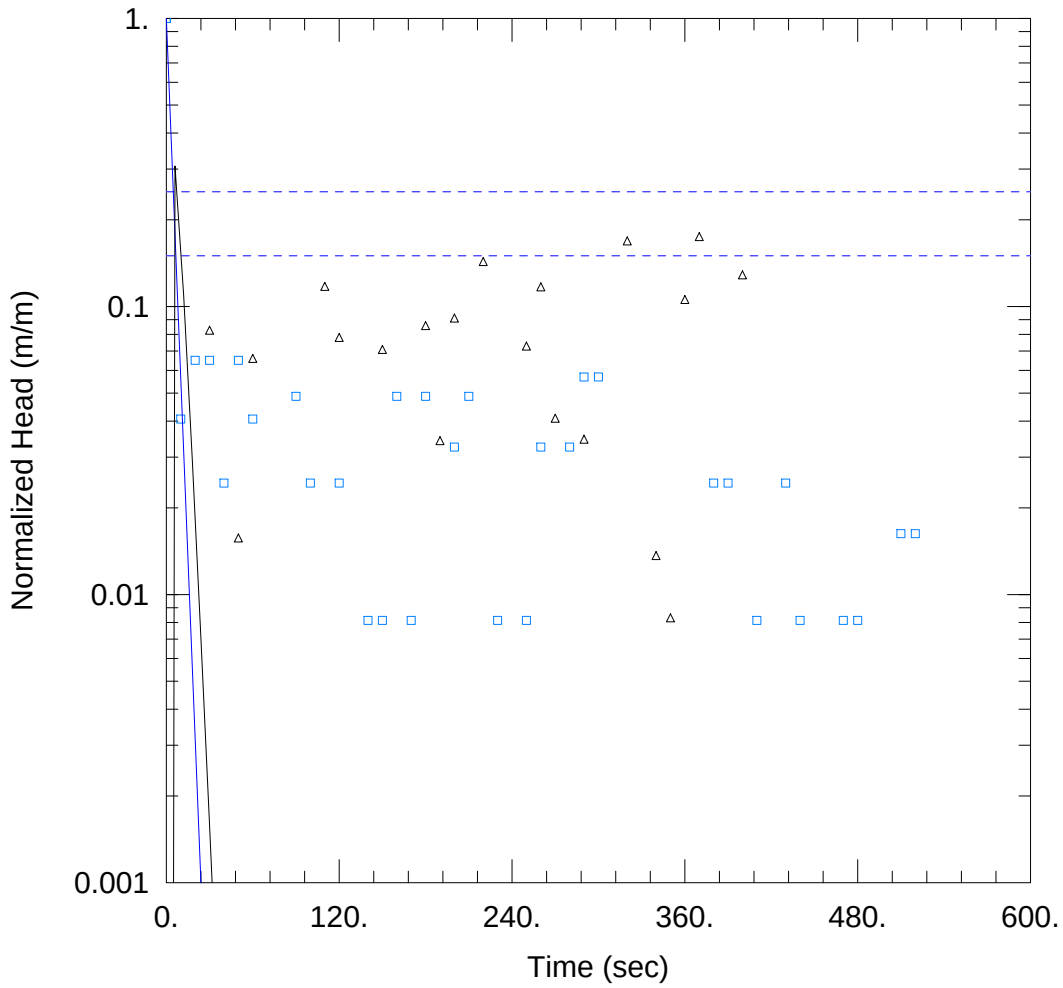
Saturated Thickness: 9.73 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Pukti 1 FHT)

Initial Displacement: 0.864 m
Total Well Penetration Depth: 9.23 m
Casing Radius: 0.025 m
Static Water Column Height: 9.73 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 22.93 m/day
y0 = 0.8639 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti1_SlugIn.aqt
Date: 10/22/12 Time: 13:51:58

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

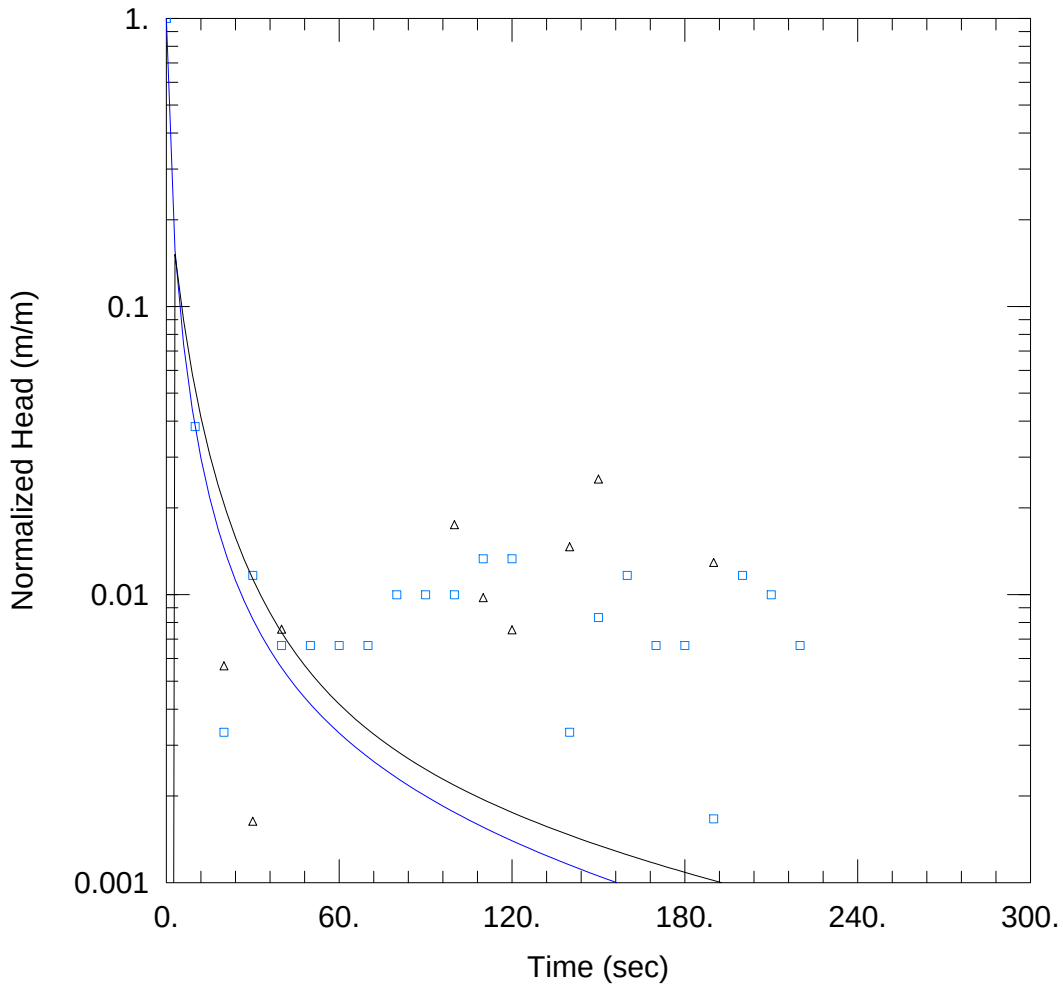
Saturated Thickness: 9.73 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Pukti 1 Slug in)

Initial Displacement: 0.123 m
Total Well Penetration Depth: 9.23 m
Casing Radius: 0.025 m
Static Water Column Height: 9.73 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 22.22 m/day
y0 = 0.123 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti1_SlugOut.aqt
Date: 10/22/12 Time: 13:52:53

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 9.73 m

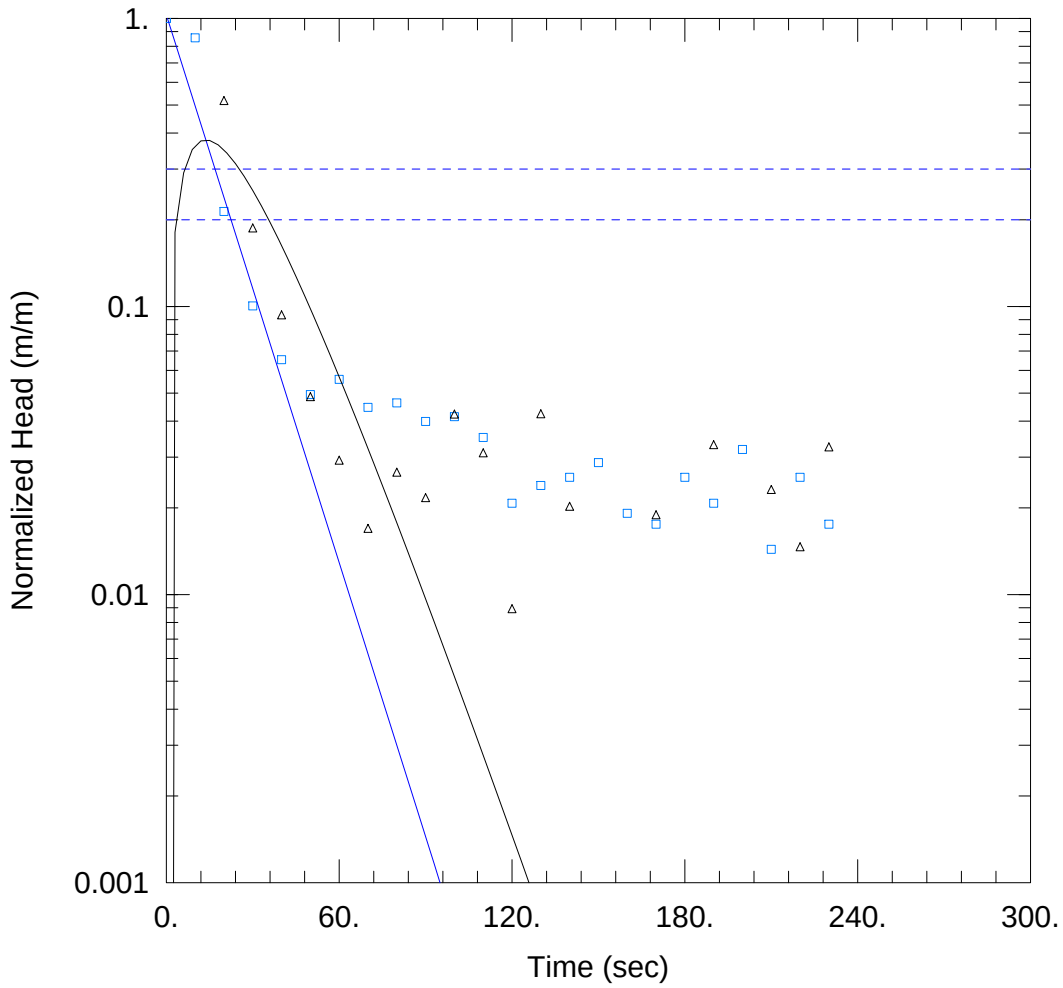
WELL DATA (Pukti 1 Slug out)

Initial Displacement: 0.601 m
Total Well Penetration Depth: 9.23 m
Casing Radius: 0.025 m
Static Water Column Height: 9.73 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 30.54 m/day
Kz/Kr = 1.
Ss = 0.03634 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\Pukti2_FHT.aqt
Date: 10/22/12 Time: 13:53:02

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

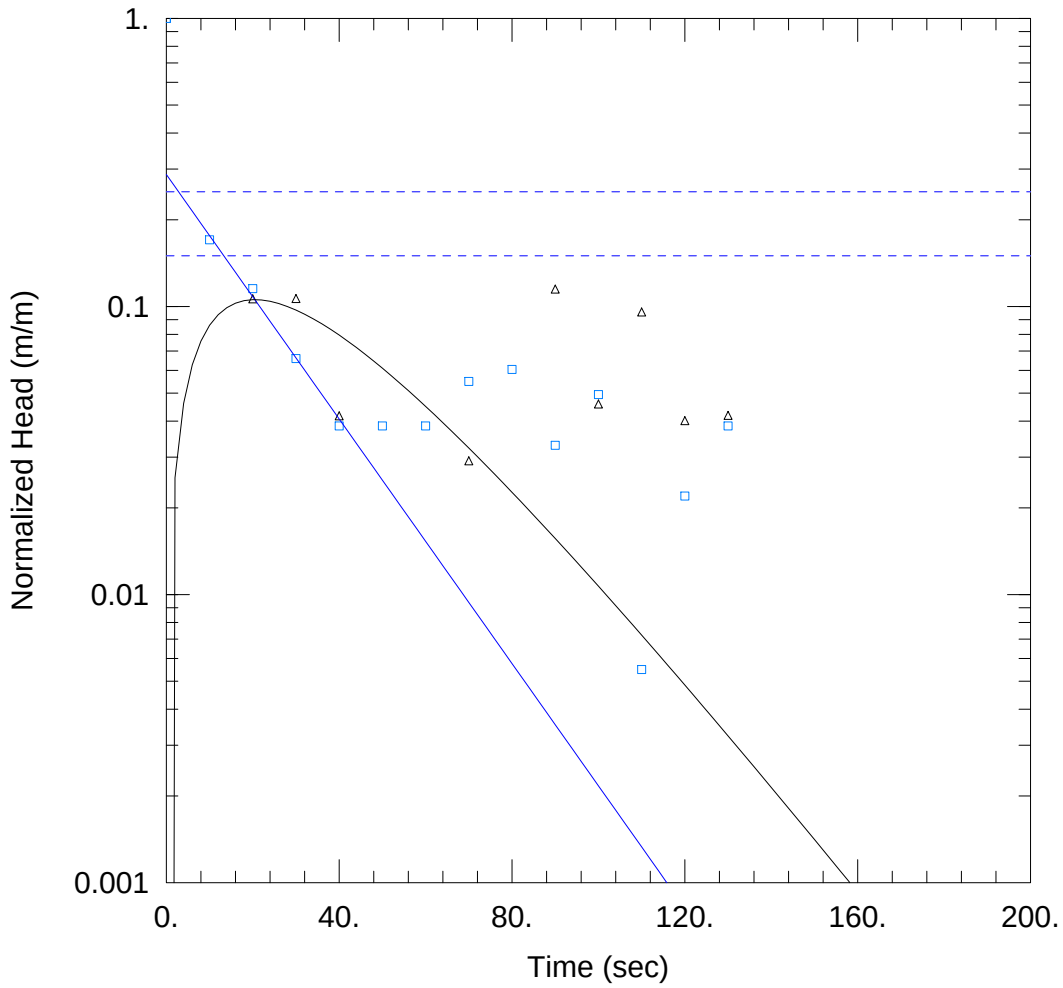
Saturated Thickness: 4.29 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Pukti 2 FHT)

Initial Displacement: 0.627 m
Total Well Penetration Depth: 3.8 m
Casing Radius: 0.025 m
Static Water Column Height: 4.29 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 4.677 m/day
y0 = 0.6457 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti2_SlugIn.aqt
Date: 10/22/12 Time: 13:53:15

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

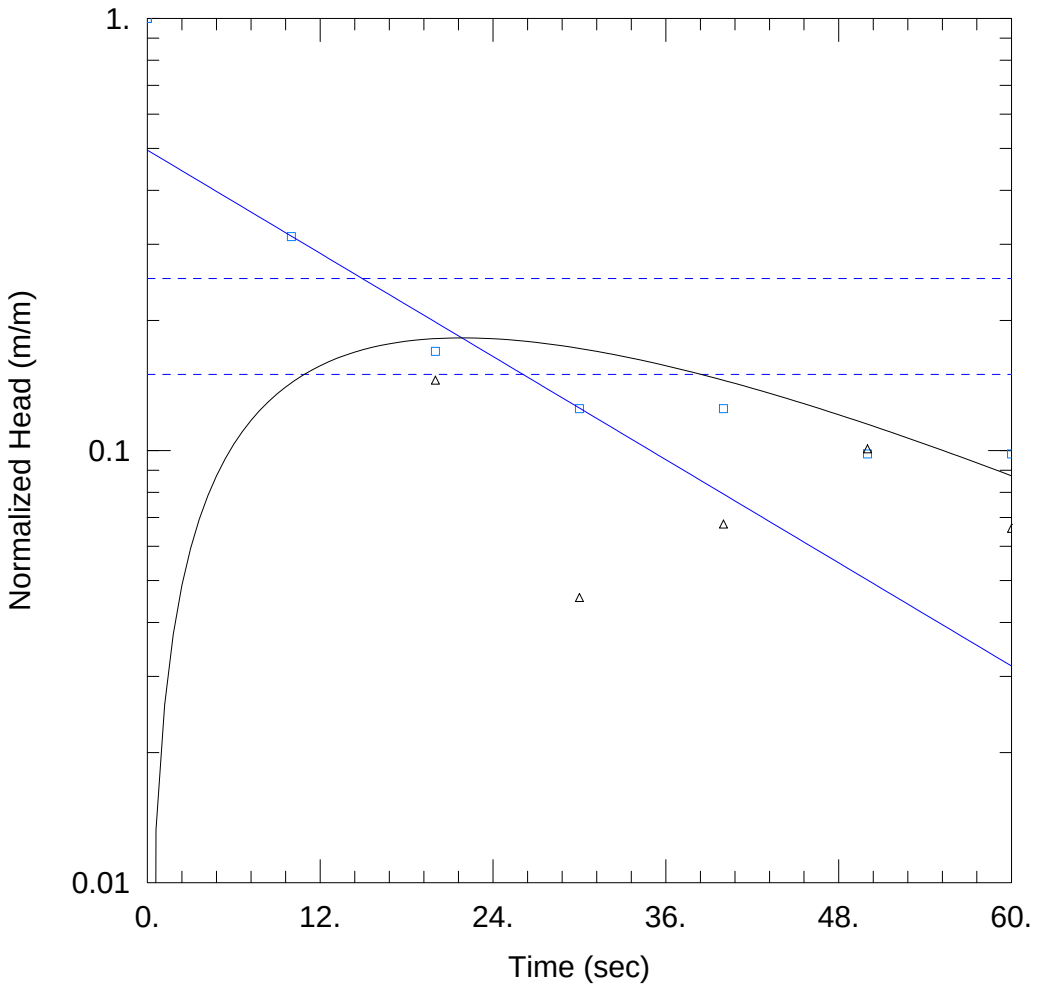
Saturated Thickness: 4.29 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Pukti 2 Slug in)

Initial Displacement: 0.182 m
Total Well Penetration Depth: 3.8 m
Casing Radius: 0.025 m
Static Water Column Height: 4.29 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 3.772 m/day
y0 = 0.05225 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti2_SlugOut.aqt
Date: 10/22/12 Time: 13:53:21

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 4.29 m Anisotropy Ratio (Kz/Kr): 1.

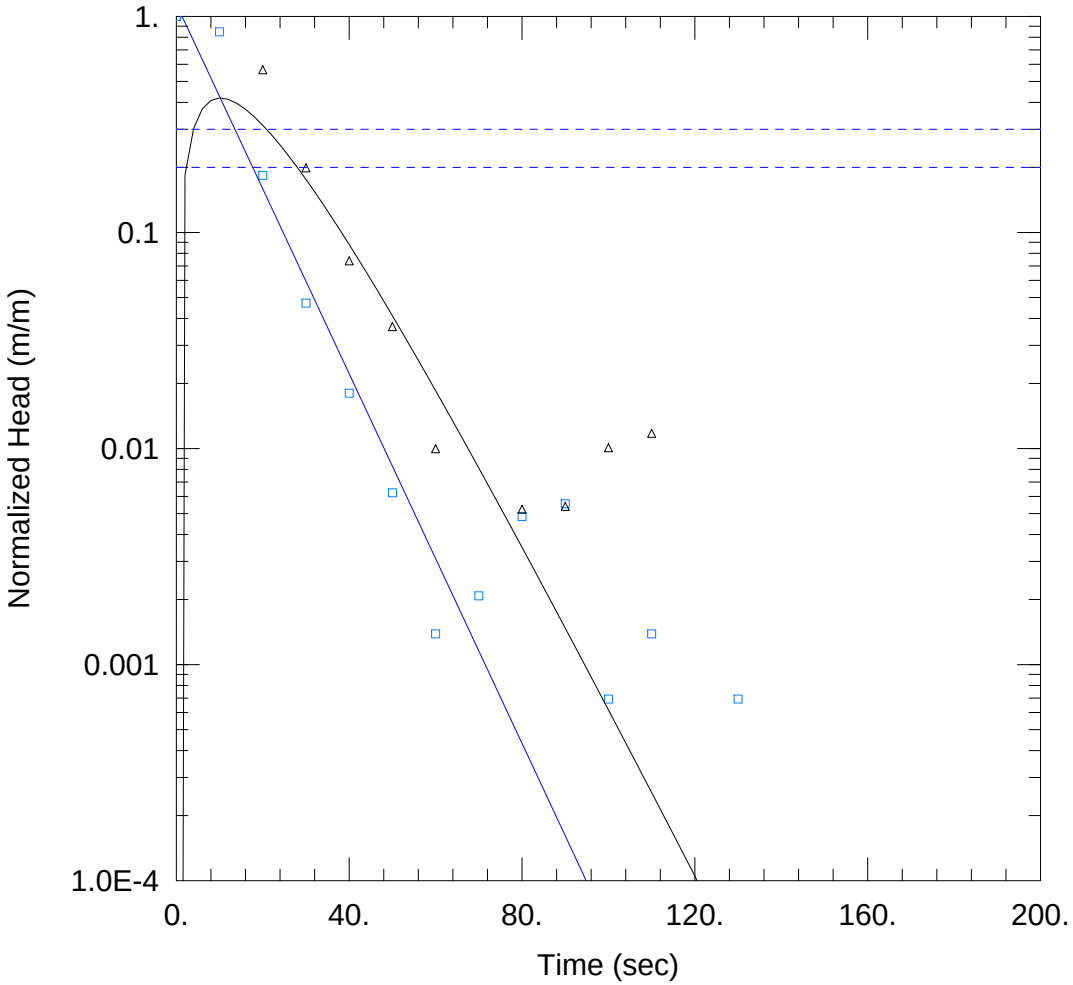
WELL DATA (Pukti 2 Slug out)

Initial Displacement: 0.112 m
Total Well Penetration Depth: 3.8 m
Casing Radius: 0.025 m
Static Water Column Height: 4.29 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 3.537 m/day y0 = 0.0555 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti3_FHT.aqt
Date: 10/22/12 Time: 13:53:27

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

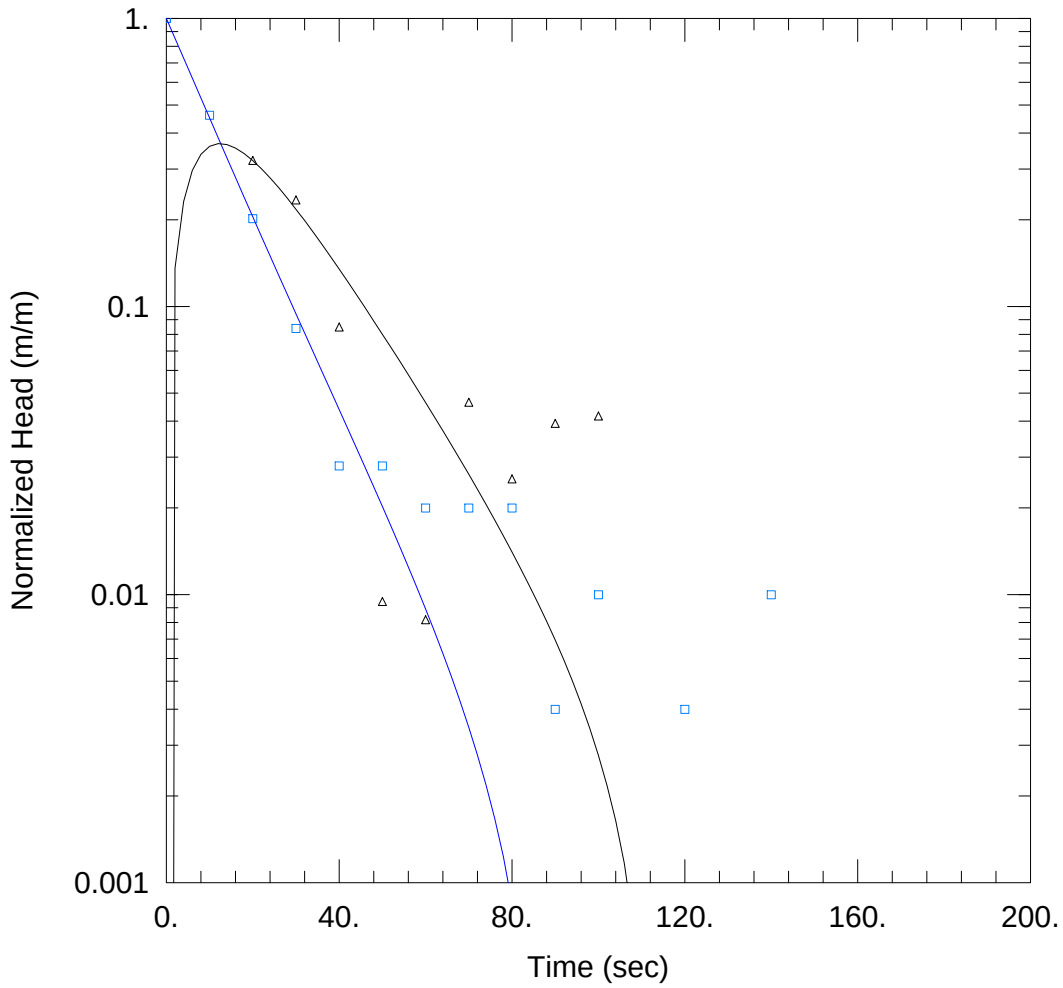
Saturated Thickness: 13.47 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (Pukti 3 FHT)

Initial Displacement: 1.443 m
Total Well Penetration Depth: 12.97 m
Casing Radius: 0.025 m
Static Water Column Height: 13.47 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 7.34 m/day
y0 = 1.645 m



WELL TEST ANALYSIS

Data Set: E:\...\Pukti3_SlugIn.aqt
Date: 10/22/12 Time: 13:53:32

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 13.47 m

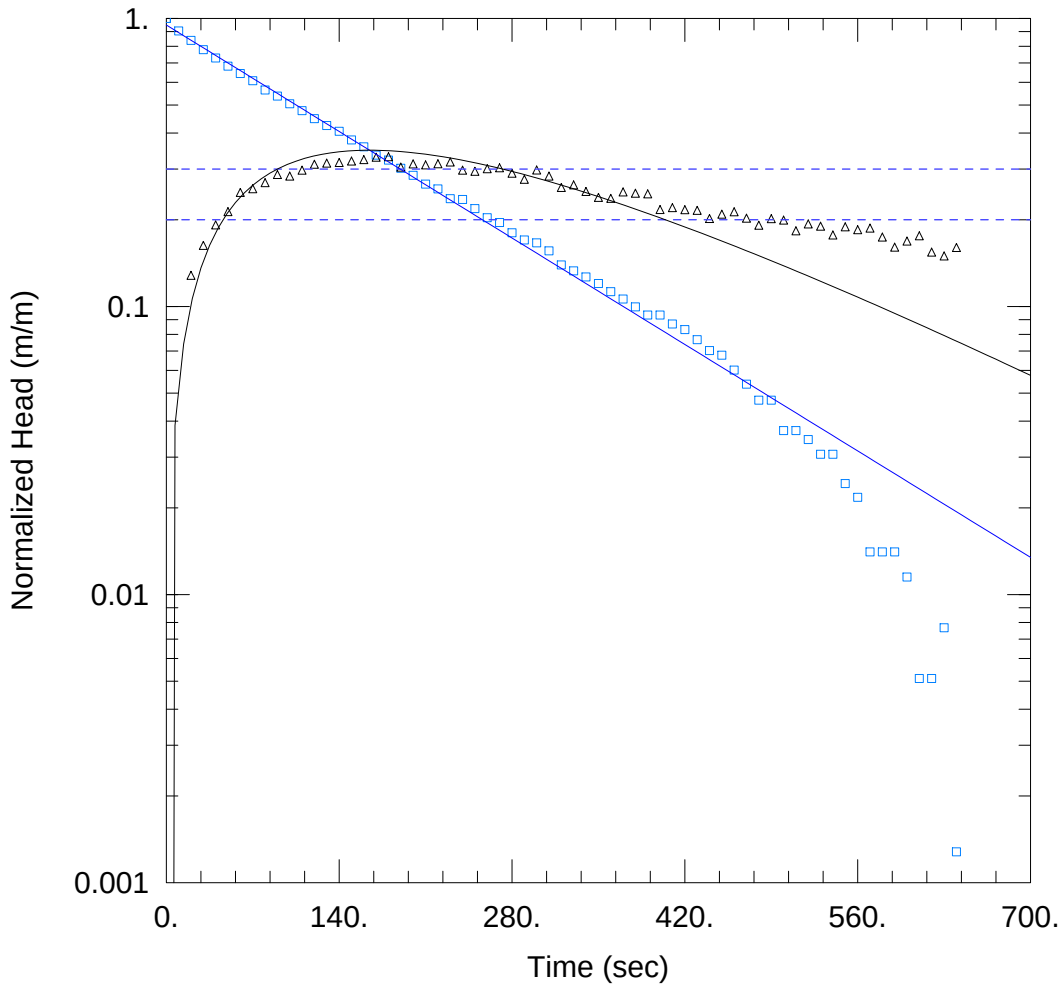
WELL DATA (Pukti 3 Slug in)

Initial Displacement: 0.501 m
Total Well Penetration Depth: 12.97 m
Casing Radius: 0.025 m
Static Water Column Height: 13.47 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 6.138 m/day
Kz/Kr = 1.
Ss = 1.745E-13 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\Pukti3_SlugOut.aqt
Date: 10/22/12 Time: 13:53:38

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 13.47 m Anisotropy Ratio (Kz/Kr): 1.

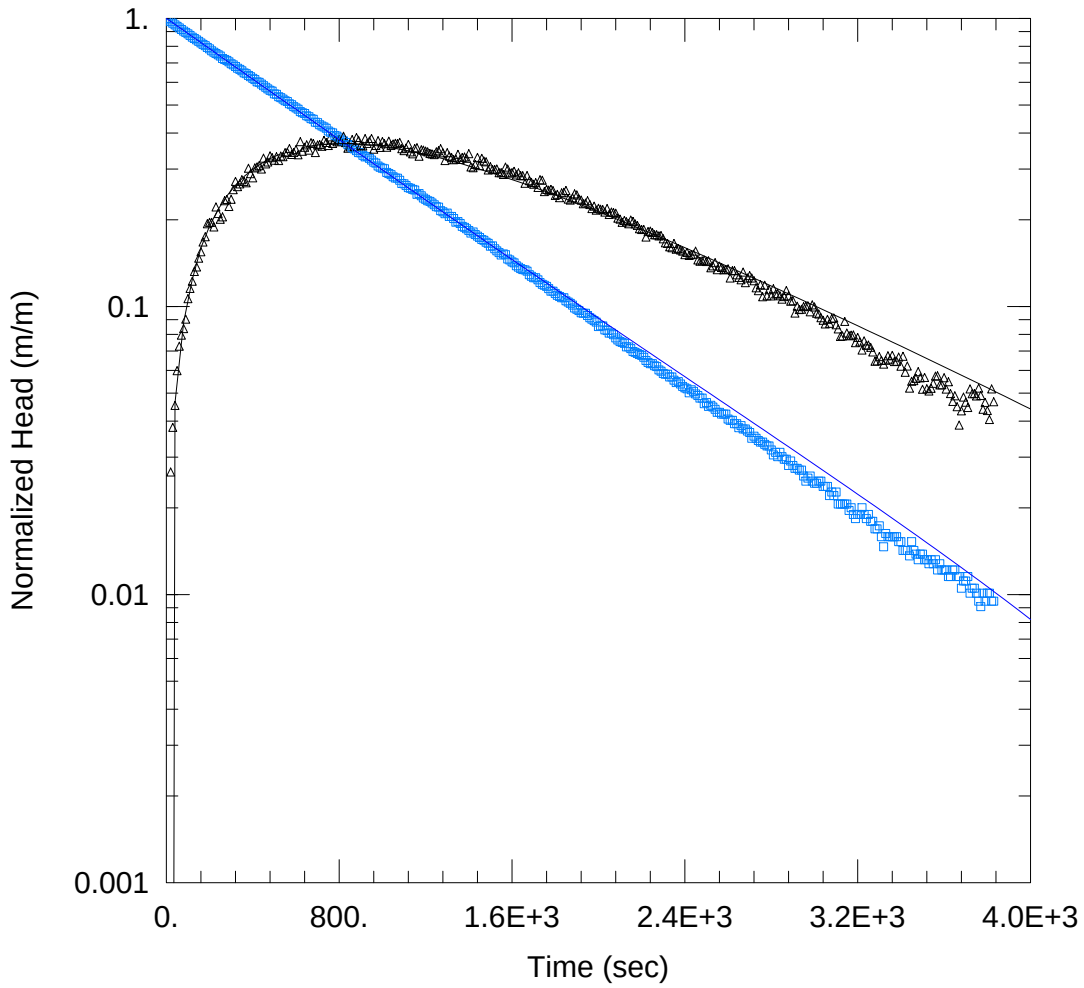
WELL DATA (Pukti 3 Slug out)

Initial Displacement: 0.782 m
Total Well Penetration Depth: 12.97 m
Casing Radius: 0.025 m
Static Water Column Height: 13.47 m
Screen Length: 1. m
Well Radius: 0.0575 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.453 m/day y0 = 0.7415 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(D)_FHT.aqt
Date: 10/22/12 Time: 14:52:50

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 45.9 m

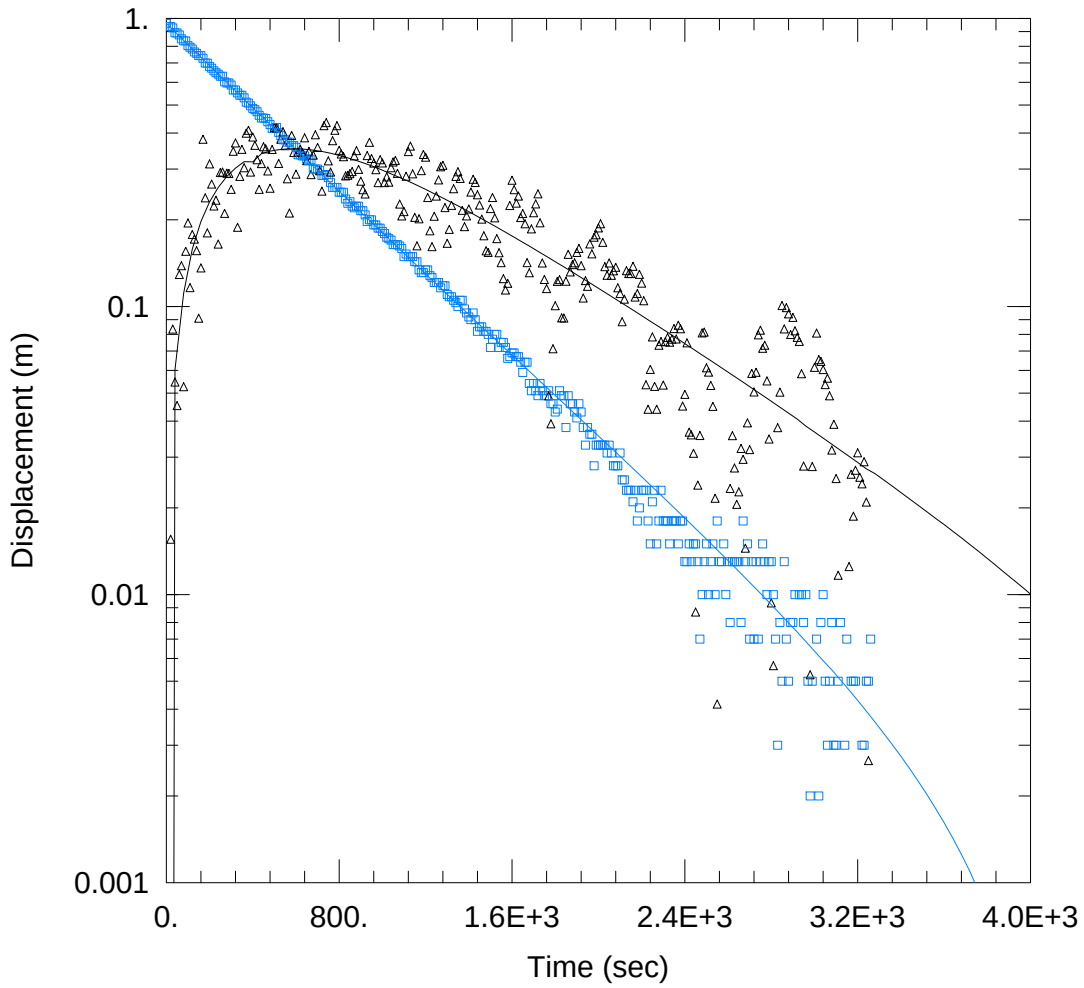
WELL DATA (RAU12HYD01(D) FHT)

Initial Displacement: 4.848 m
Total Well Penetration Depth: 45.4 m
Casing Radius: 0.025 m
Static Water Column Height: 45.9 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.04206 m/day
Kz/Kr = 1.
Ss = 2.179E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(D)_slugIn.aqt
Date: 10/22/12 Time: 14:52:55

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 45.9 m

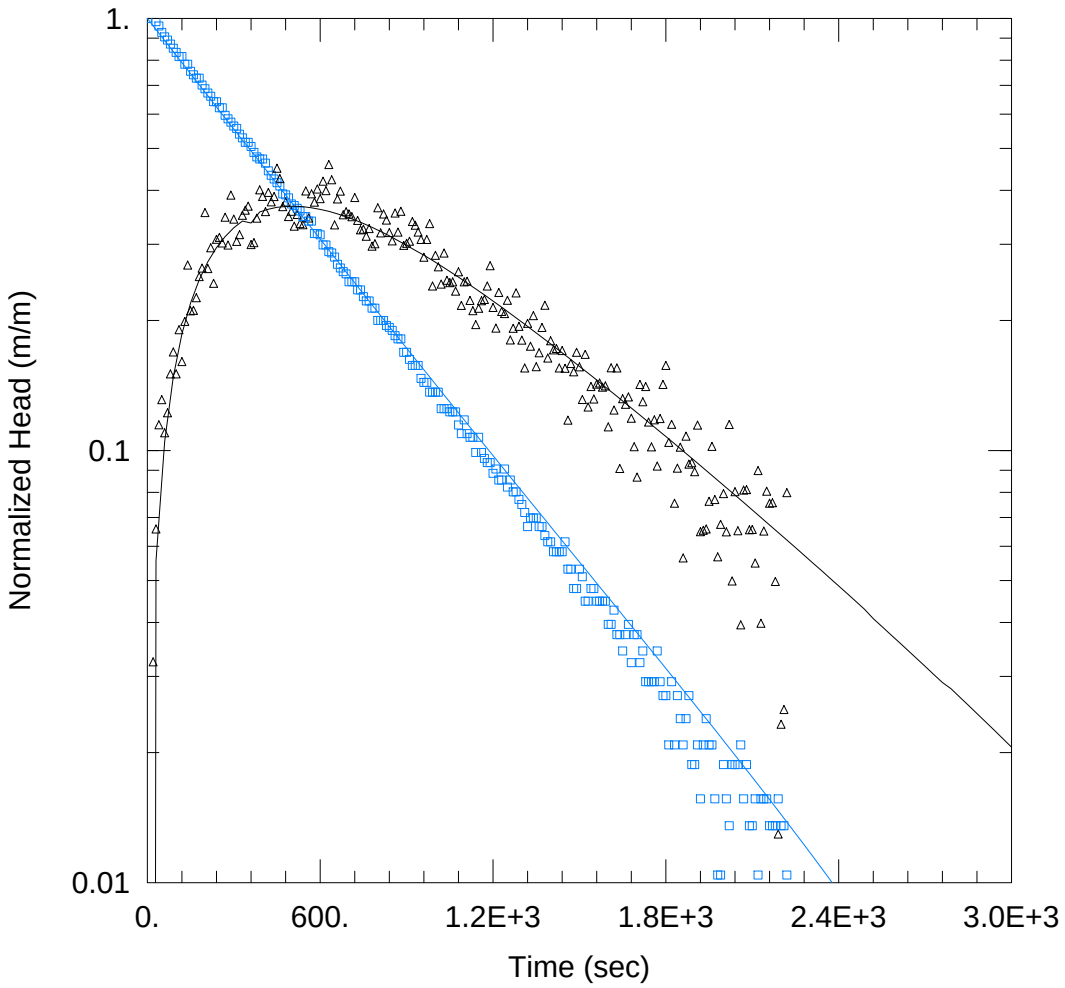
WELL DATA (RAU12HYD01(D))

Initial Displacement: 0.96 m
Total Well Penetration Depth: 45.4 m
Casing Radius: 0.025 m
Static Water Column Height: 45.9 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.05827 m/day
Kz/Kr = 1.
Ss = 2.179E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(D)_slugout.aqt
Date: 10/22/12 Time: 14:55:45

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 45.9 m

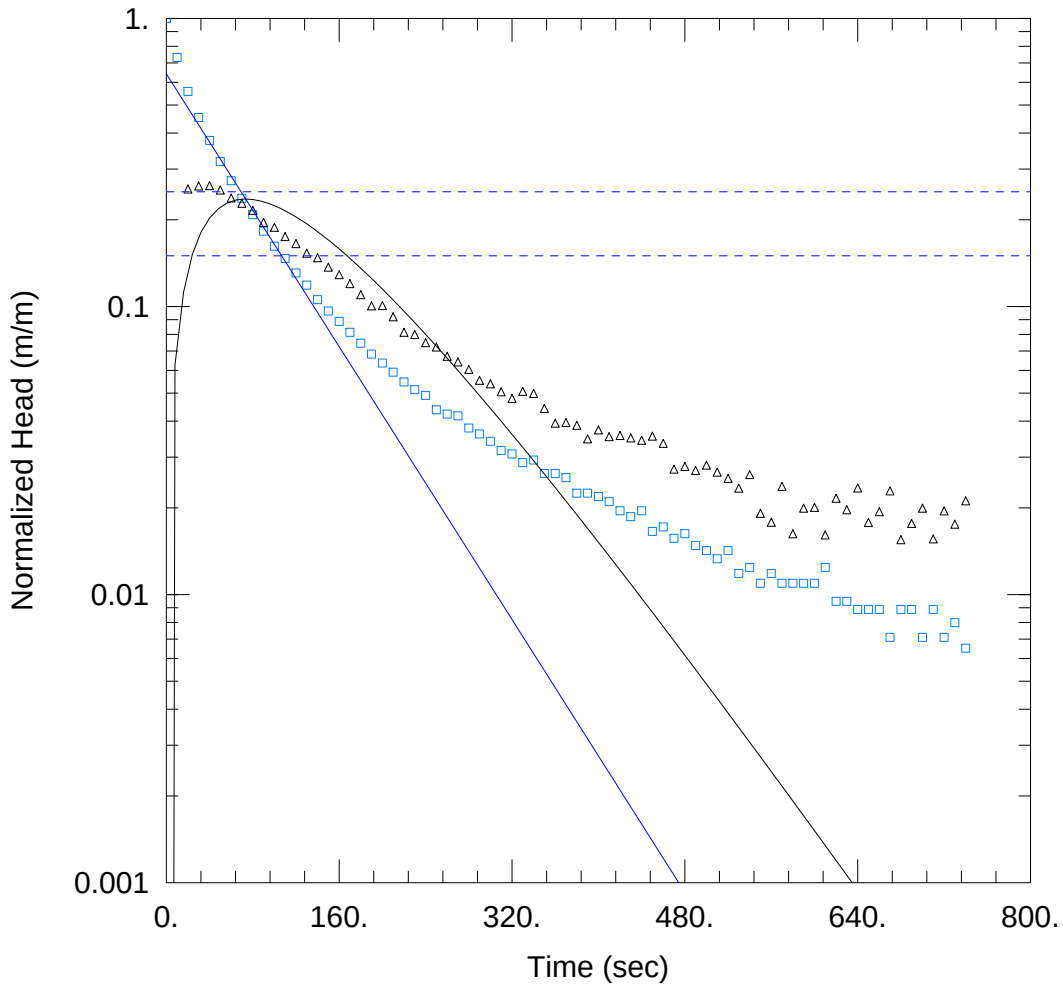
WELL DATA (RAU12HYD01(D) Slug out)

Initial Displacement: 0.96 m
Total Well Penetration Depth: 45.4 m
Casing Radius: 0.025 m
Static Water Column Height: 45.9 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.06808 m/day
Kz/Kr = 1.
Ss = 2.179E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(S)_FHT.aqt
Date: 10/22/12 Time: 14:55:49

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

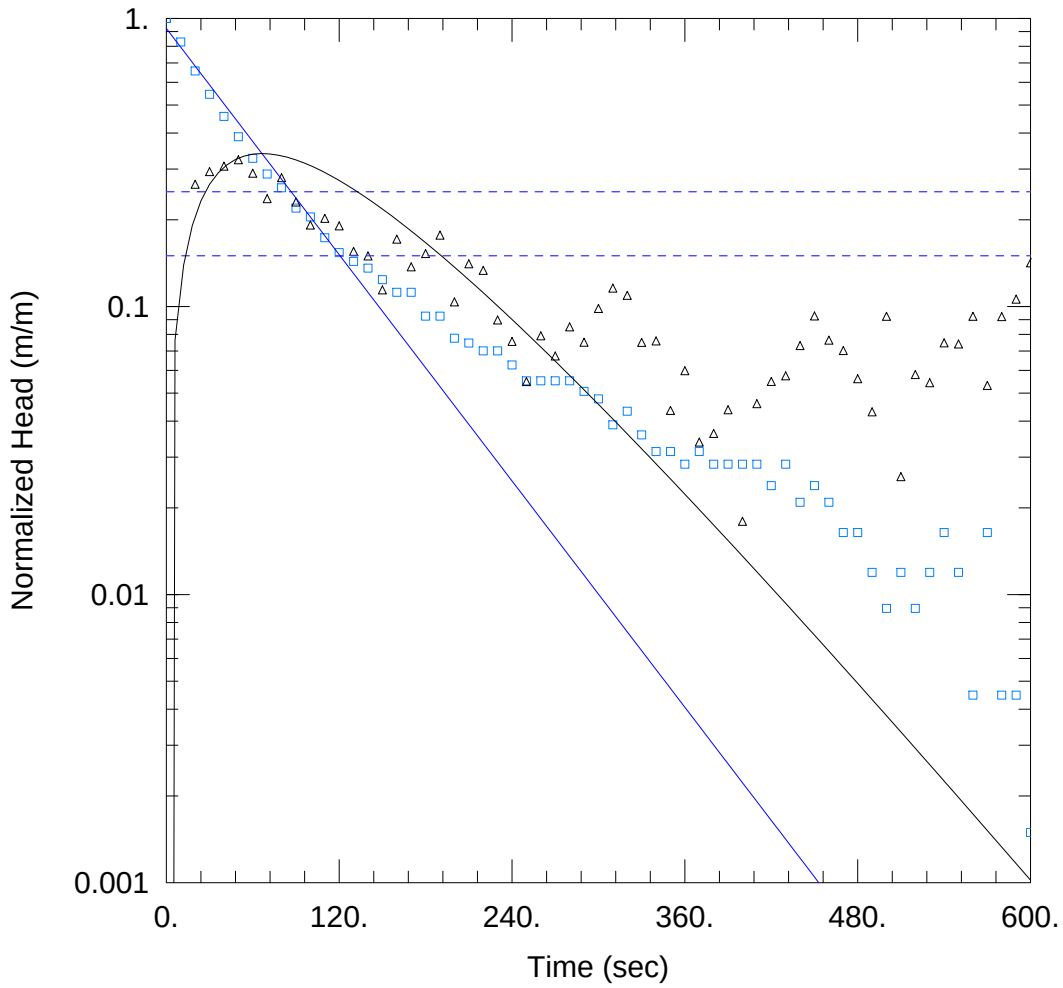
Saturated Thickness: 24.94 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD01(S) FHT)

Initial Displacement: 3.38 m
Total Well Penetration Depth: 21.94 m
Casing Radius: 0.025 m
Static Water Column Height: 24.94 m
Screen Length: 3. m
Well Radius: 0.075 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.4526 m/day
y0 = 2.17 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(S)_slugIn.aqt
Date: 10/22/12 Time: 14:55:54

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

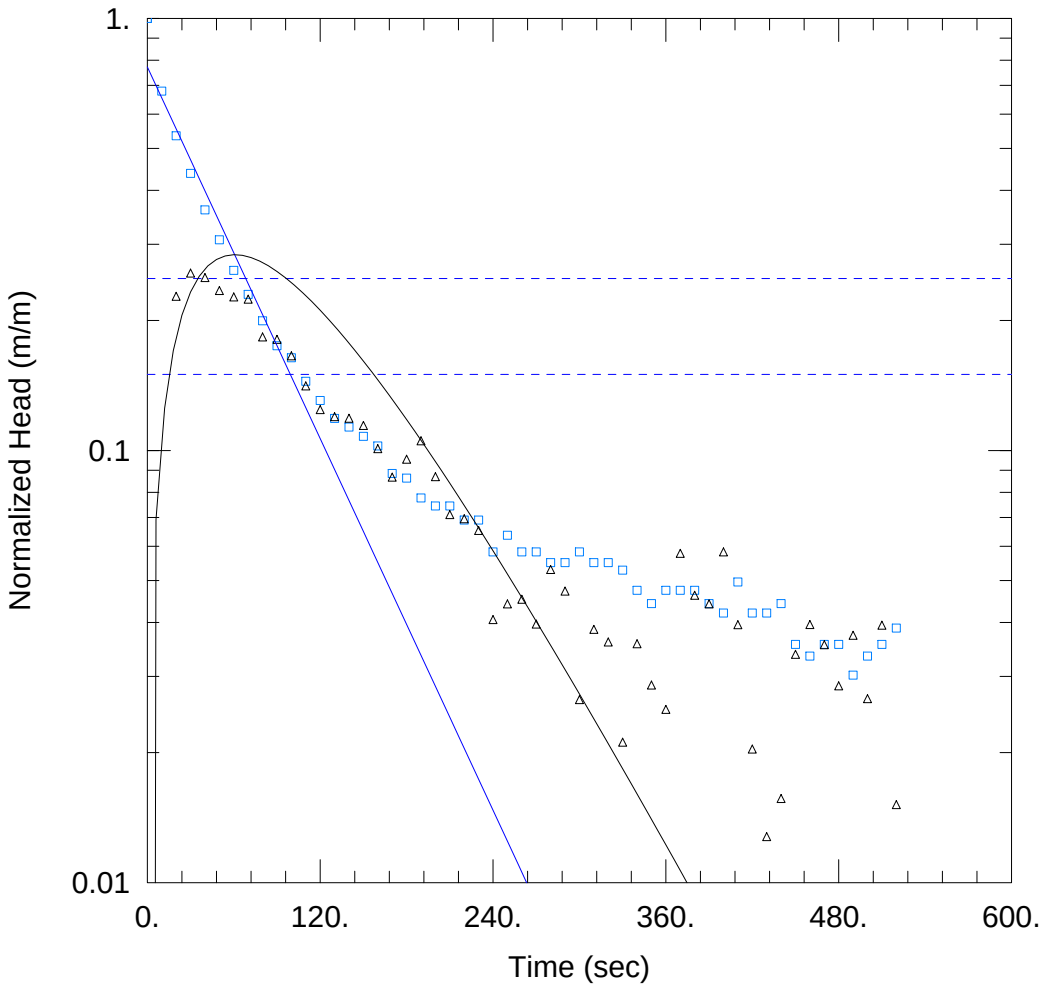
Saturated Thickness: 24.94 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD01(S) Slug in)

Initial Displacement: 0.67 m
Total Well Penetration Depth: 21.94 m
Casing Radius: 0.025 m
Static Water Column Height: 24.94 m
Screen Length: 3. m
Well Radius: 0.075 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.5005 m/day
y0 = 0.6186 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD01(S)_slugOut.aqt
Date: 10/22/12 Time: 14:56:00

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

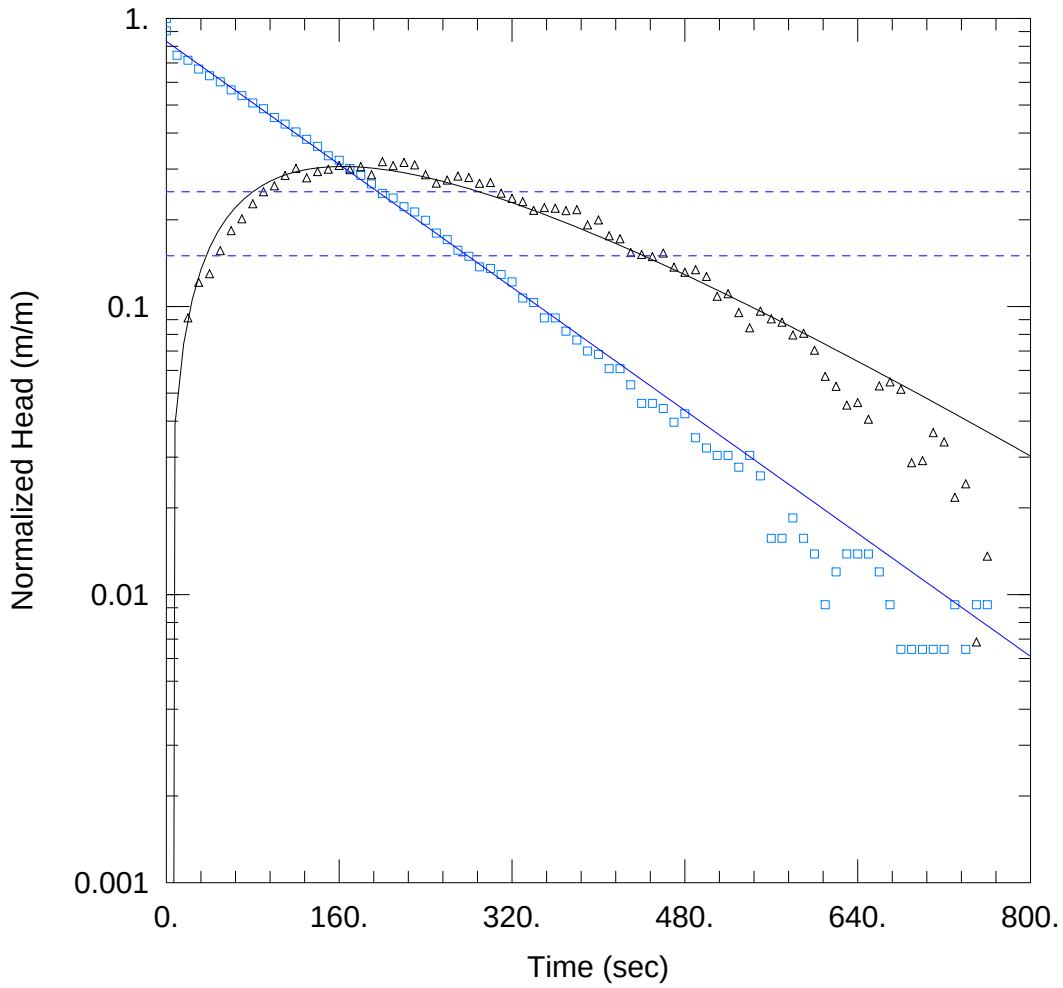
Saturated Thickness: 24.94 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD01(S) Slug out)

Initial Displacement: 0.927 m
Total Well Penetration Depth: 21.94 m
Casing Radius: 0.025 m
Static Water Column Height: 24.94 m
Screen Length: 3. m
Well Radius: 0.075 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.548 m/day
y0 = 0.7157 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(D)_SlugIn1.aqt
Date: 10/22/12 Time: 14:56:04

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

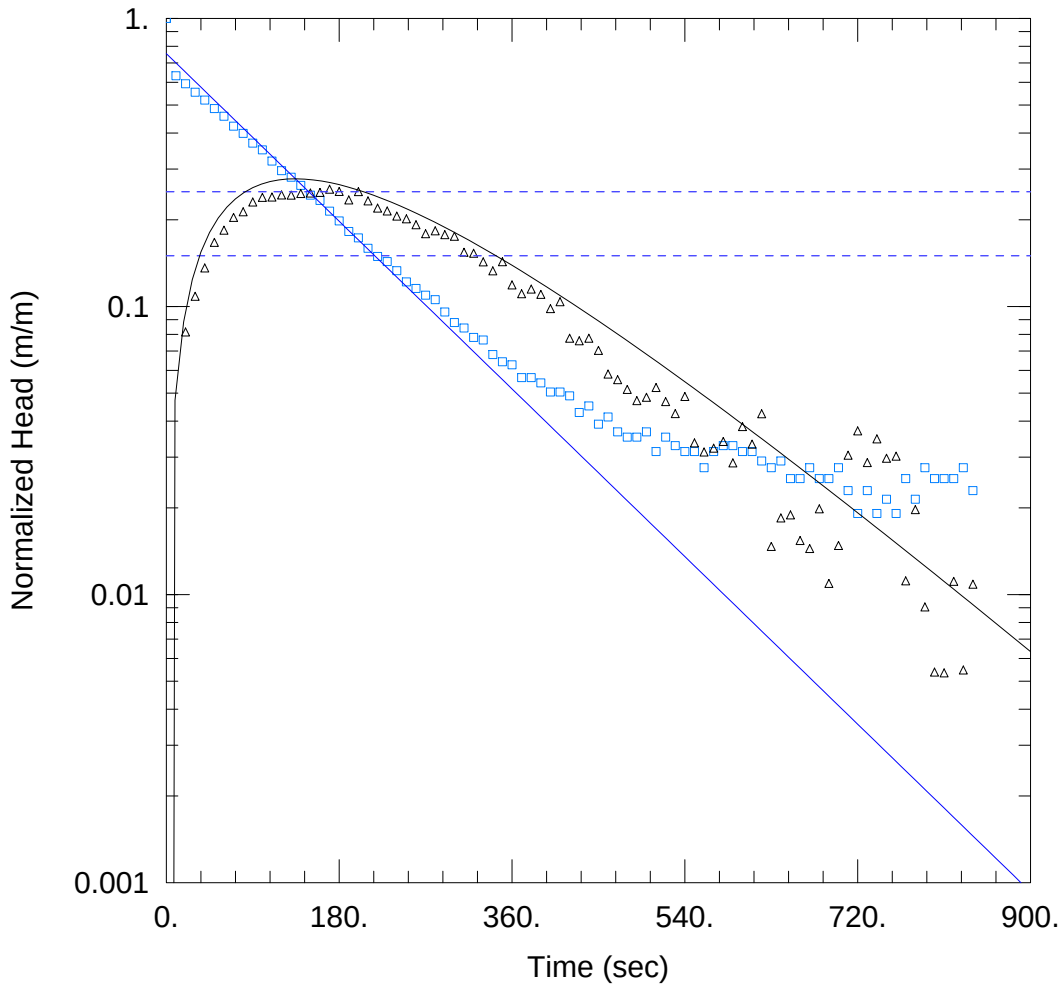
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(D) Slug in 1)

Initial Displacement: 1.085 m
Total Well Penetration Depth: 47.13 m
Casing Radius: 0.025 m
Static Water Column Height: 47.63 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.2462 m/day
y0 = 0.9032 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(D)_SlugIn2.aqt
Date: 10/22/12 Time: 14:56:09

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

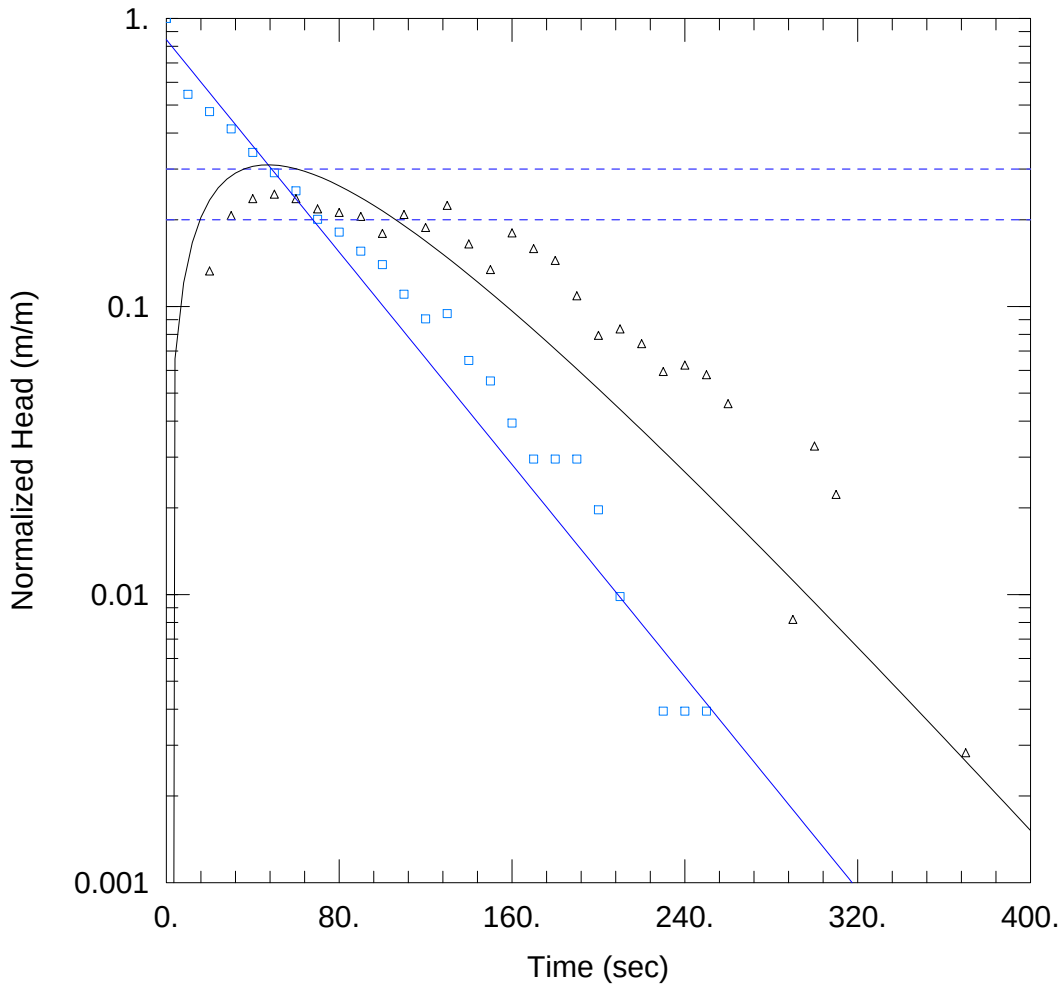
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(D) Slug in 2)

Initial Displacement: 1.307 m
Total Well Penetration Depth: 47.13 m
Casing Radius: 0.025 m
Static Water Column Height: 47.63 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.2982 m/day
y0 = 0.9862 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(D)_SlugIn3.aqt
Date: 10/22/12 Time: 14:56:13

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

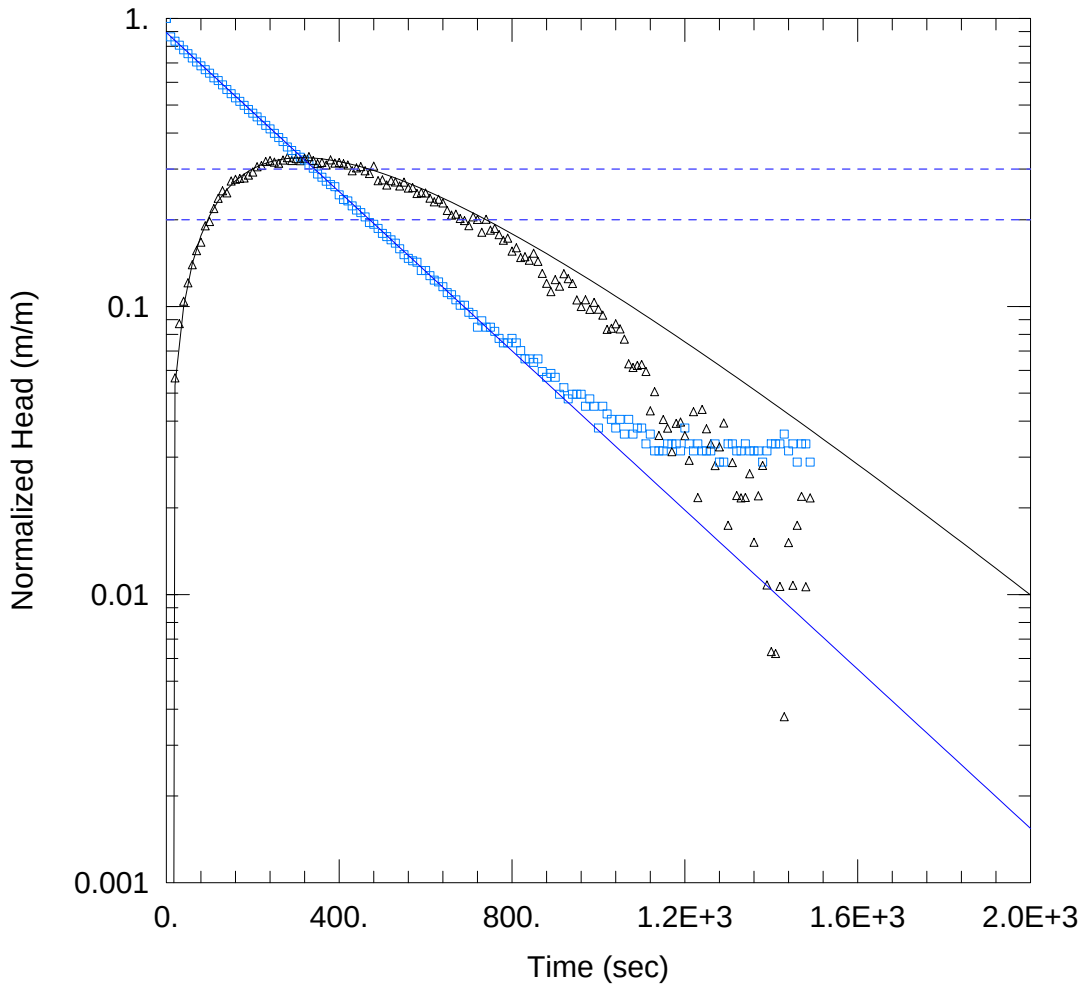
WELL DATA (RAU12HYD02(D) Slug in 3)

Initial Displacement: 0.508 m
Total Well Penetration Depth: 47.13 m
Casing Radius: 0.025 m
Static Water Column Height: 47.63 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.8499 m/day
y0 = 0.4286 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(D)_SlugOut1.aqt
Date: 10/22/12 Time: 14:56:17

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

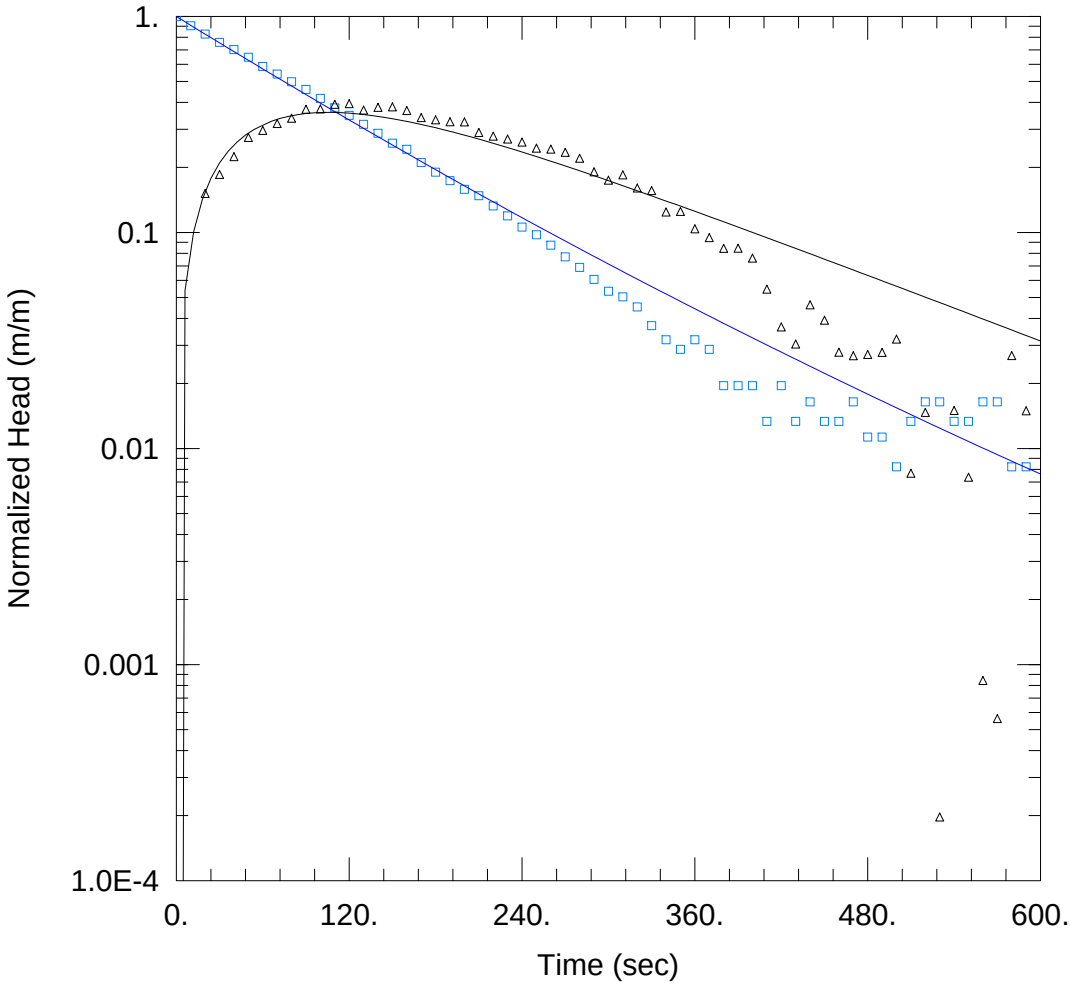
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(D) Slug out 1)

Initial Displacement: 1.11 m
Total Well Penetration Depth: 47.13 m
Casing Radius: 0.025 m
Static Water Column Height: 47.63 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.1274 m/day
y0 = 0.9914 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(D)_SlugOut3.aqt
Date: 10/22/12 Time: 14:56:21

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 20. m

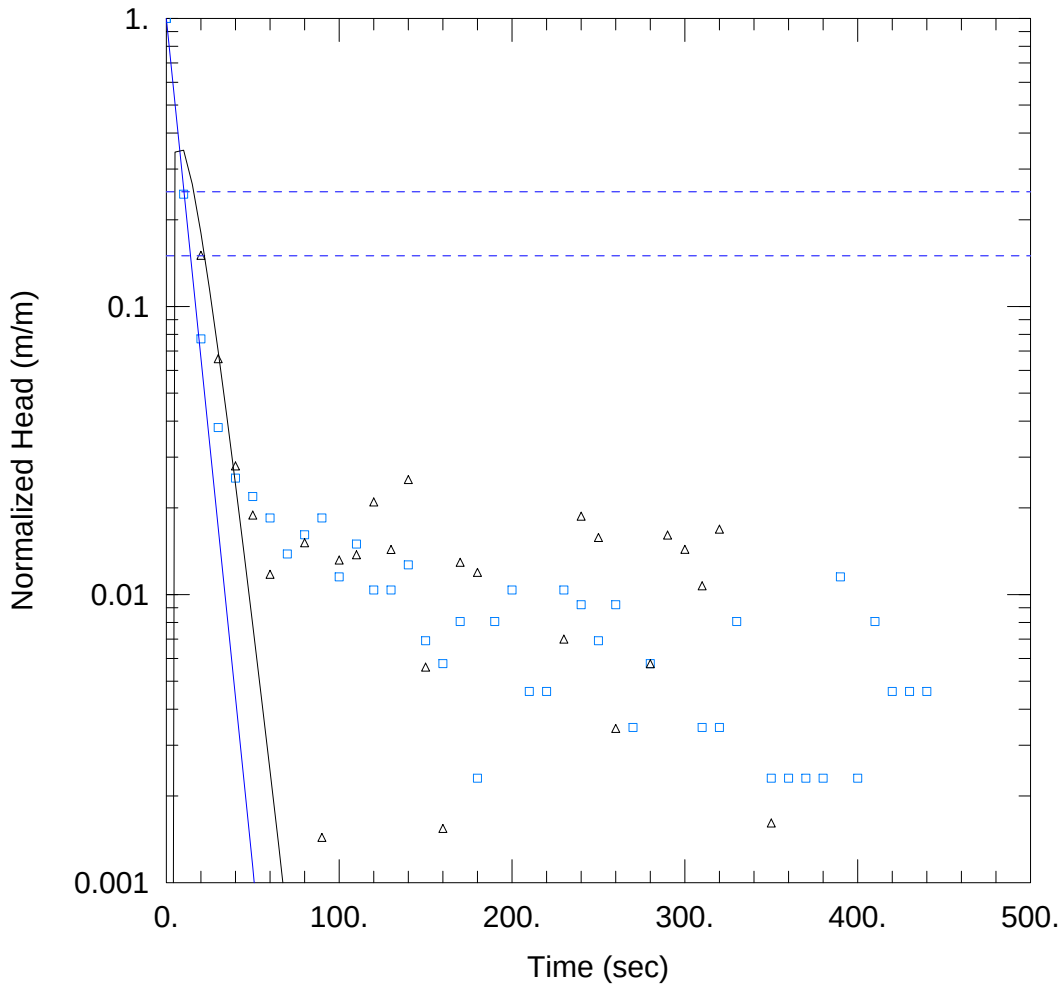
WELL DATA (RAU12HYD02(D) Slug out 3)

Initial Displacement: 0.973 m
Total Well Penetration Depth: 47.13 m
Casing Radius: 0.025 m
Static Water Column Height: 47.63 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.4871 m/day
Kz/Kr = 1.
Ss = 5.0E-20 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(S)_FHT1.aqt
Date: 10/22/12 Time: 14:56:25

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

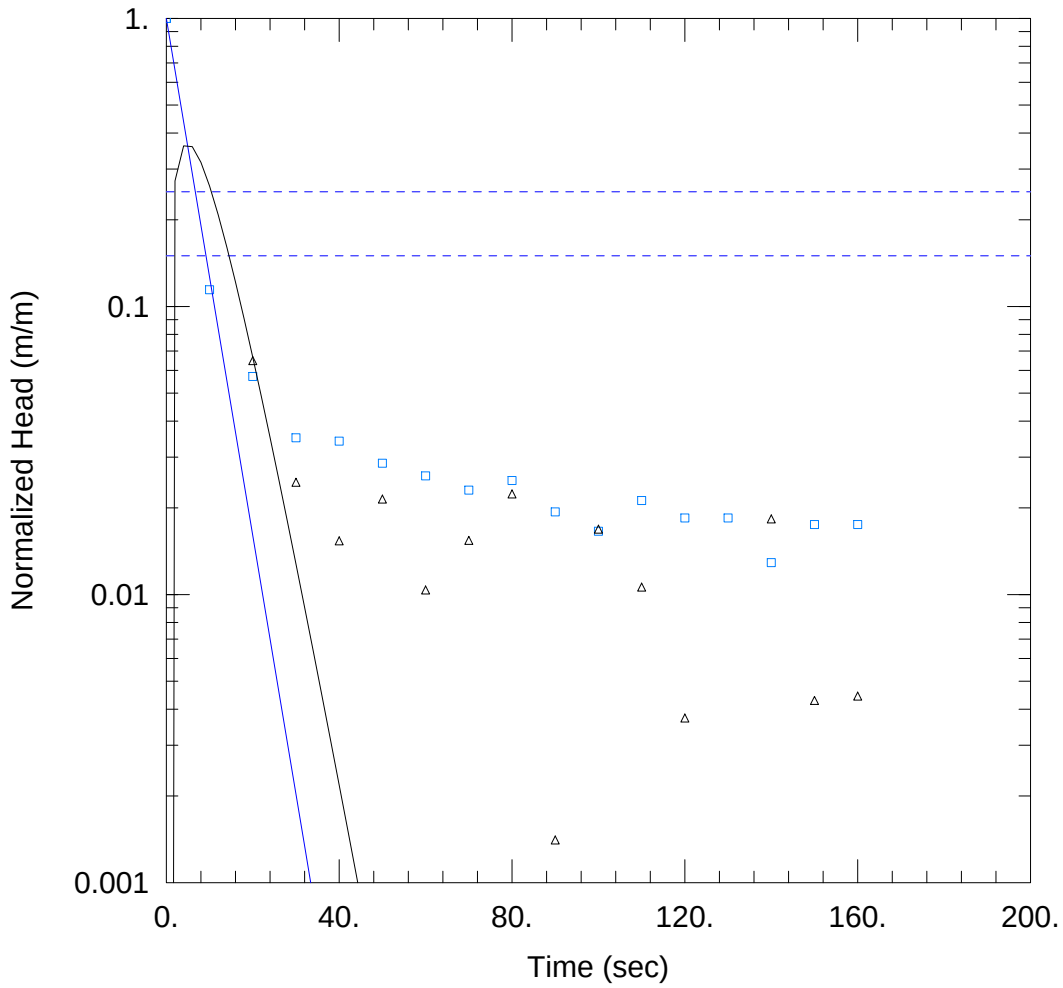
Saturated Thickness: 26.14 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(S) FHT 1)

Initial Displacement: 0.868 m
Total Well Penetration Depth: 24.14 m
Casing Radius: 0.025 m
Static Water Column Height: 26.14 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 4.365 m/day
y0 = 0.8664 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(S)_FHT2.aqt
Date: 10/22/12 Time: 14:56:29

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

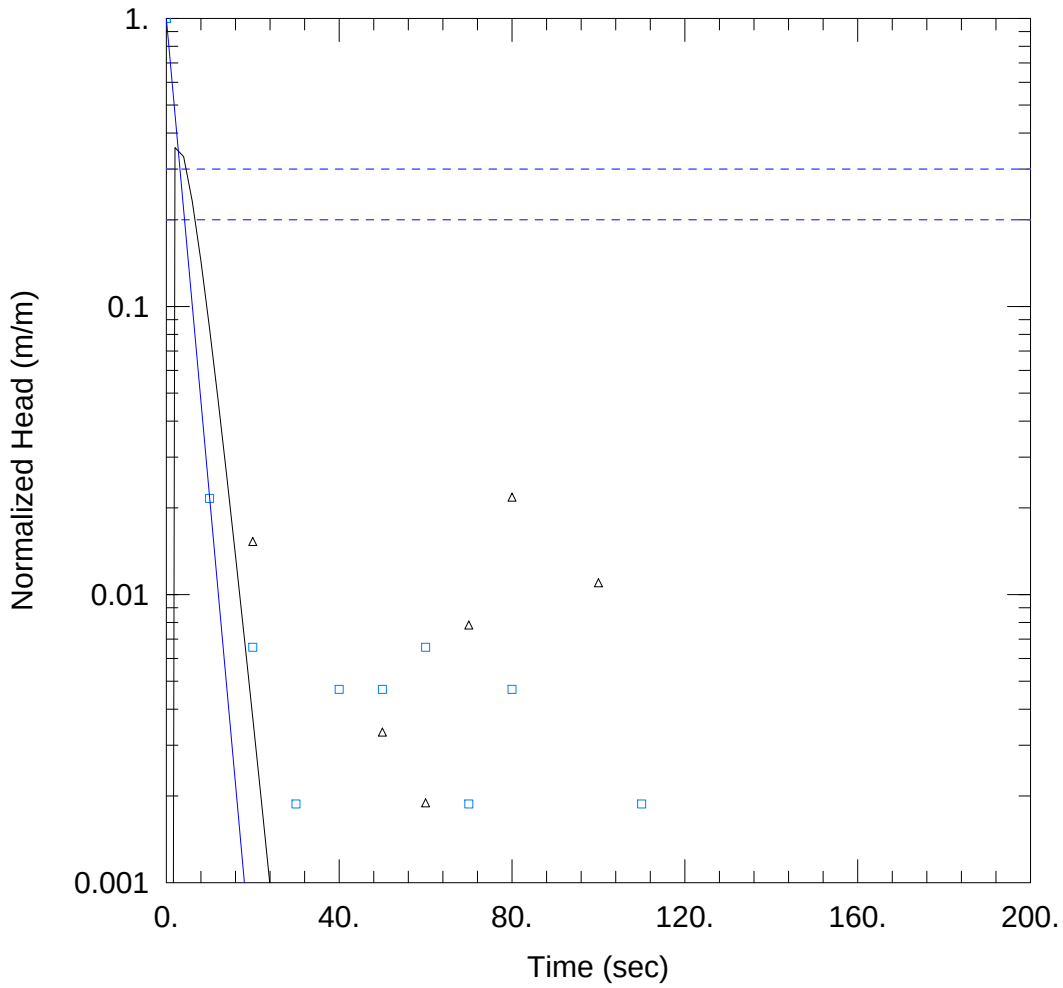
Saturated Thickness: 26.14 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(S) FHT 2)

Initial Displacement: 1.085 m
Total Well Penetration Depth: 24.14 m
Casing Radius: 0.025 m
Static Water Column Height: 26.14 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 6.652 m/day
y0 = 1.084 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(S)_slugIn1.aqt
Date: 10/22/12 Time: 14:56:33

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

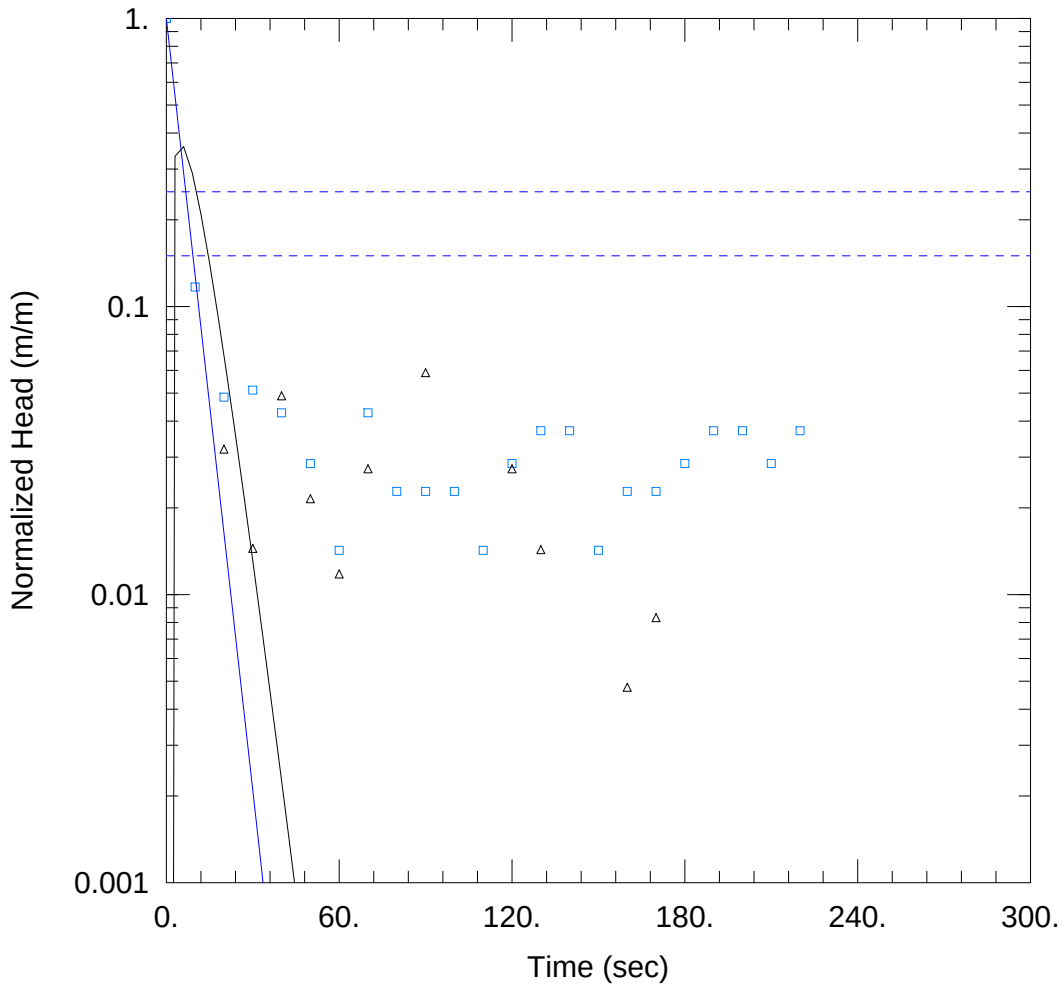
Saturated Thickness: 26.14 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(S) slug in 1)

Initial Displacement: 1.067 m
Total Well Penetration Depth: 24.14 m
Casing Radius: 0.025 m
Static Water Column Height: 26.14 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 11.26 m/day
y0 = 1.067 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD02(S)_slugOut1.aqt
Date: 10/22/12 Time: 14:56:40

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

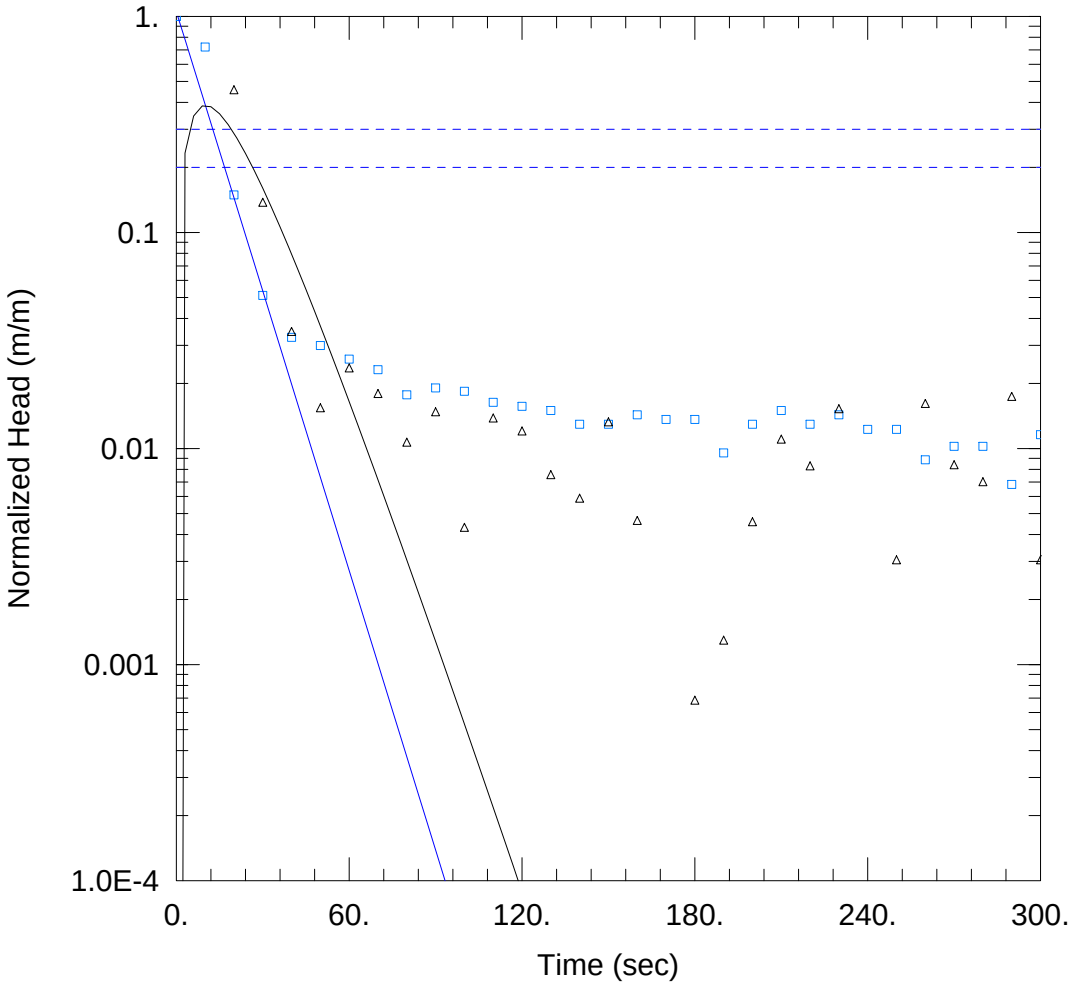
Saturated Thickness: 26.14 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD02(S) Slug out 1)

Initial Displacement: 0.351 m
Total Well Penetration Depth: 24.14 m
Casing Radius: 0.025 m
Static Water Column Height: 26.14 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 6.619 m/day
y0 = 0.3507 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(D)_FHT1.aqt
Date: 10/22/12 Time: 14:56:44

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

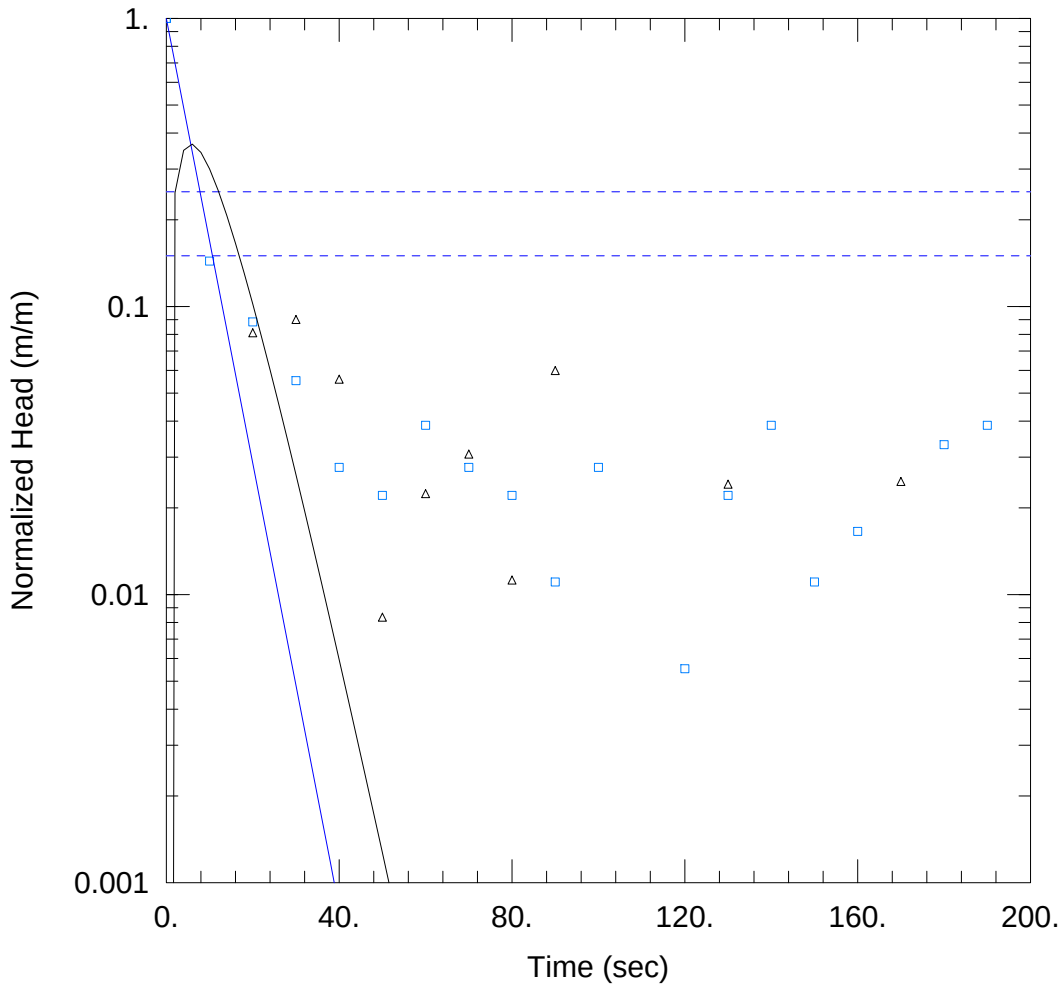
Saturated Thickness: 9.32 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(D) FHT 1)

Initial Displacement: 1.467 m
Total Well Penetration Depth: 7.32 m
Casing Radius: 0.025 m
Static Water Column Height: 9.32 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.635 m/day
y0 = 1.547 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(D)_SlugIn.aqt
Date: 10/22/12 Time: 14:56:49

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

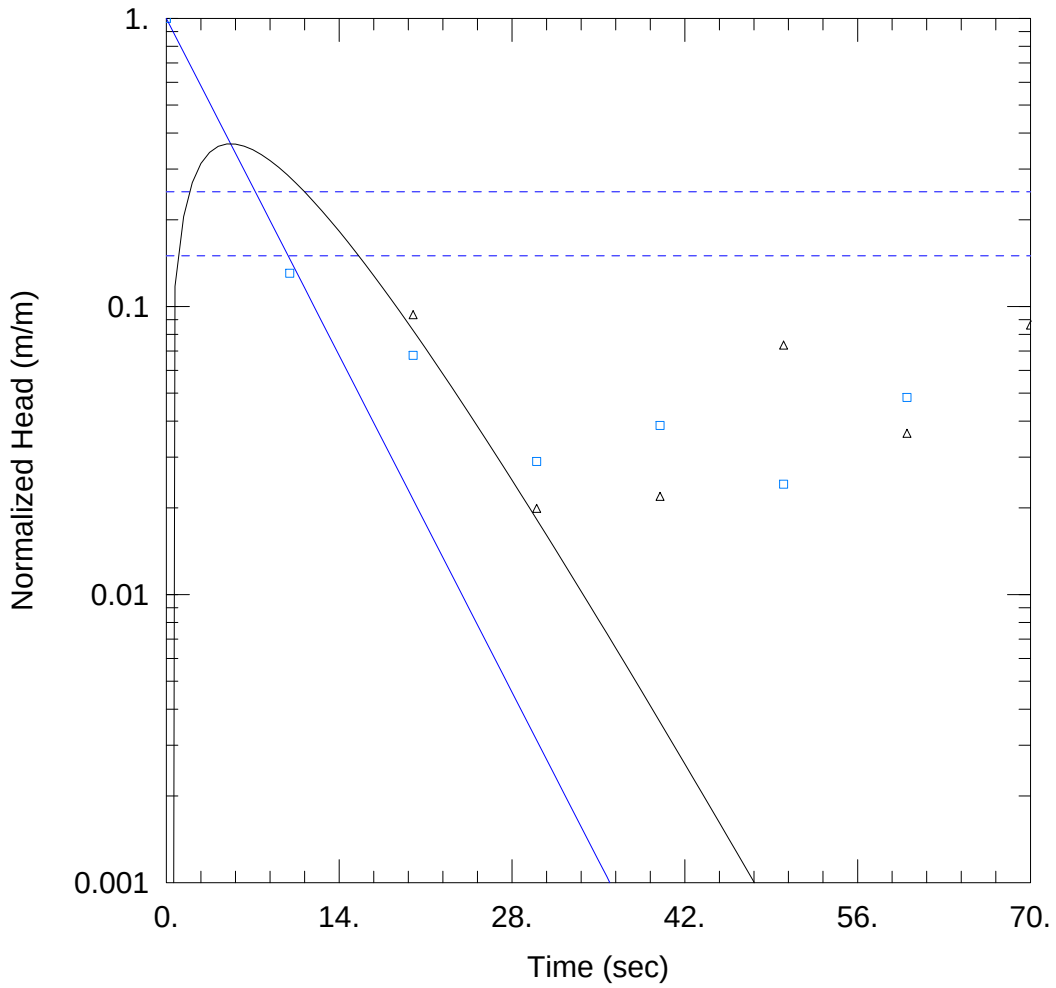
Saturated Thickness: 9.32 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(D) Slug in)

Initial Displacement: 0.181 m
Total Well Penetration Depth: 7.32 m
Casing Radius: 0.025 m
Static Water Column Height: 9.32 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 6.009 m/day
y0 = 0.1806 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(D)_SlugOut.aqt
Date: 10/22/12 Time: 14:56:53

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

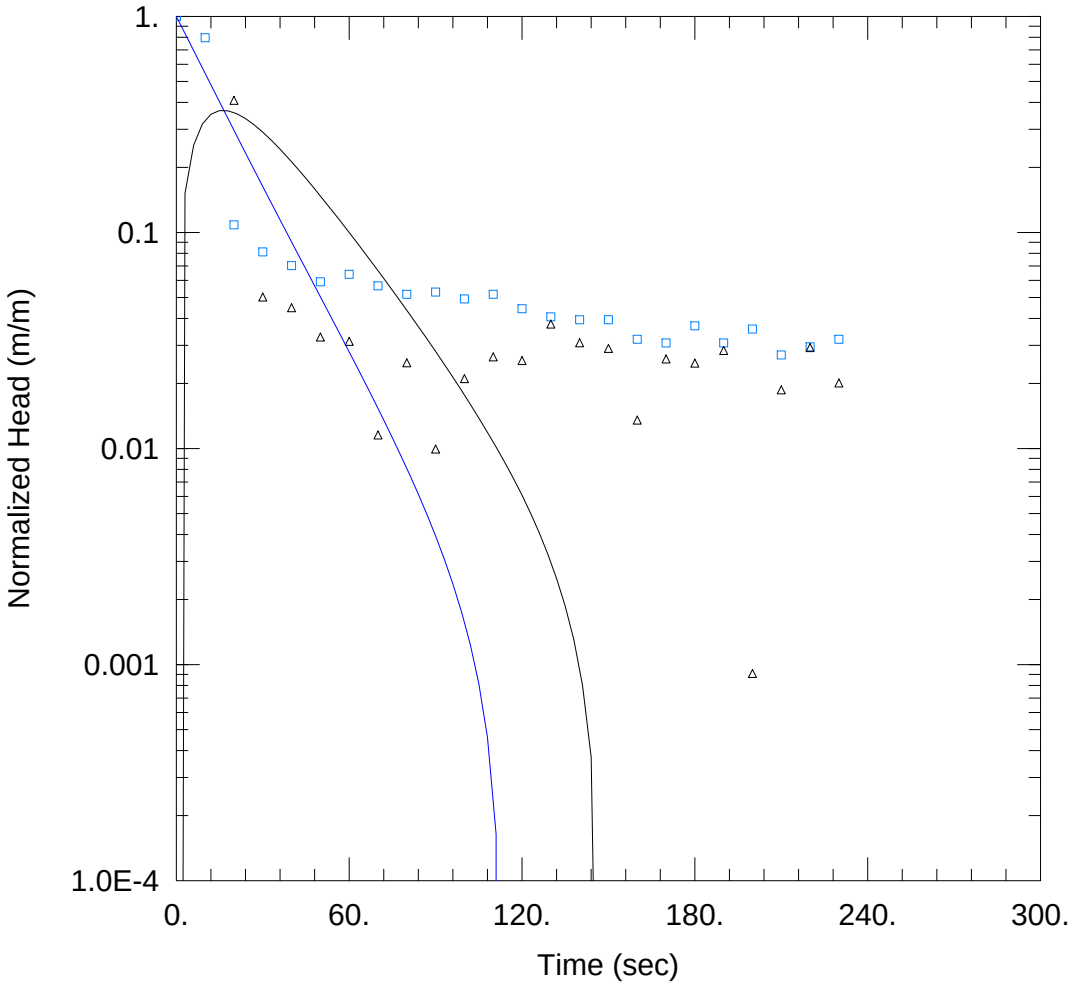
Saturated Thickness: 9.32 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(D) Slug out)

Initial Displacement: 0.207 m
Total Well Penetration Depth: 7.32 m
Casing Radius: 0.025 m
Static Water Column Height: 9.32 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 6.502 m/day
y0 = 0.2068 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(Mid)_FHT1.aqt
Date: 10/22/12 Time: 14:57:04

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 11. m

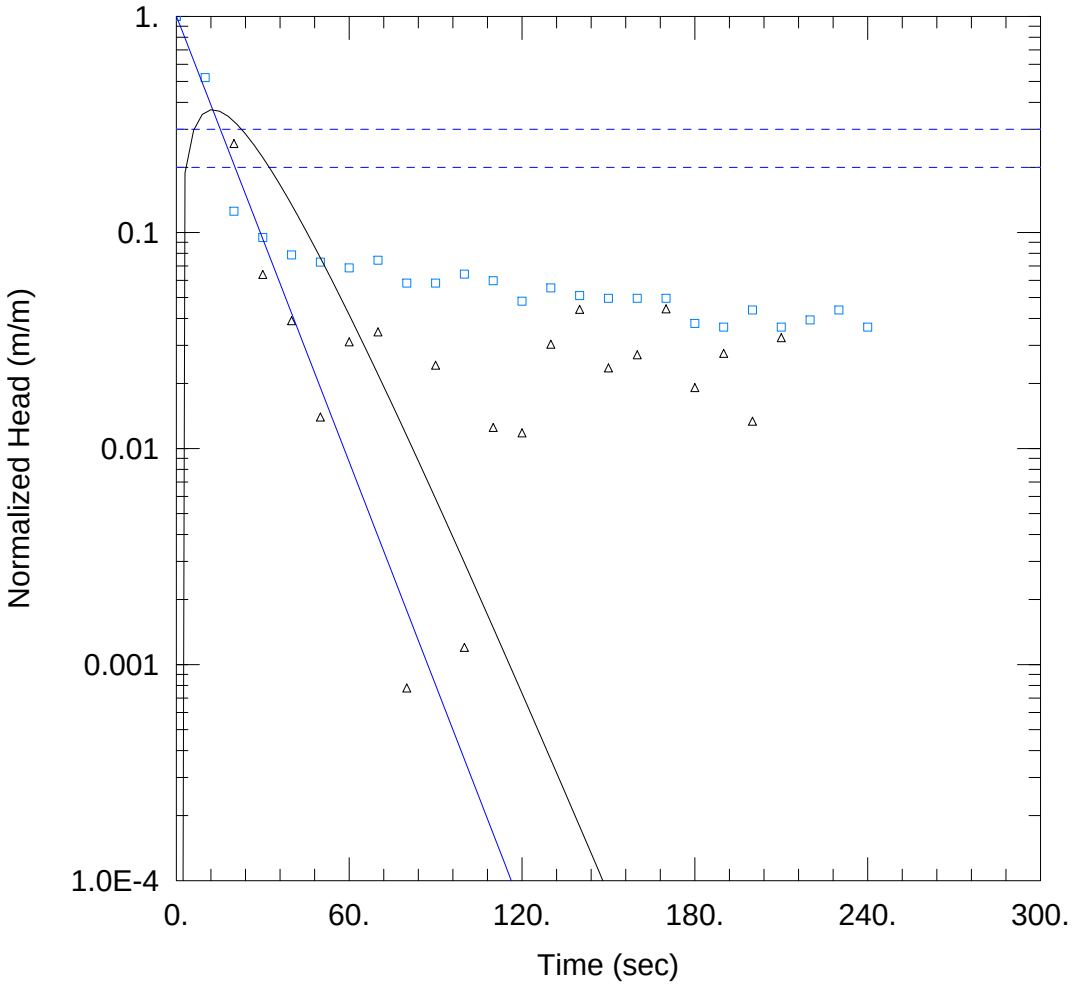
WELL DATA (RAU12HYD03(Mid) FHT 1)

Initial Displacement: 0.812 m
Total Well Penetration Depth: 11.5 m
Casing Radius: 0.025 m
Static Water Column Height: 11. m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 7.505 m/day
Kz/Kr = 1.
Ss = 3.214E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(Mid)_FHT2.aqt
Date: 10/22/12 Time: 14:57:08

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

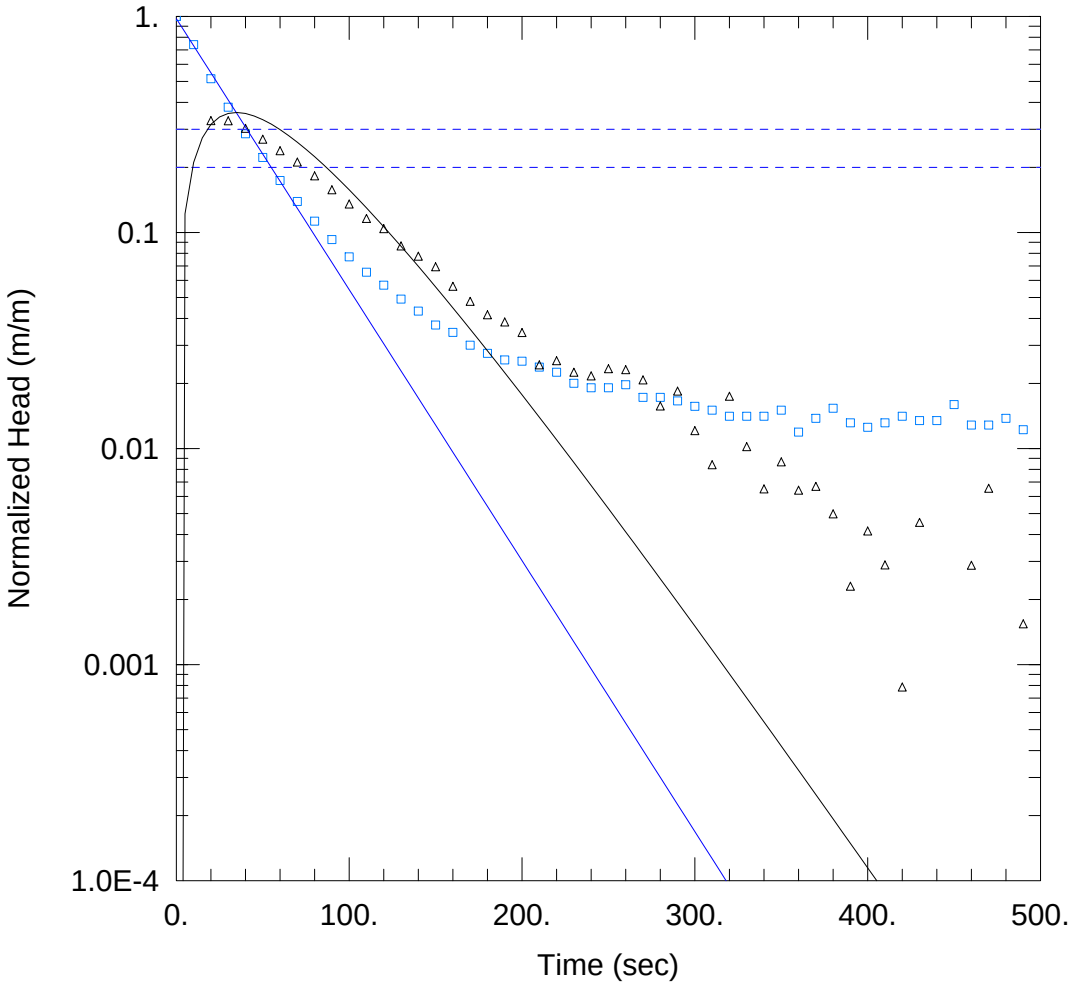
Saturated Thickness: 11. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(Mid) FHT 2)

Initial Displacement: 0.686 m
Total Well Penetration Depth: 11.5 m
Casing Radius: 0.025 m
Static Water Column Height: 11. m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 6.307 m/day
y0 = 0.6903 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(S)_FHT.aqt
Date: 10/22/12 Time: 14:57:12

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

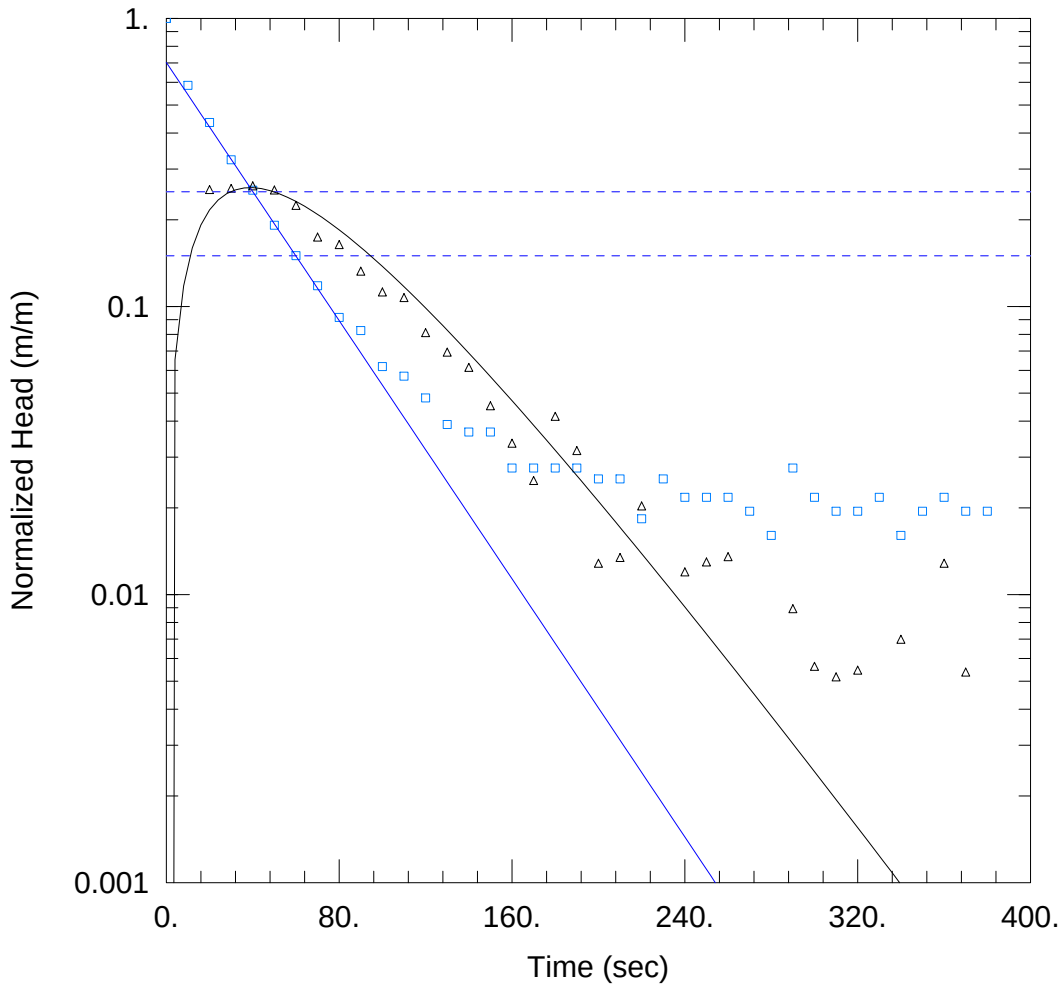
Saturated Thickness: 31.11 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(S) FHT)

Initial Displacement: 3.192 m
Total Well Penetration Depth: 30.61 m
Casing Radius: 0.025 m
Static Water Column Height: 31.11 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.924 m/day
y0 = 3.116 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(S)_SlugIn.aqt
Date: 10/22/12 Time: 14:57:16

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

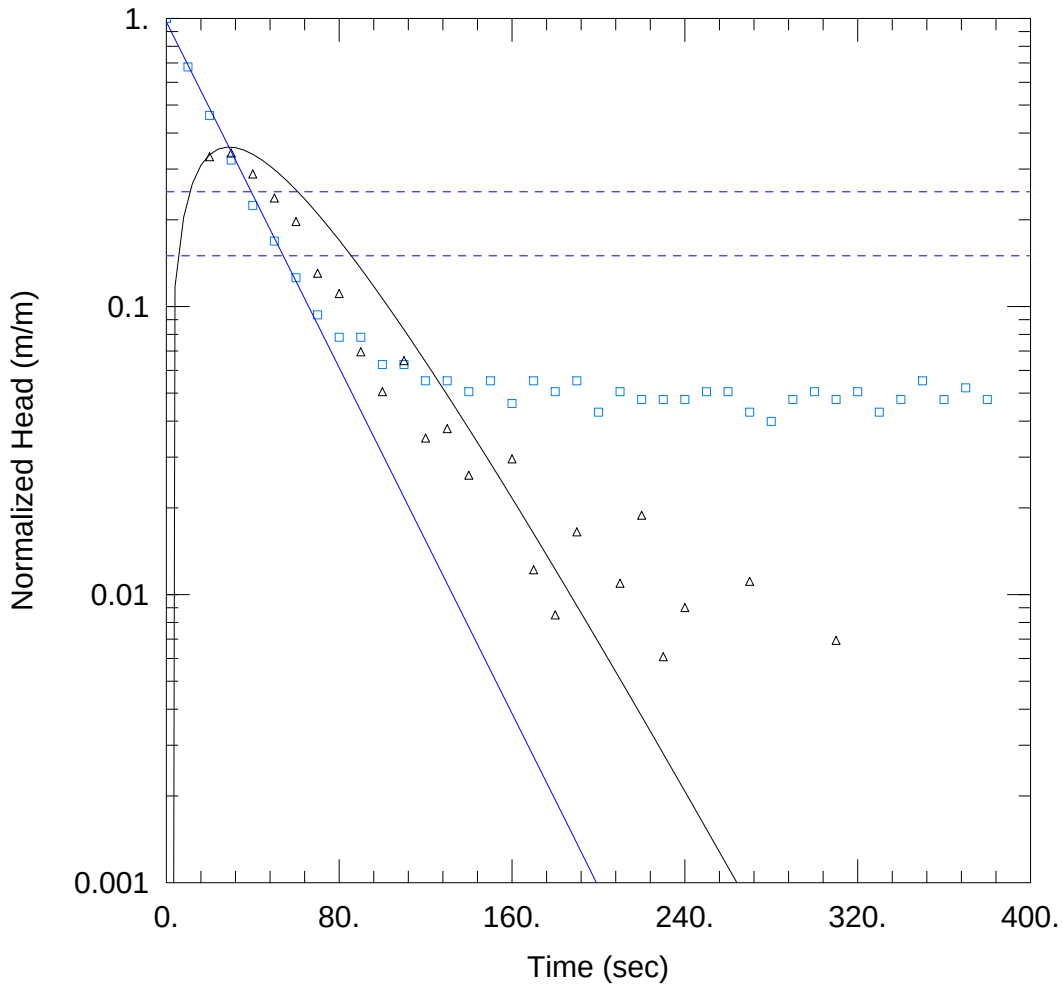
Saturated Thickness: 31.11 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD03(S) Slug in)

Initial Displacement: 0.873 m
Total Well Penetration Depth: 30.61 m
Casing Radius: 0.025 m
Static Water Column Height: 31.11 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.8302 m/day
y0 = 0.6137 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD03(S)_SlugOut.aqt
Date: 10/22/12 Time: 14:57:20

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 31.11 m Anisotropy Ratio (Kz/Kr): 1.

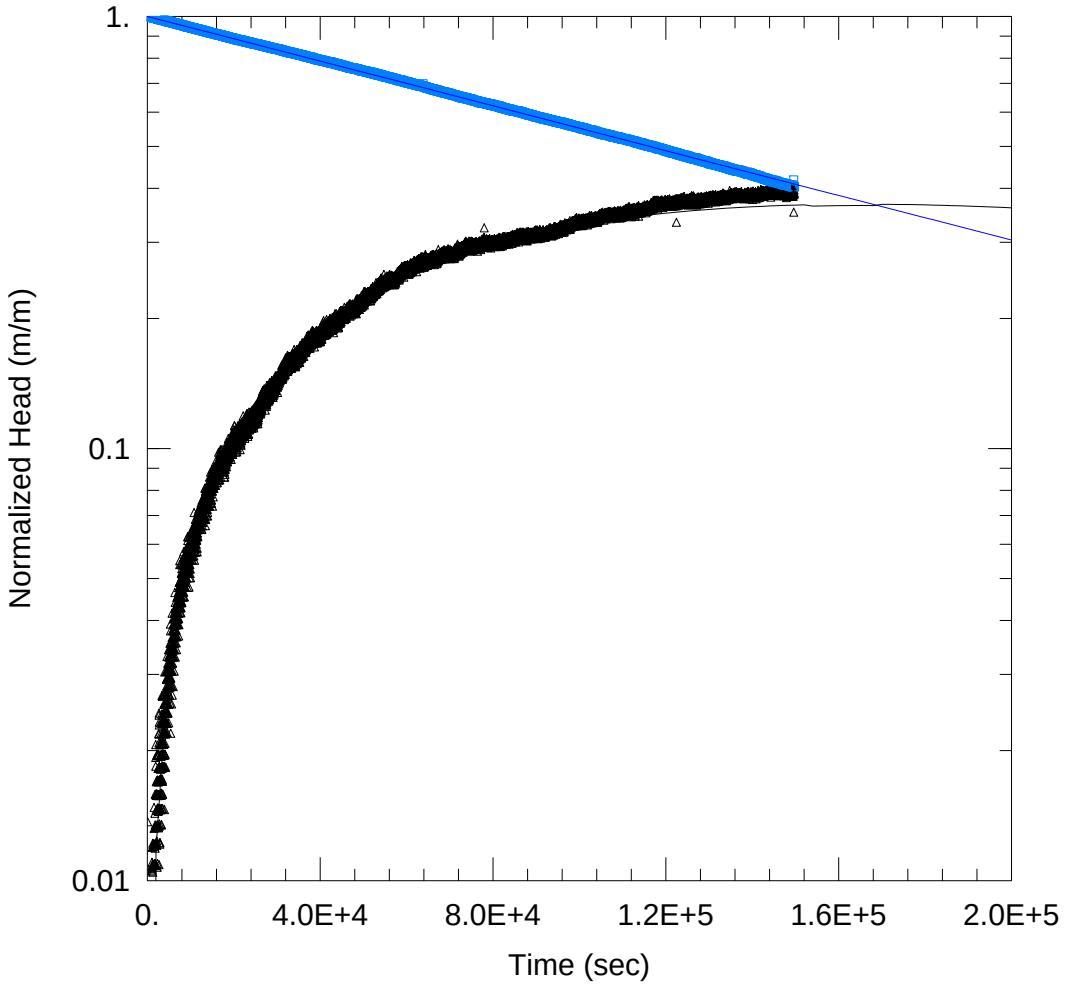
WELL DATA (RAU12HYD03(S) Slug out)

Initial Displacement: 0.652 m
Total Well Penetration Depth: 30.61 m
Casing Radius: 0.025 m
Static Water Column Height: 31.11 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 1.112 m/day y0 = 0.6343 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD04(D)_FHT.aqt
Date: 10/22/12 Time: 14:57:26

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 24.59 m

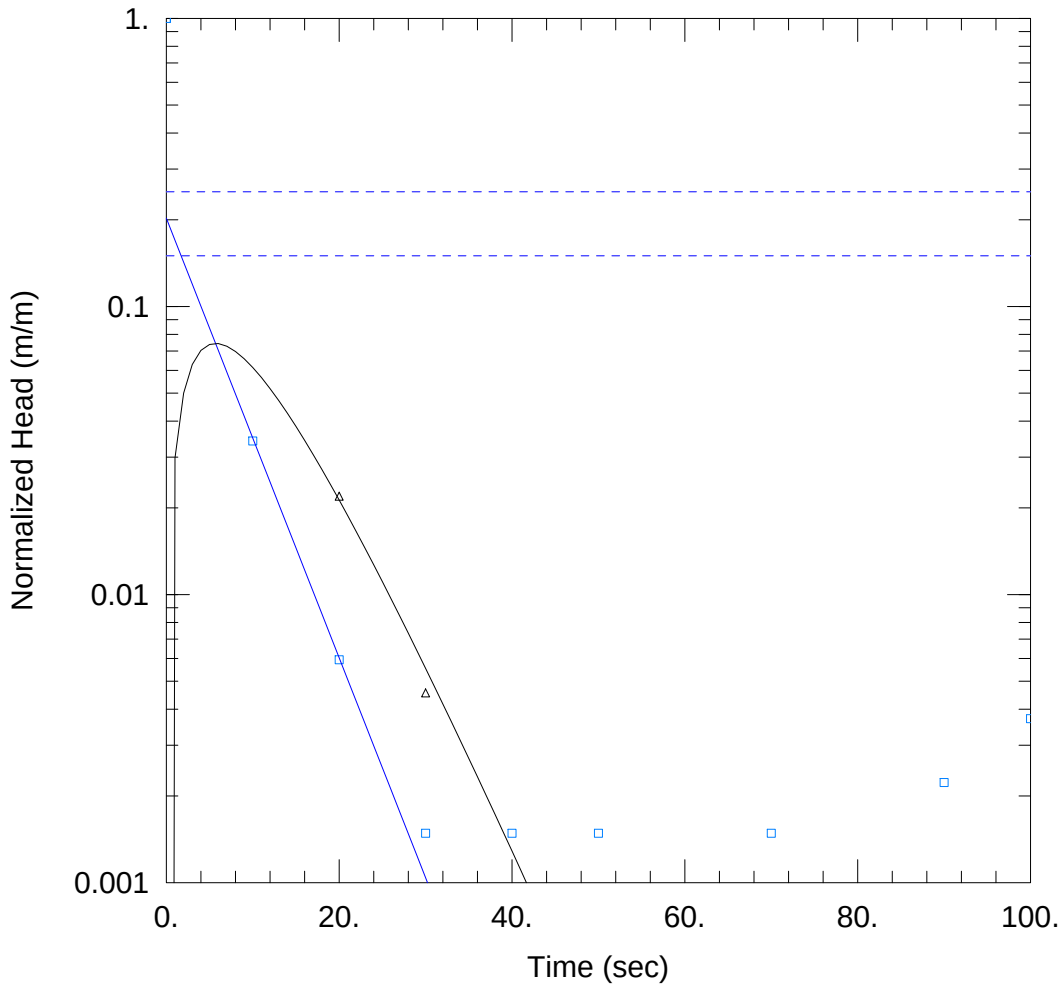
WELL DATA (RAU12HYD04(D) FHT)

Initial Displacement: 2.036 m
Total Well Penetration Depth: 24.09 m
Casing Radius: 0.025 m
Static Water Column Height: 24.59 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.0002051 m/day
Kz/Kr = 1.
Ss = 4.067E-14 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD04(S)_FHT1.aqt
Date: 10/22/12 Time: 14:57:31

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

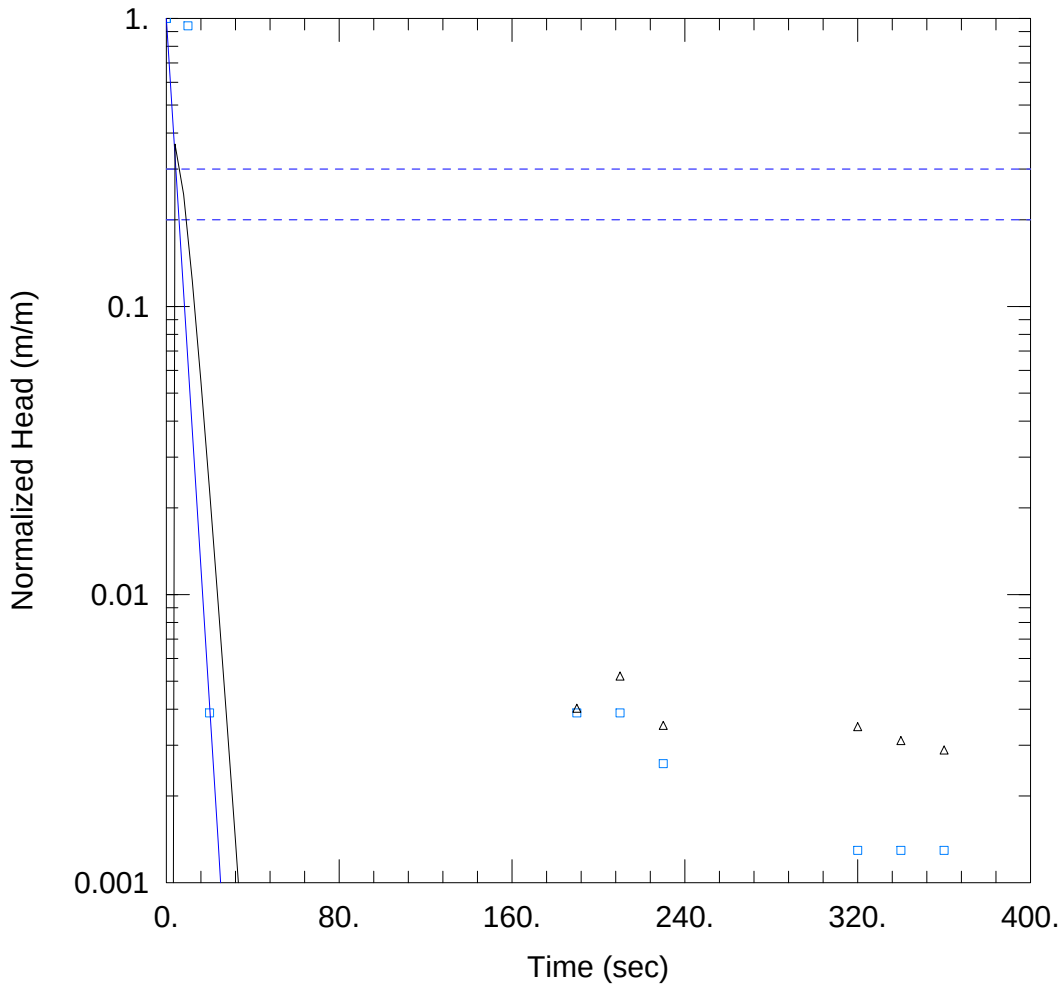
Saturated Thickness: 3.86 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD04(S) FHT 1)

Initial Displacement: 1.348 m
Total Well Penetration Depth: 2.61 m
Casing Radius: 0.025 m
Static Water Column Height: 3.86 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 11.78 m/day
y0 = 0.2728 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD04(S)_FHT2.aqt
Date: 10/22/12 Time: 14:57:36

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

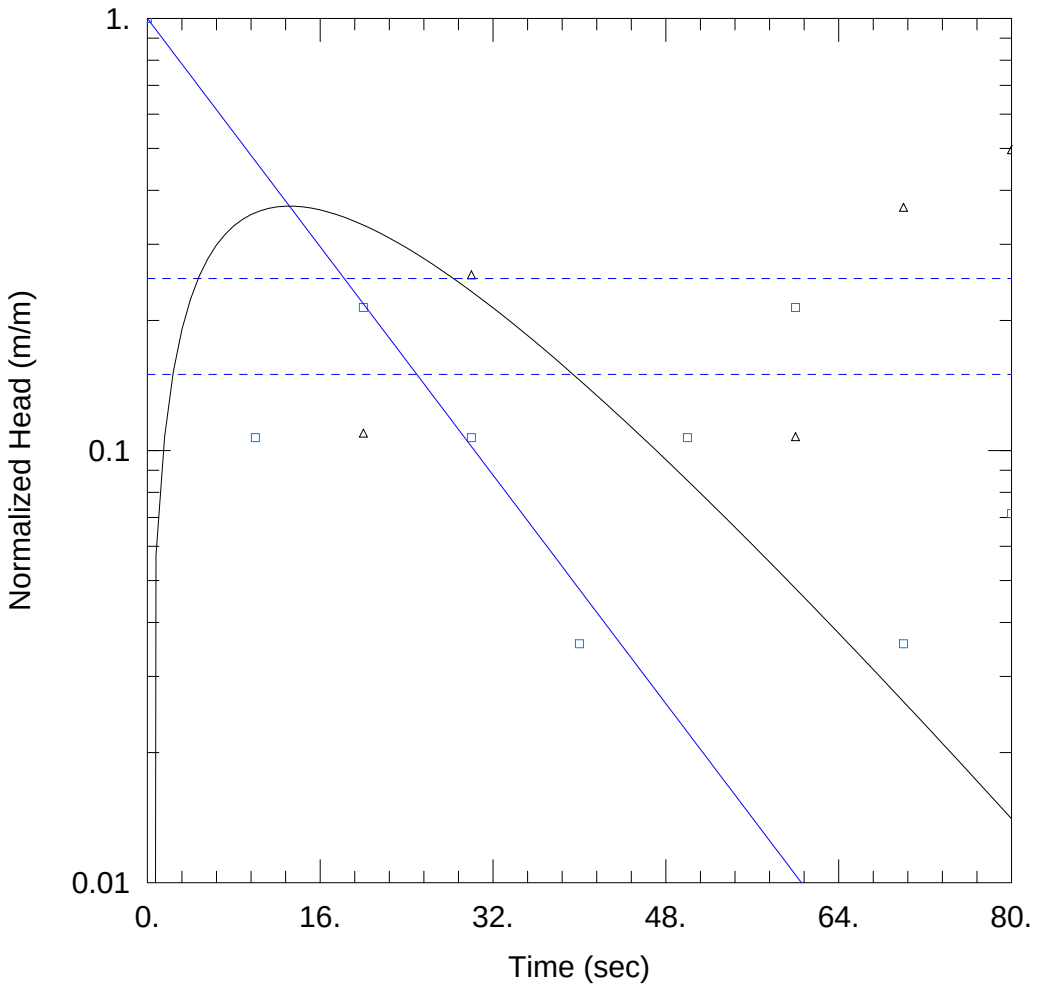
Saturated Thickness: 3.86 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD04(S) FHT 2)

Initial Displacement: 0.773 m
Total Well Penetration Depth: 2.61 m
Casing Radius: 0.025 m
Static Water Column Height: 3.86 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 13.55 m/day
y0 = 0.773 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD04(S)_SlugIn.aqt
Date: 10/22/12 Time: 14:57:39

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

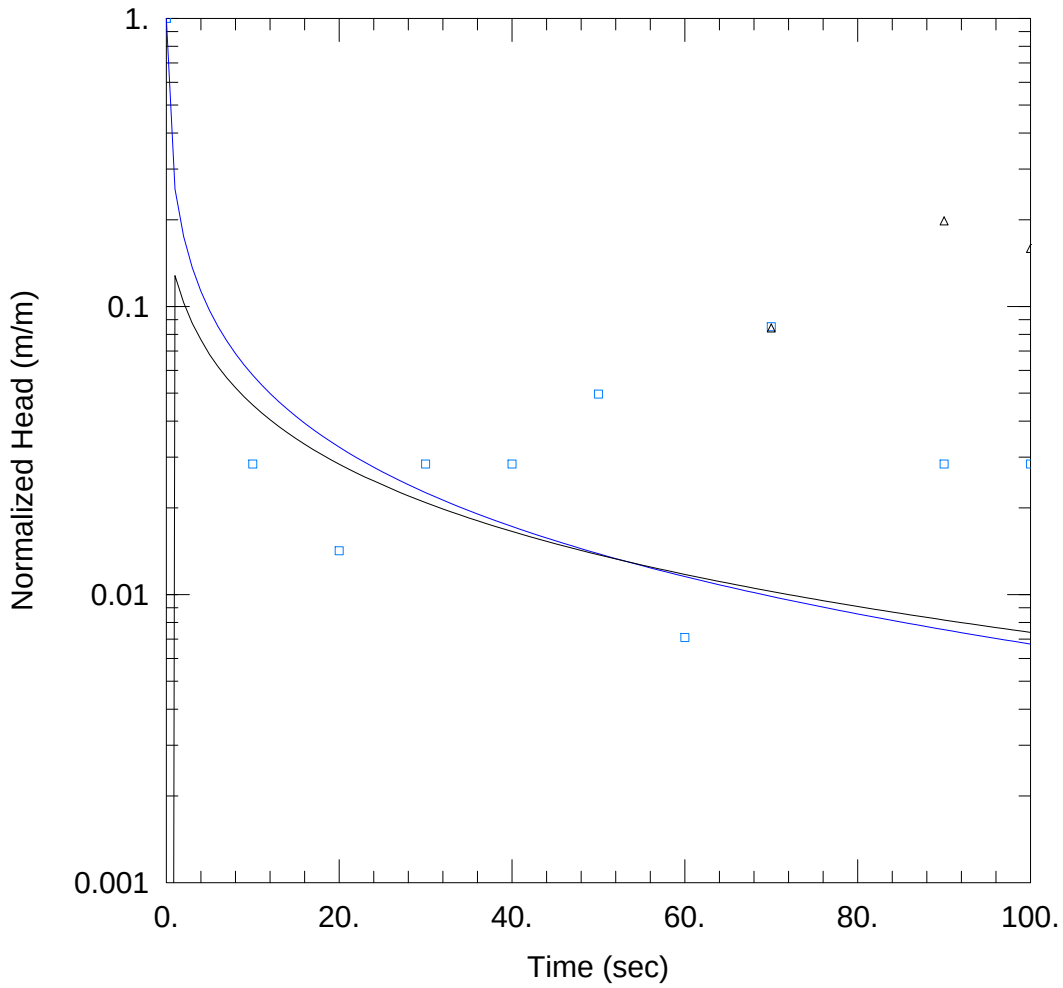
Saturated Thickness: 3.86 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD04(S) Slug in)

Initial Displacement: 0.028 m
Total Well Penetration Depth: 2.61 m
Casing Radius: 0.025 m
Static Water Column Height: 3.86 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 5.1 m/day
y0 = 0.028 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD04(S)_SlugOut.aqt
Date: 10/22/12 Time: 14:57:43

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 3.86 m

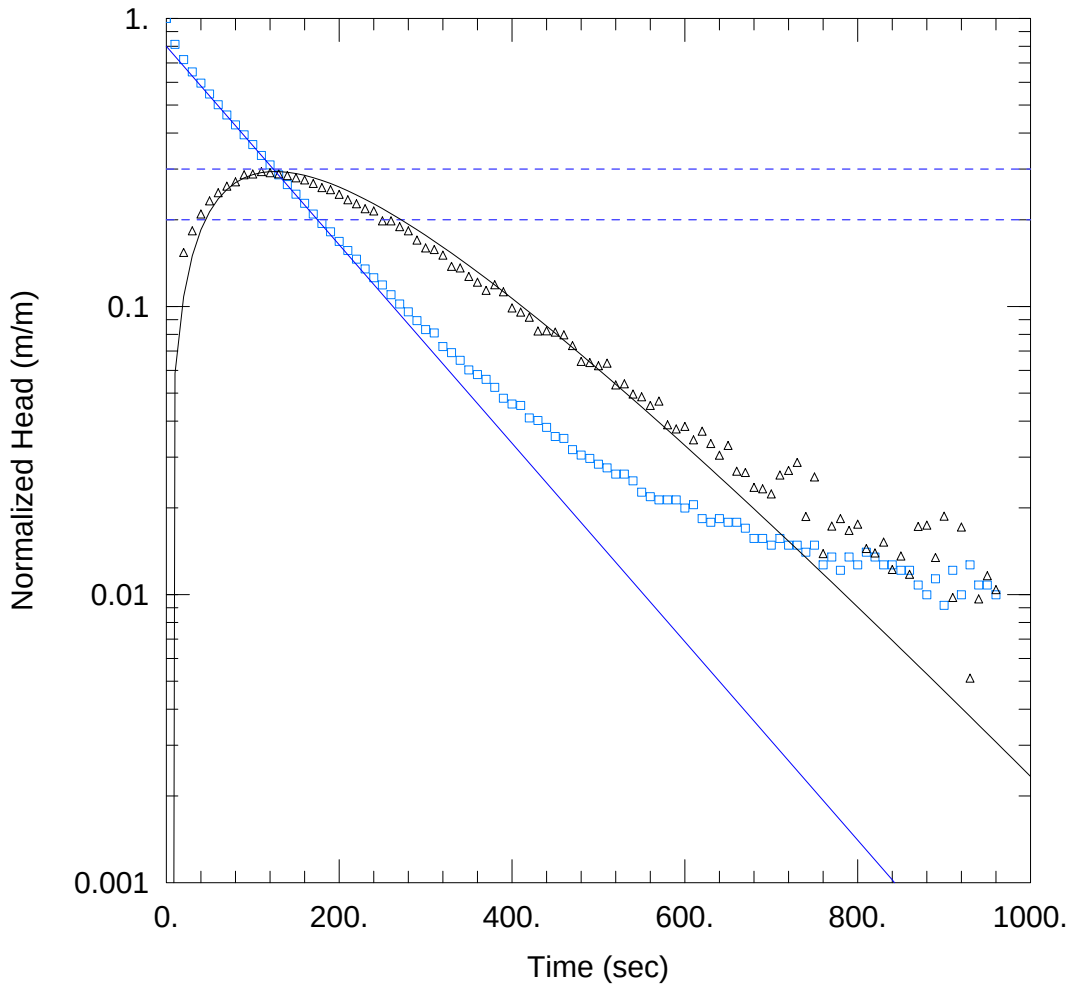
WELL DATA (RAU12HYD04(S) Slug out)

Initial Displacement: 0.141 m
Total Well Penetration Depth: 2.61 m
Casing Radius: 0.025 m
Static Water Column Height: 3.86 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 12.96 m/day
Kz/Kr = 1.
Ss = 0.2591 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD05(D)_FHT.aqt
Date: 10/22/12 Time: 14:57:47

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

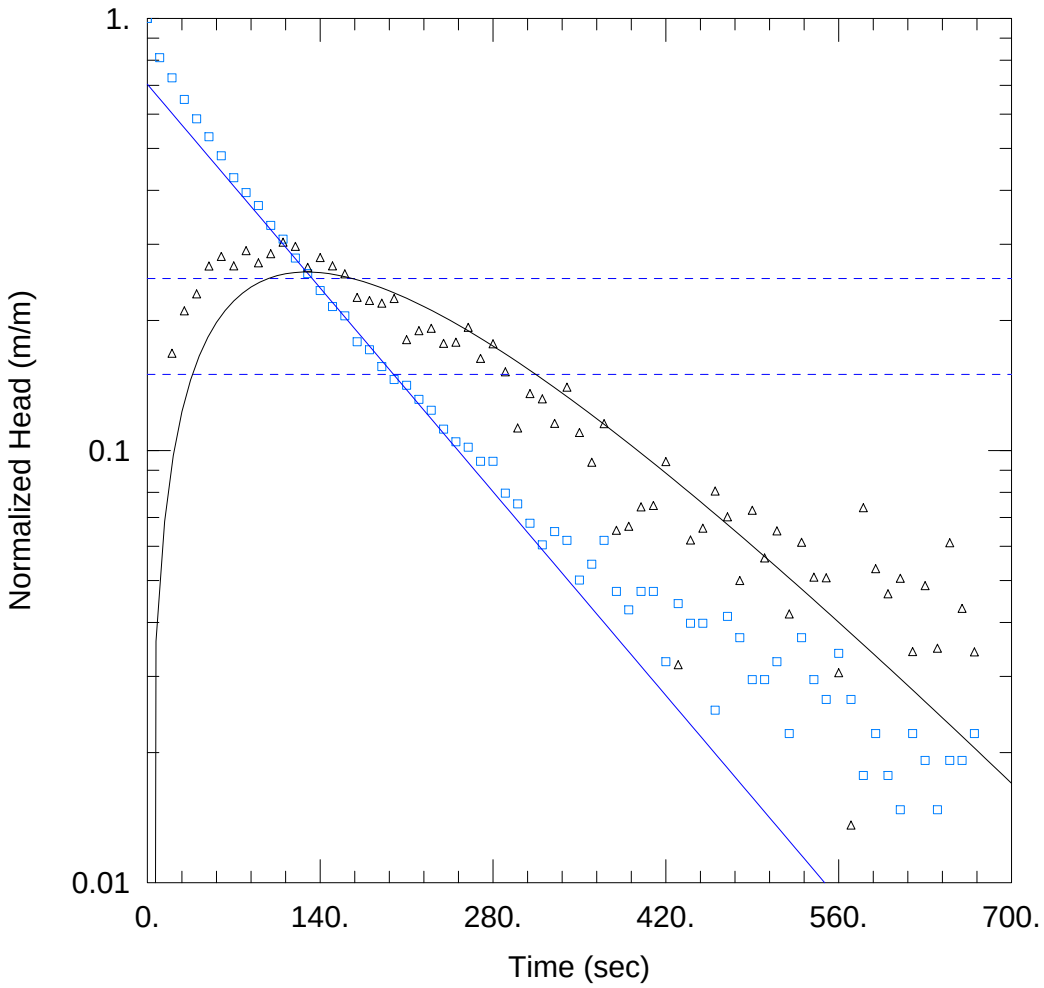
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD05(D) FHT)

Initial Displacement: 3.705 m
Total Well Penetration Depth: 22.58 m
Casing Radius: 0.025 m
Static Water Column Height: 23.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.2898 m/day
y0 = 2.963 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD05(D)_SlugIn.aqt
Date: 10/22/12 Time: 14:57:51

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

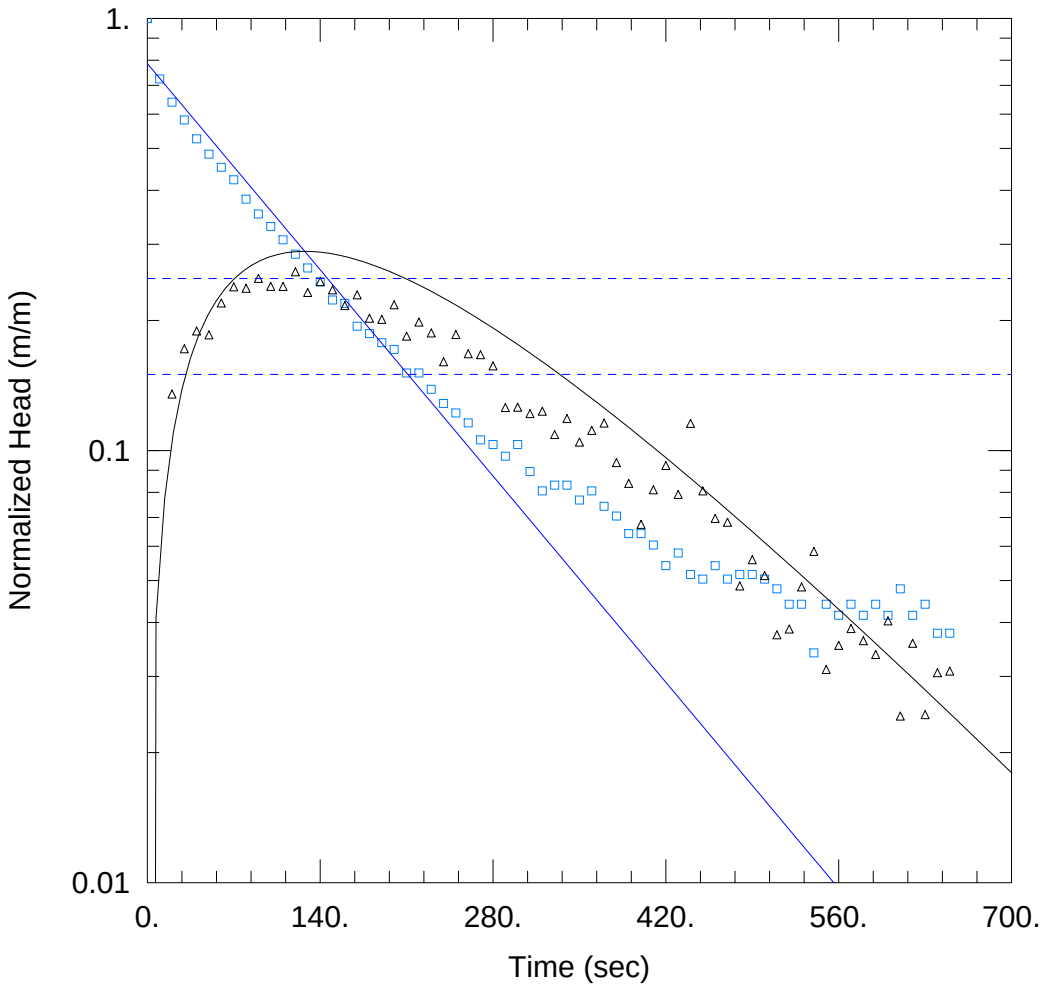
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD05(D) Slug in)

Initial Displacement: 0.678 m
Total Well Penetration Depth: 22.58 m
Casing Radius: 0.025 m
Static Water Column Height: 23.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.3106 m/day
y0 = 0.4773 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD05(D)_SlugOut.aqt
Date: 10/22/12 Time: 14:57:55

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

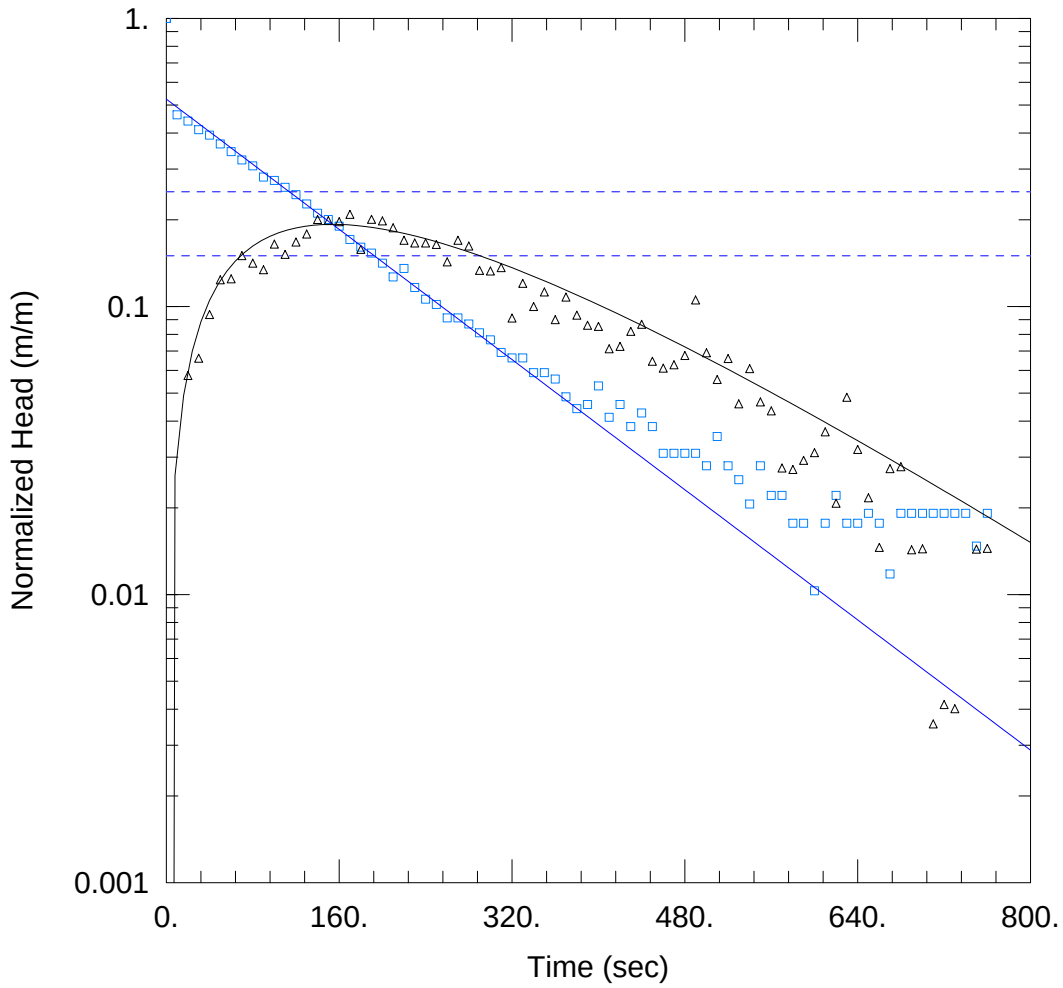
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD05(D) Slug out)

Initial Displacement: 0.794 m
Total Well Penetration Depth: 22.58 m
Casing Radius: 0.025 m
Static Water Column Height: 23.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.3145 m/day
y0 = 0.6242 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:10:17

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

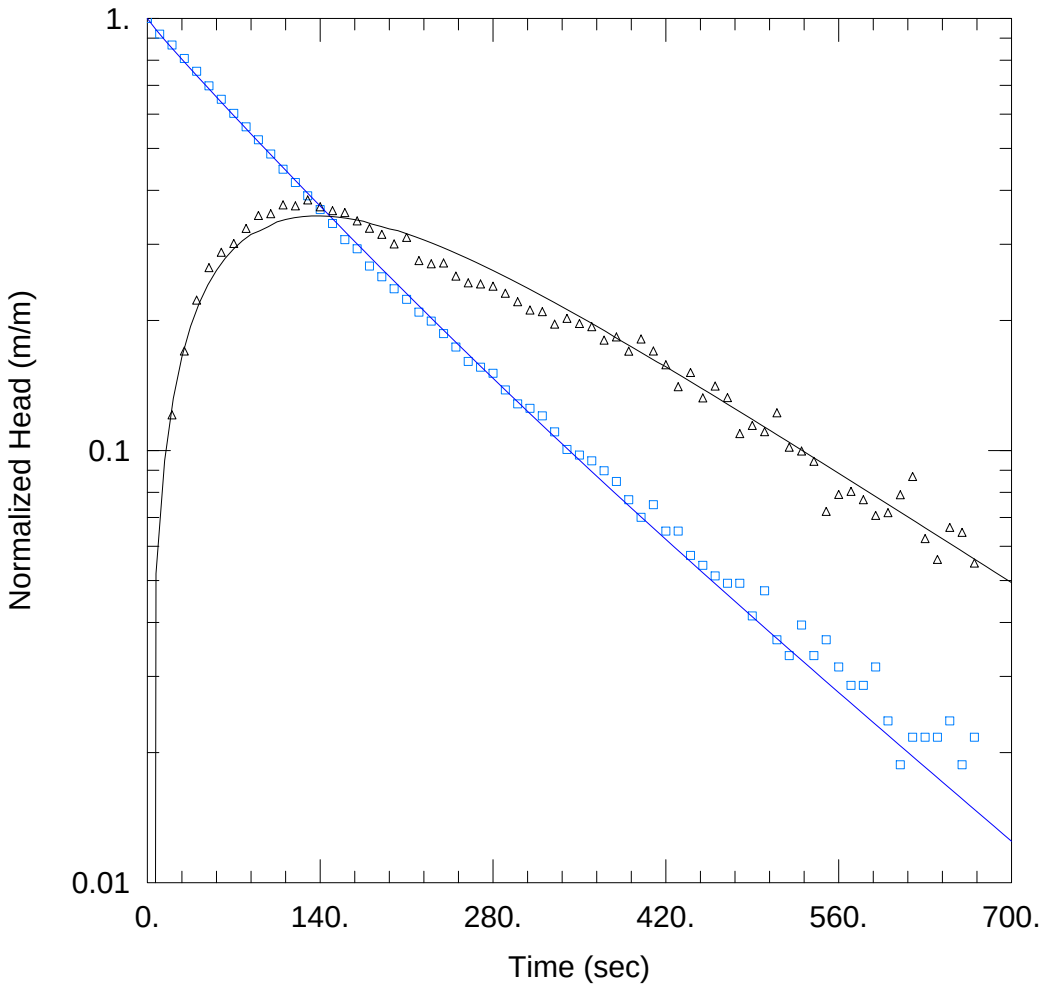
Saturated Thickness: 34.58 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD06(D) slug in)

Initial Displacement: 0.679 m
Total Well Penetration Depth: 32.08 m
Casing Radius: 0.025 m
Static Water Column Height: 34.58 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.22 m/day
y0 = 0.356 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(D)_SlugOut.aqt
Date: 10/22/12 Time: 14:58:08

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 34.58 m

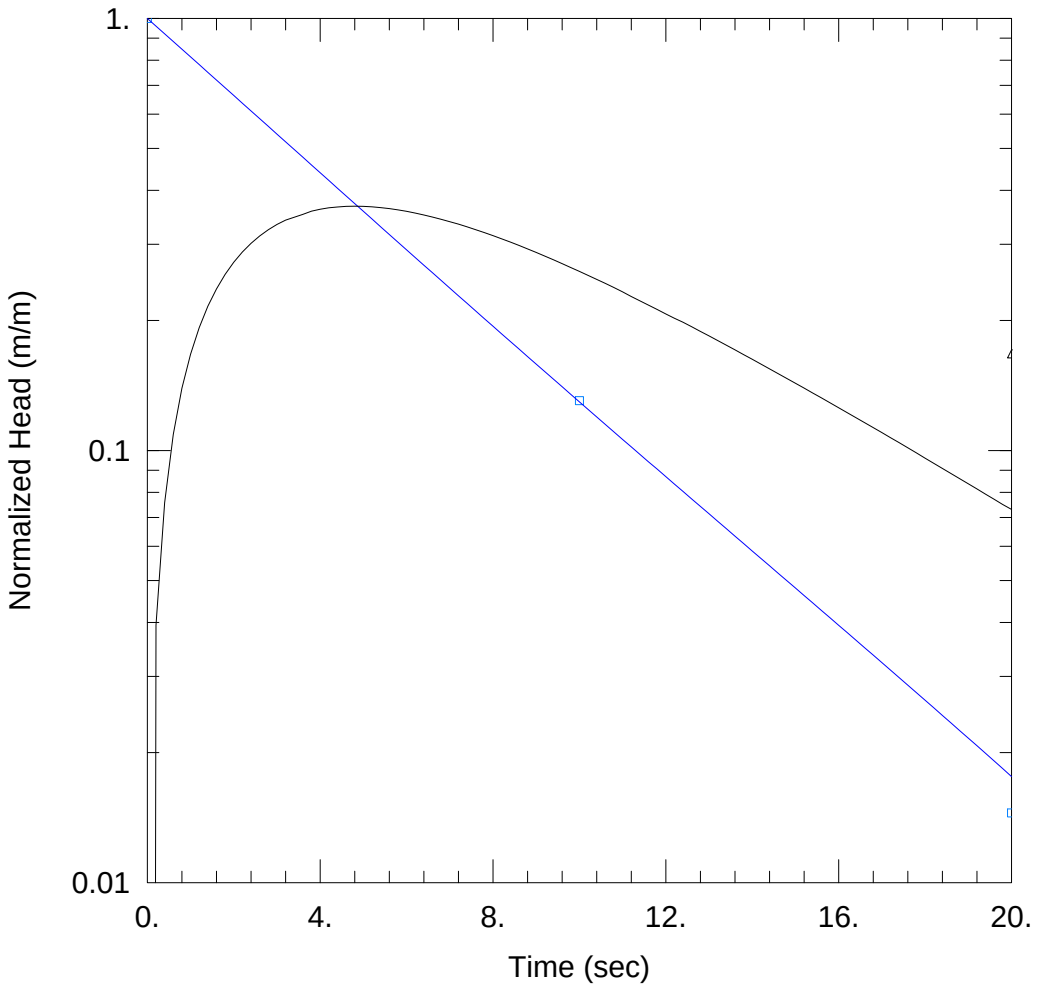
WELL DATA (RAU12HYD06(D) slug out)

Initial Displacement: 1.014 m
Total Well Penetration Depth: 32.08 m
Casing Radius: 0.025 m
Static Water Column Height: 34.58 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.2242 m/day
Kz/Kr = 1.
Ss = 3.493E-6 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(S)_SlugIn1.aqt
Date: 10/22/12 Time: 14:58:13

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 14.46 m

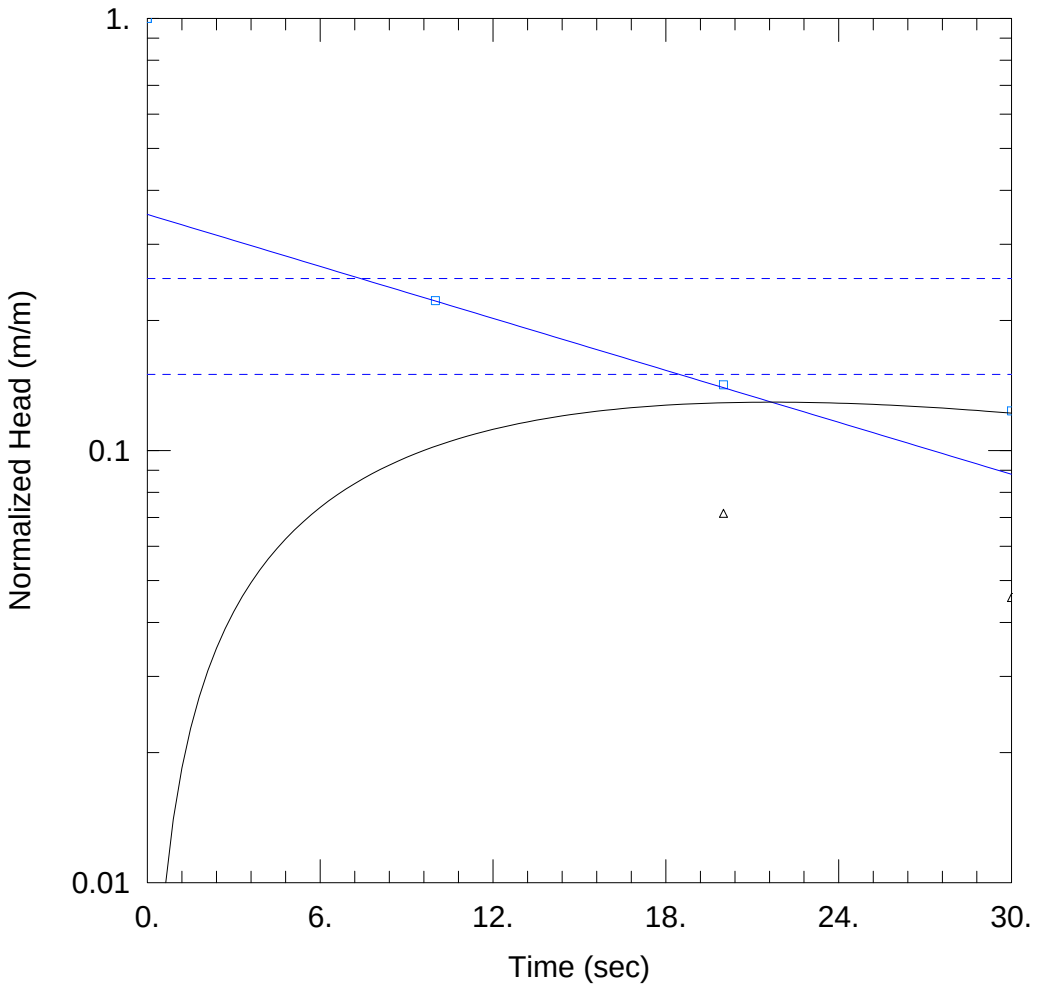
WELL DATA (RAU12HYD06(S) slug in 1)

Initial Displacement: 0.069 m
Total Well Penetration Depth: 10.96 m
Casing Radius: 0.025 m
Static Water Column Height: 14.46 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 6.13 m/day
Kz/Kr = 1.
Ss = 2.445E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(S)_SlugIn2.aqt
Date: 10/22/12 Time: 14:58:18

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

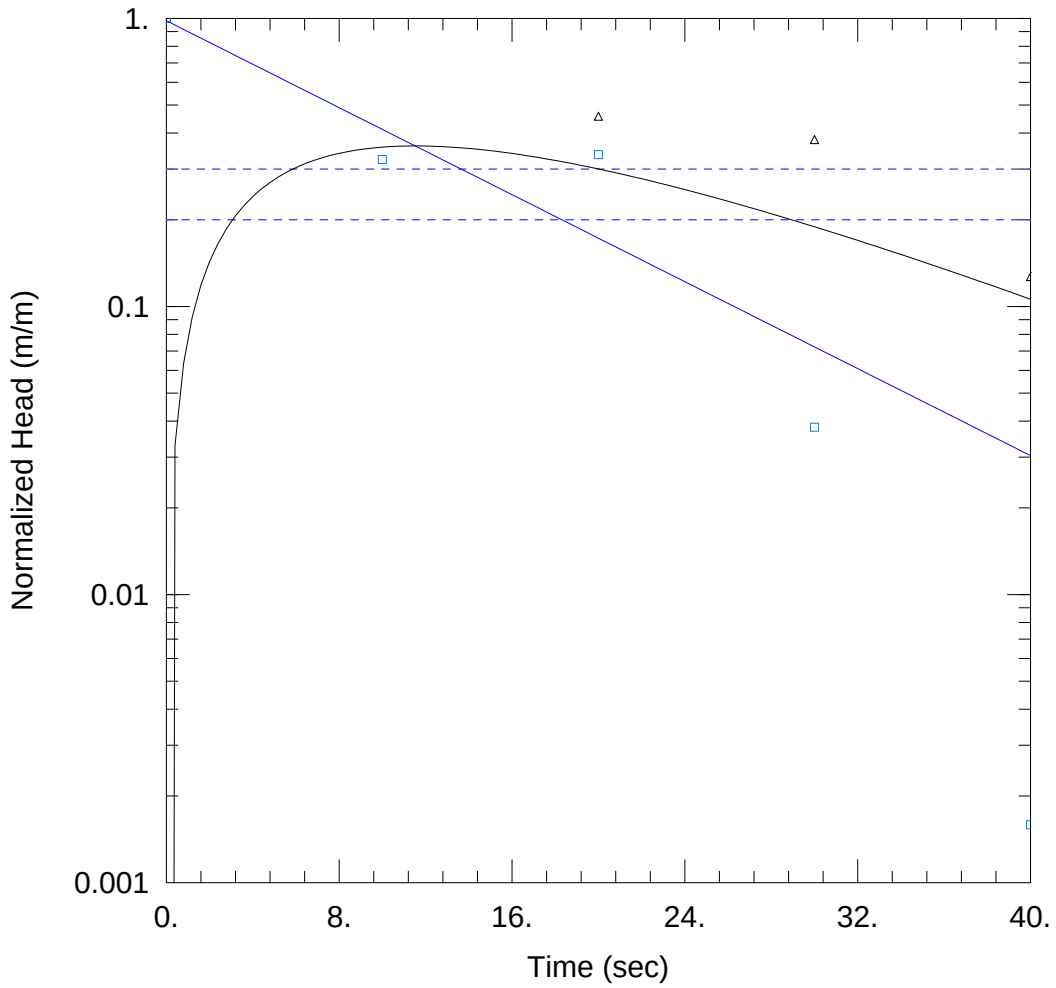
Saturated Thickness: 14.46 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD06(S) slug in 2)

Initial Displacement: 0.162 m
Total Well Penetration Depth: 10.96 m
Casing Radius: 0.025 m
Static Water Column Height: 14.46 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.486 m/day
y0 = 0.057 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(S)_SlugOut1.aqt
Date: 10/22/12 Time: 14:58:22

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

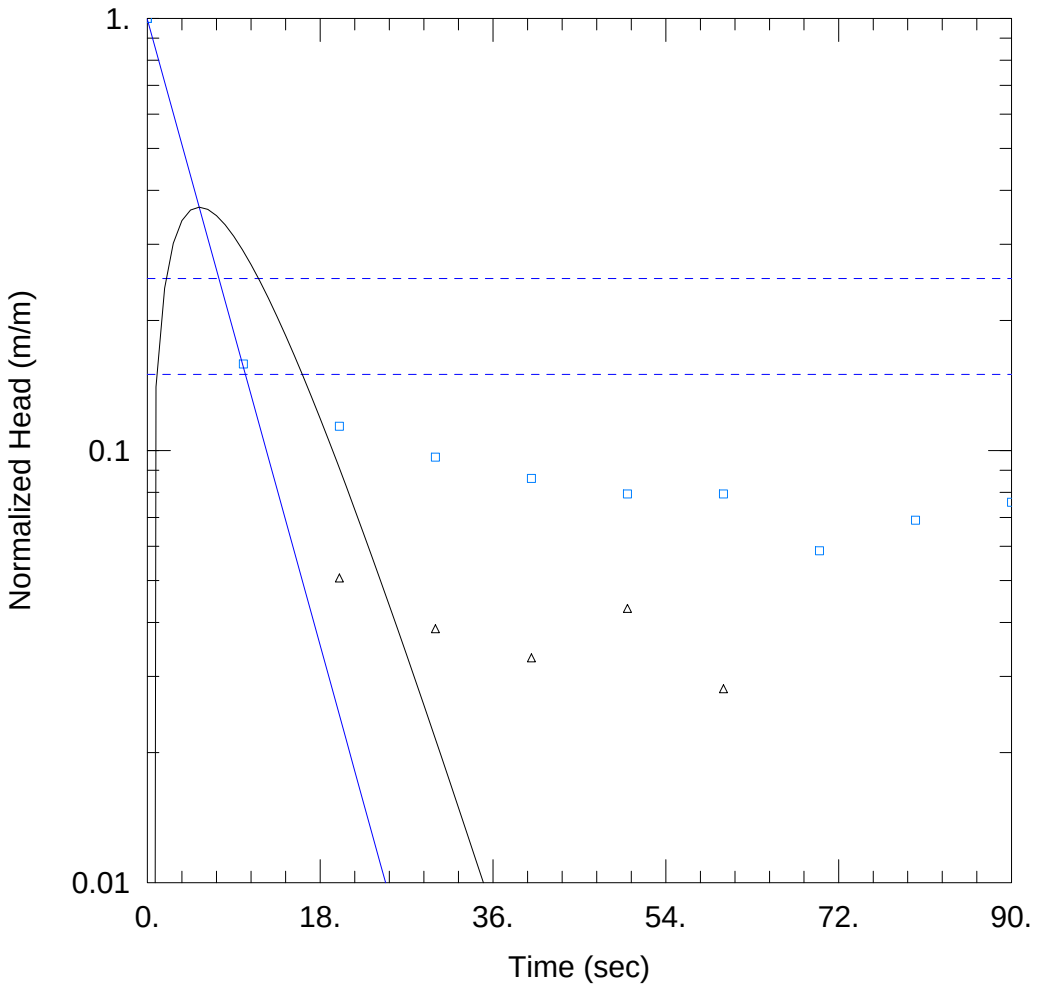
Saturated Thickness: 14.46 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD06(S) slug out 1)

Initial Displacement: 0.63 m
Total Well Penetration Depth: 10.96 m
Casing Radius: 0.025 m
Static Water Column Height: 14.46 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.274 m/day
y0 = 0.6182 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD06(S)_SlugOut2.aqt
Date: 10/22/12 Time: 14:59:02

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

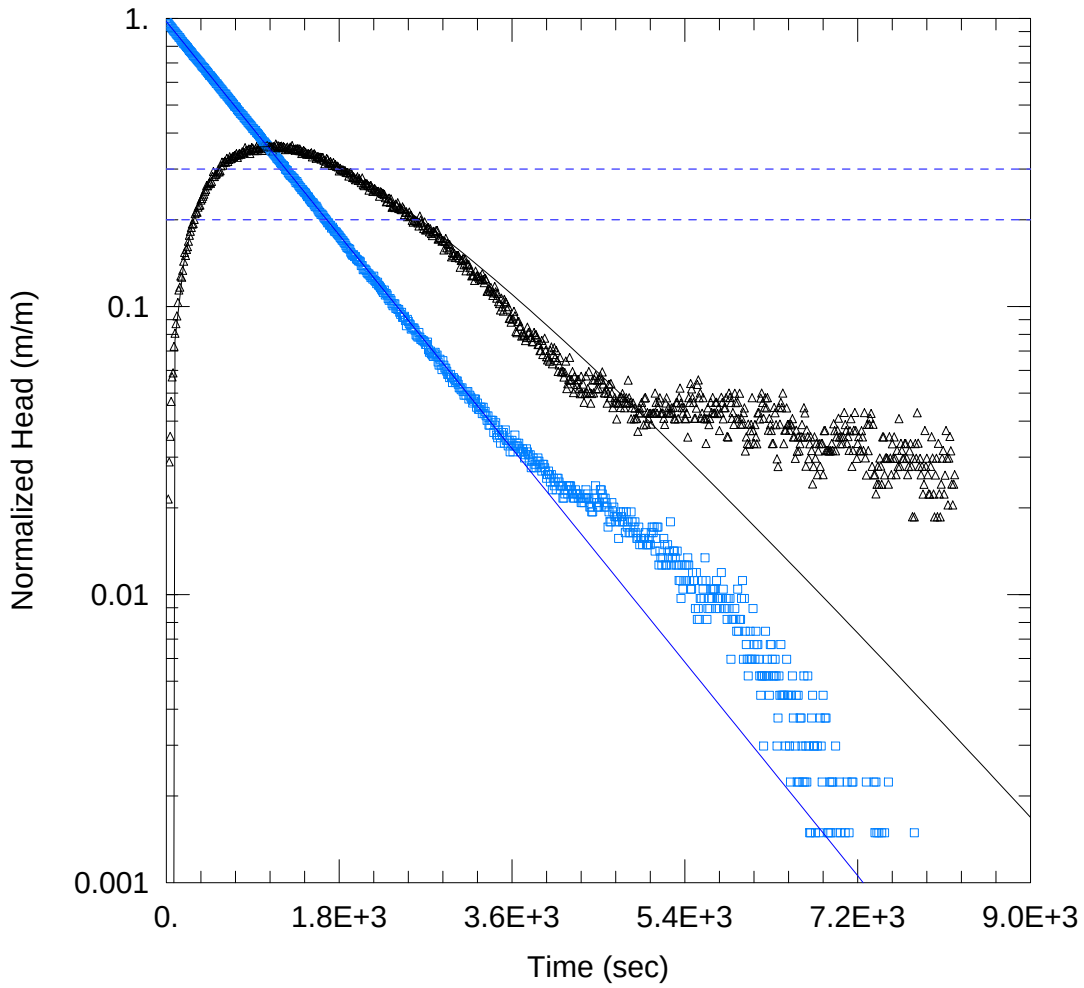
Saturated Thickness: 14.46 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD06(S) slug out 2)

Initial Displacement: 0.29 m
Total Well Penetration Depth: 10.96 m
Casing Radius: 0.025 m
Static Water Column Height: 14.46 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 5.965 m/day
y0 = 0.2885 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD07(D)_FHT.aqt
Date: 10/22/12 Time: 14:59:07

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

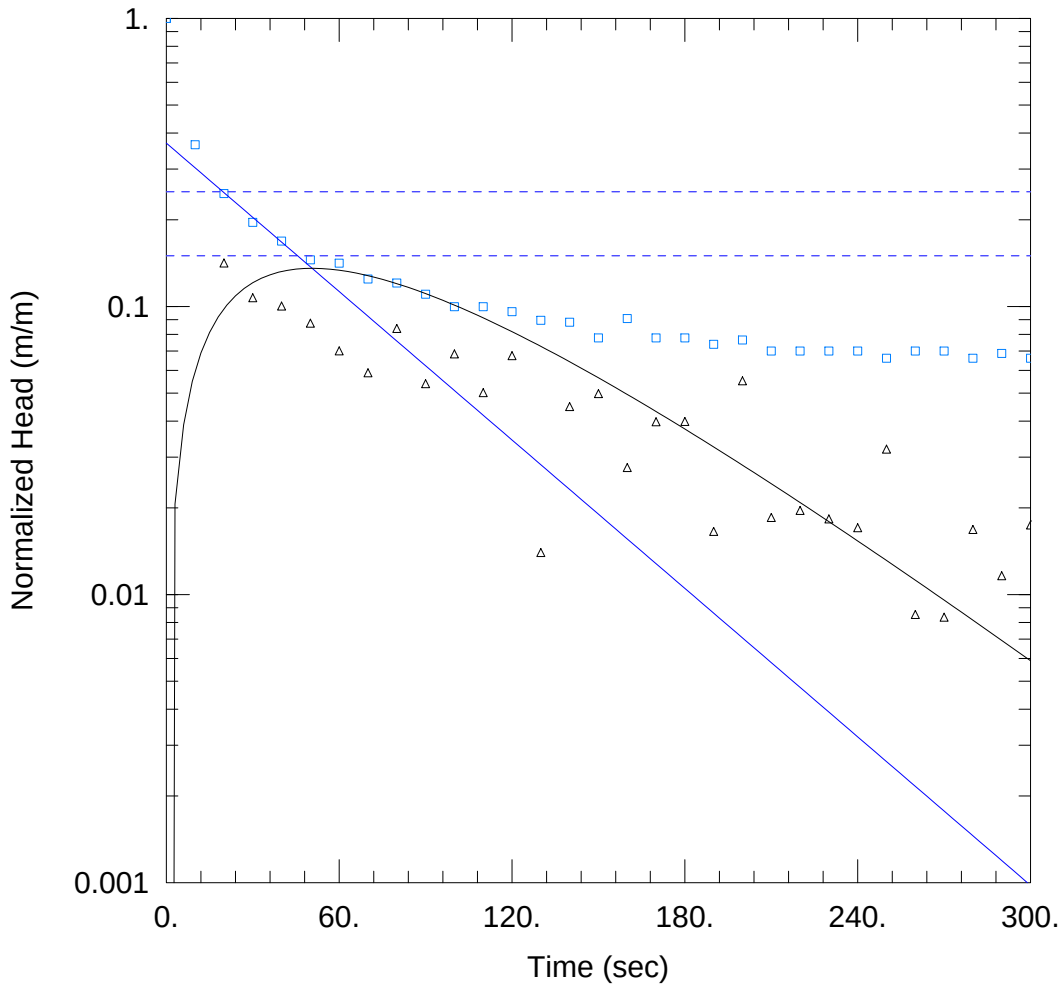
Saturated Thickness: 37.19 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD07(D) FHT)

Initial Displacement: 1.342 m
Total Well Penetration Depth: 33.69 m
Casing Radius: 0.025 m
Static Water Column Height: 37.19 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.02977 m/day
y0 = 1.31 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD07(S)_FHT.aqt
Date: 10/22/12 Time: 14:59:11

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

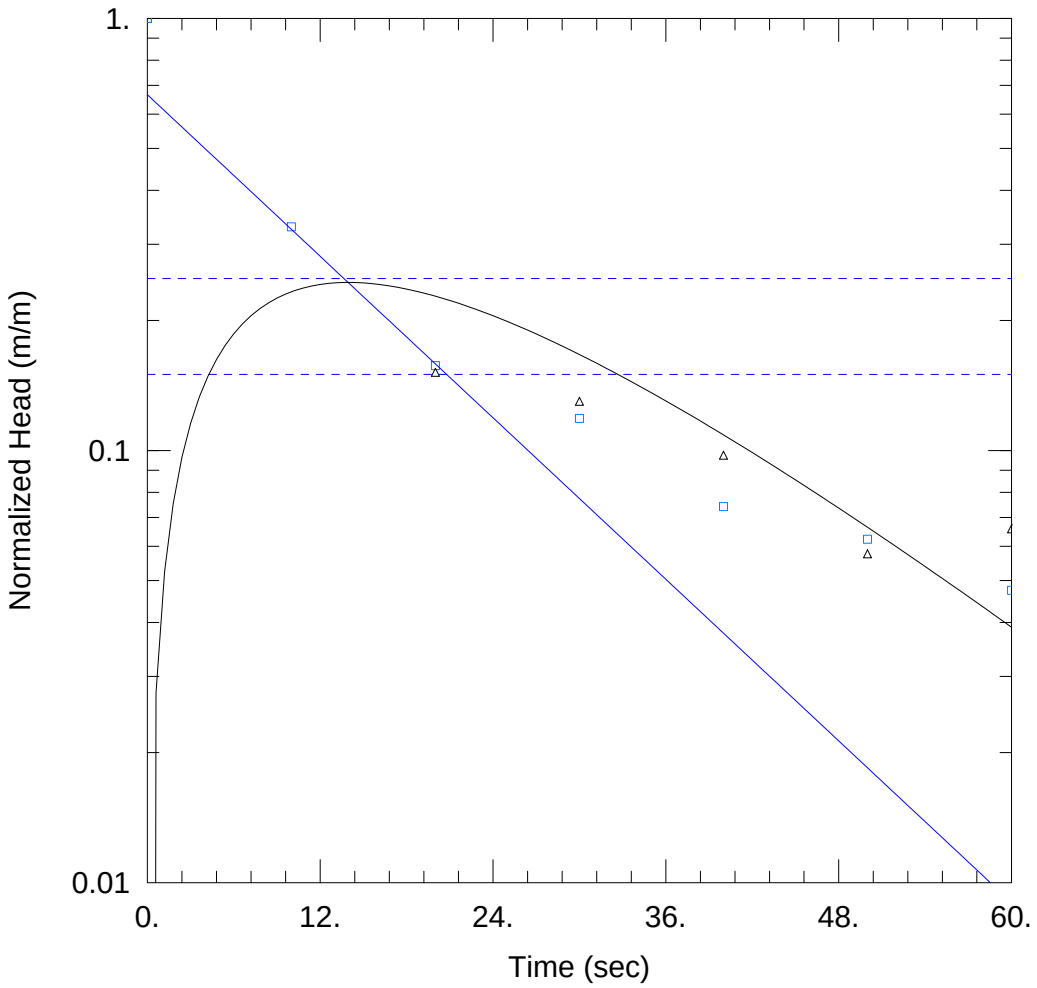
Saturated Thickness: 14.05 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD07(S) FHT)

Initial Displacement: 0.771 m
Total Well Penetration Depth: 11.55 m
Casing Radius: 0.025 m
Static Water Column Height: 14.05 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.6364 m/day
y0 = 0.2845 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD07(S)_SlugIn.aqt
Date: 10/22/12 Time: 14:59:15

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

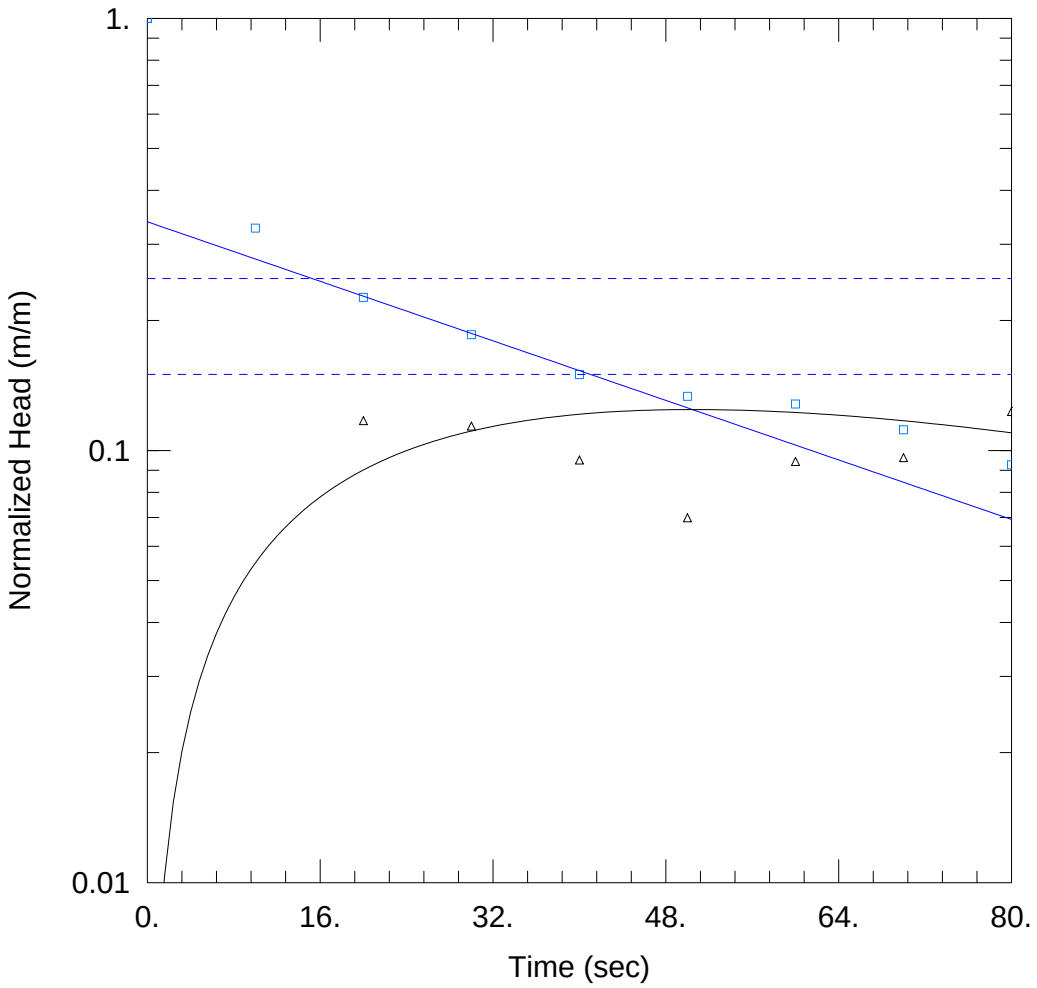
Saturated Thickness: 14.05 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD07(S) slug in)

Initial Displacement: 0.337 m
Total Well Penetration Depth: 11.55 m
Casing Radius: 0.025 m
Static Water Column Height: 14.05 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 2.309 m/day
y0 = 0.2244 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD07(S)_SlugOut.aqt
Date: 10/22/12 Time: 14:59:20

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

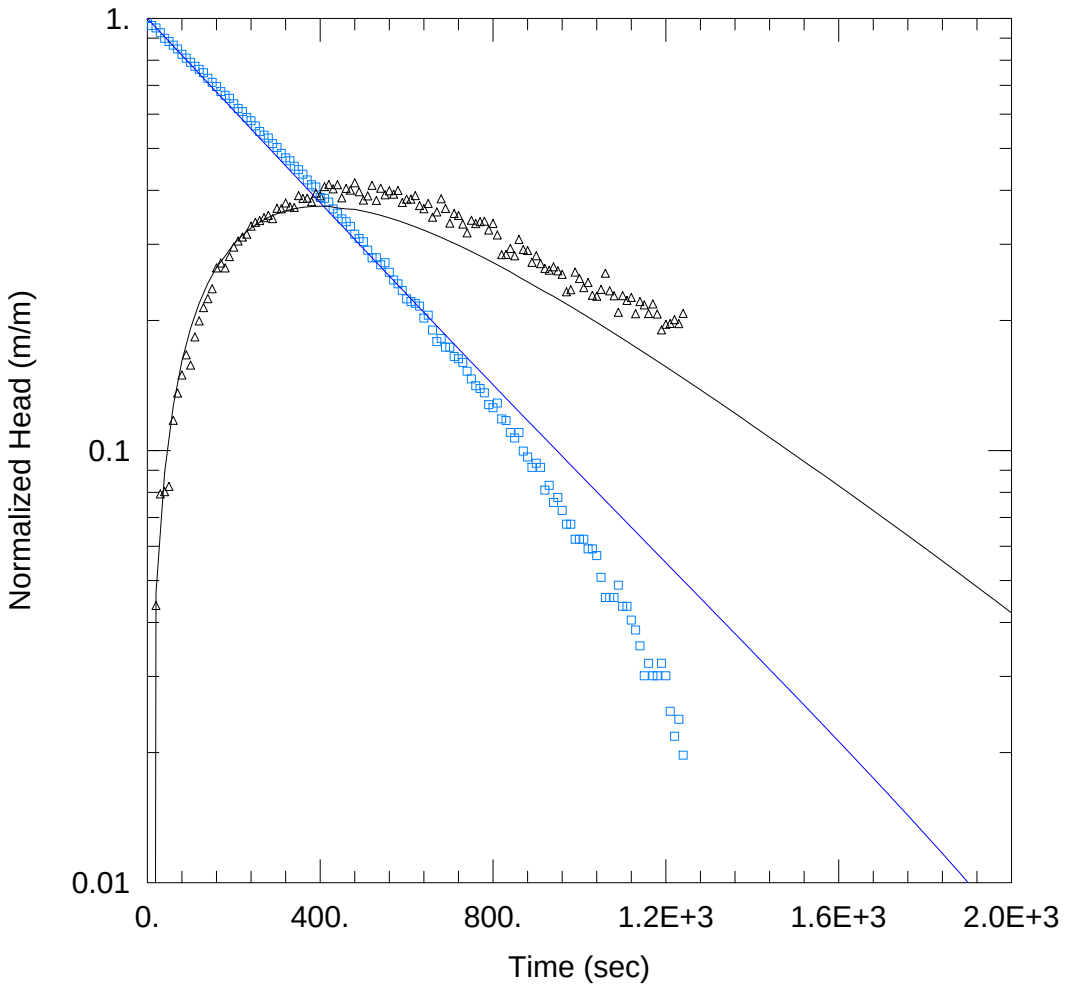
Saturated Thickness: 14.05 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD07(S) slug out)

Initial Displacement: 0.367 m
Total Well Penetration Depth: 11.55 m
Casing Radius: 0.025 m
Static Water Column Height: 14.05 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.6381 m/day
y0 = 0.1241 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD08(D)_SlugIn.aqt
Date: 10/22/12 Time: 14:59:27

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 20. m

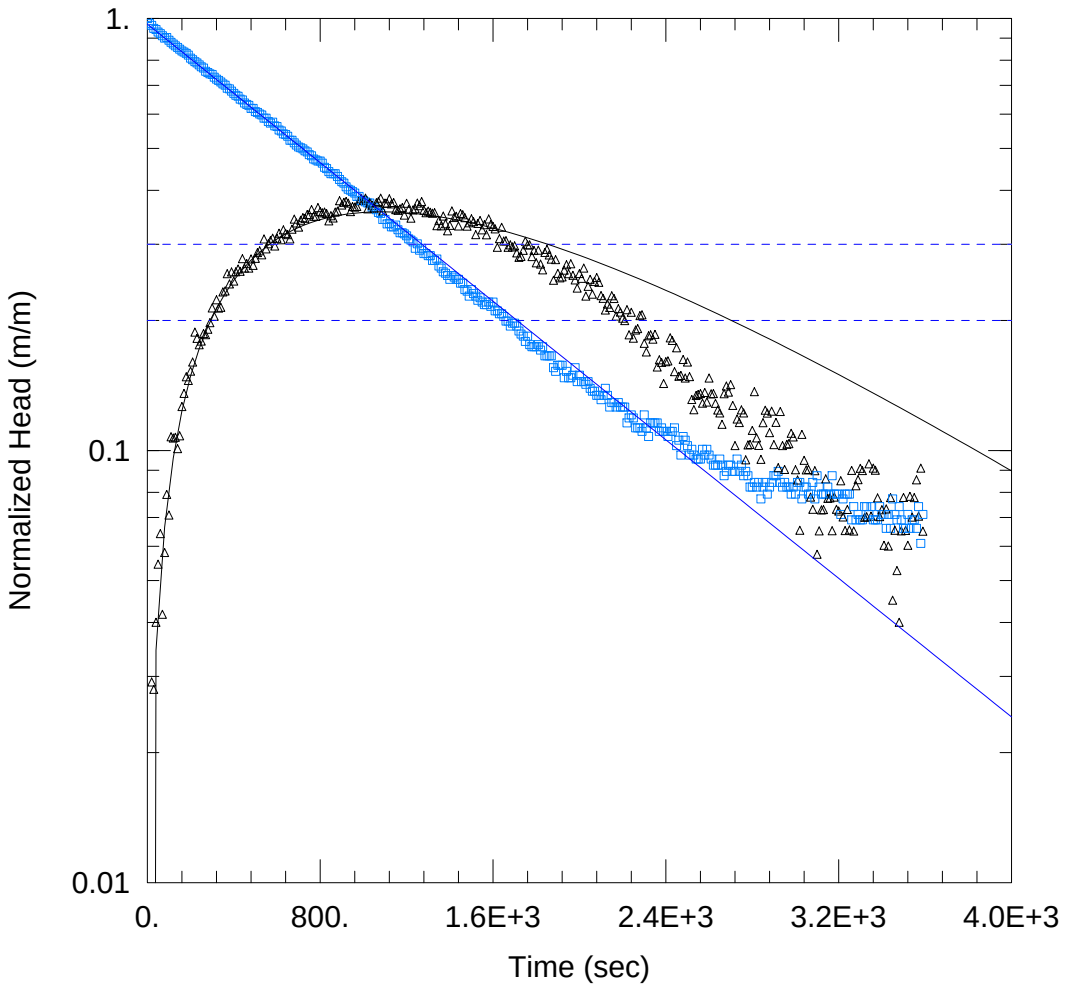
WELL DATA (RAU12HYD08(D) slug in)

Initial Displacement: 0.963 m
Total Well Penetration Depth: 35.88 m
Casing Radius: 0.025 m
Static Water Column Height: 36.38 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.0742 m/day
Kz/Kr = 1.
Ss = 2.06E-16 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD08(D)_SlugOut.aqt
Date: 10/22/12 Time: 14:59:32

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

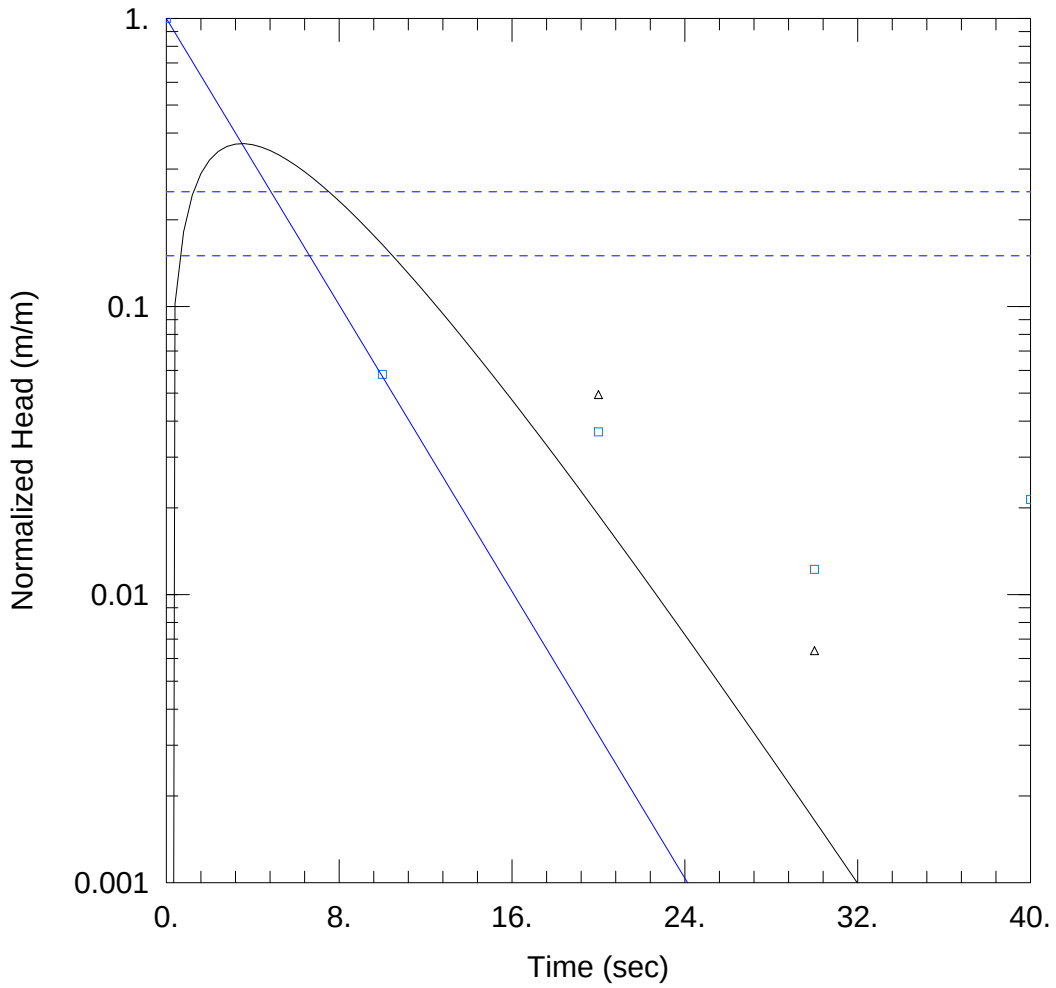
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD08(D) slug out)

Initial Displacement: 0.984 m
Total Well Penetration Depth: 35.88 m
Casing Radius: 0.025 m
Static Water Column Height: 36.38 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.03578 m/day
y0 = 0.9545 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD08(S)_FHT.aqt
Date: 10/22/12 Time: 14:59:36

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

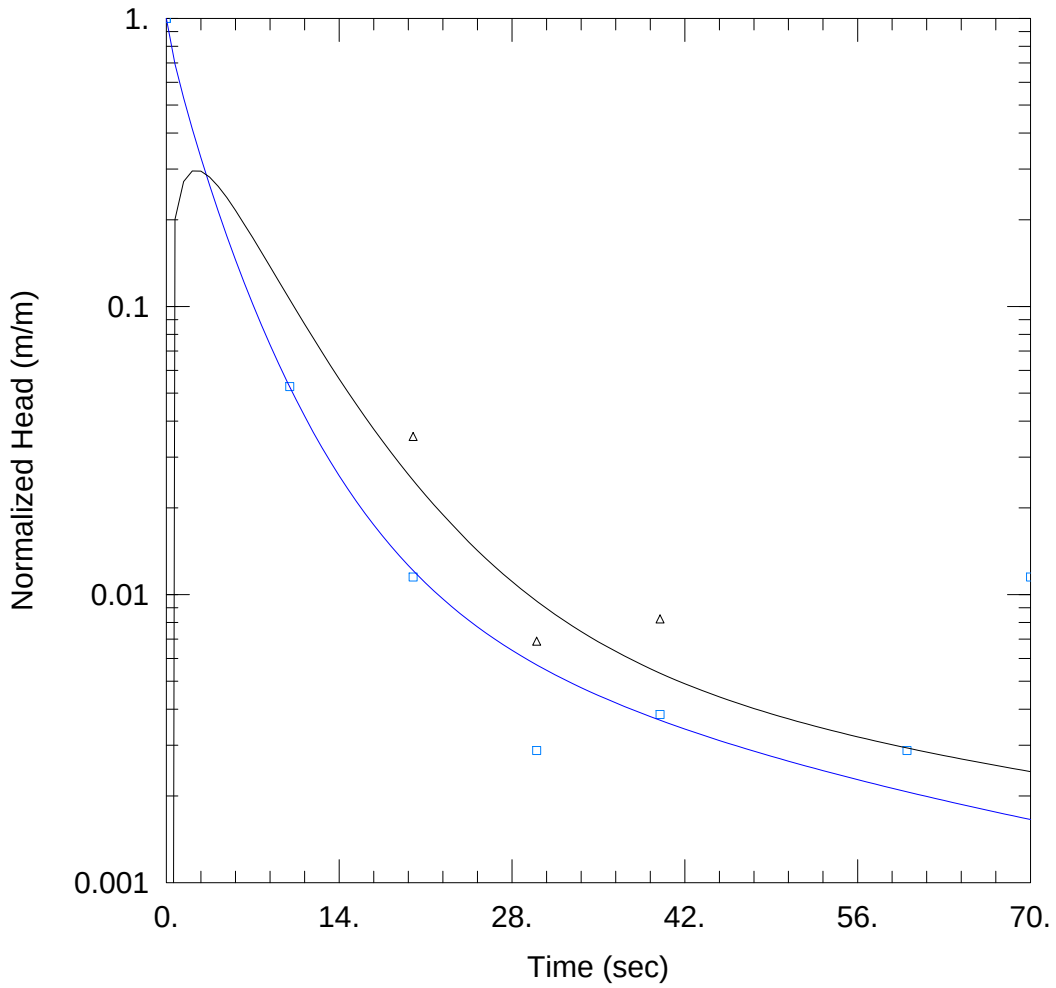
Saturated Thickness: 15.9 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD08(S) FHT)

Initial Displacement: 0.327 m
Total Well Penetration Depth: 13.9 m
Casing Radius: 0.025 m
Static Water Column Height: 15.9 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 9.214 m/day
y0 = 0.327 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD08(S)_SlugIn.aqt
Date: 10/22/12 Time: 14:59:40

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 15.9 m

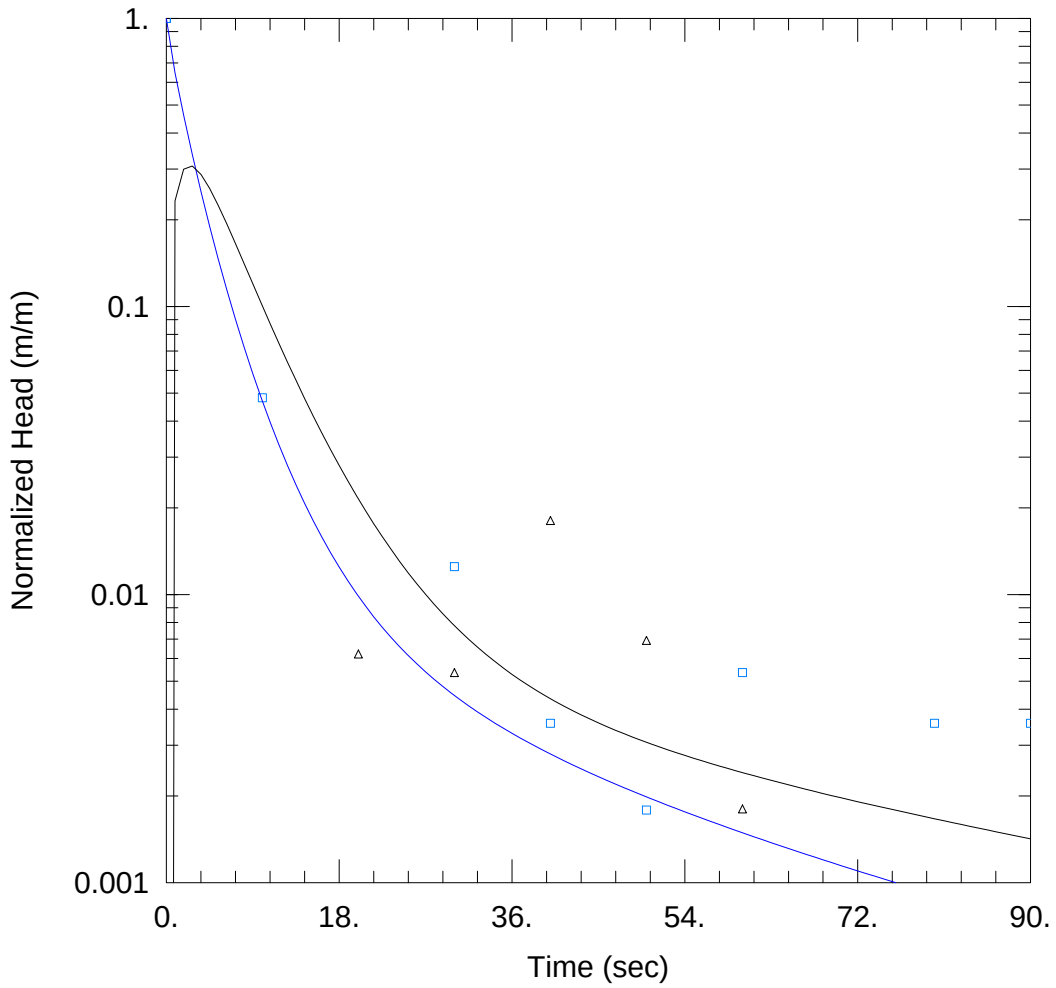
WELL DATA (RAU12HYD08(S) Slug in)

Initial Displacement: 1.043 m
Total Well Penetration Depth: 13.9 m
Casing Radius: 0.025 m
Static Water Column Height: 15.9 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 9.702 m/day
Kz/Kr = 1.
Ss = 0.0001719 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD08(S)_SlugOut.aqt
Date: 10/22/12 Time: 14:59:44

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 15.9 m

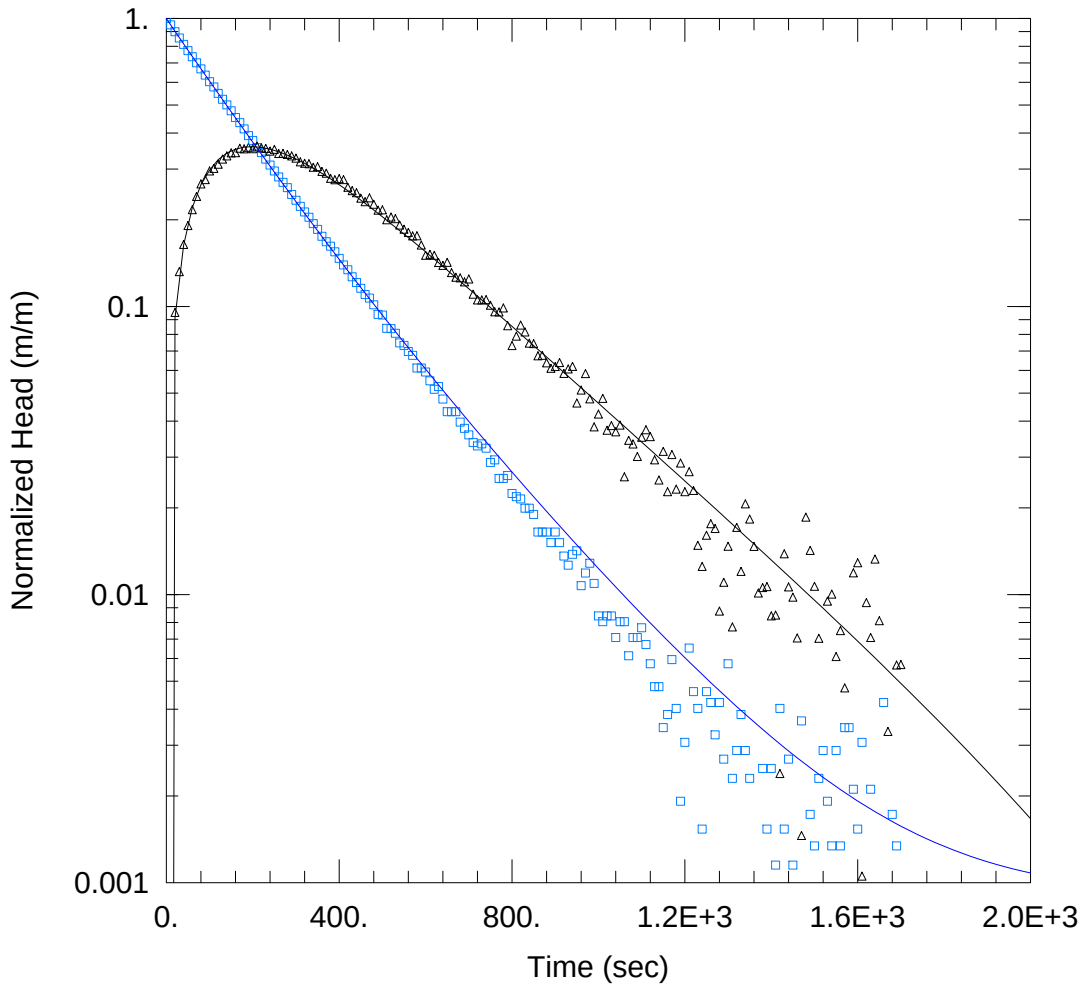
WELL DATA (RAU12HYD08(S) Slug out)

Initial Displacement: 0.56 m
Total Well Penetration Depth: 13.9 m
Casing Radius: 0.025 m
Static Water Column Height: 15.9 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 10.25 m/day
Kz/Kr = 1.
Ss = 0.0001027 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD09(D)_FHT_Con.aqt
Date: 10/22/12 Time: 14:59:48

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 20. m

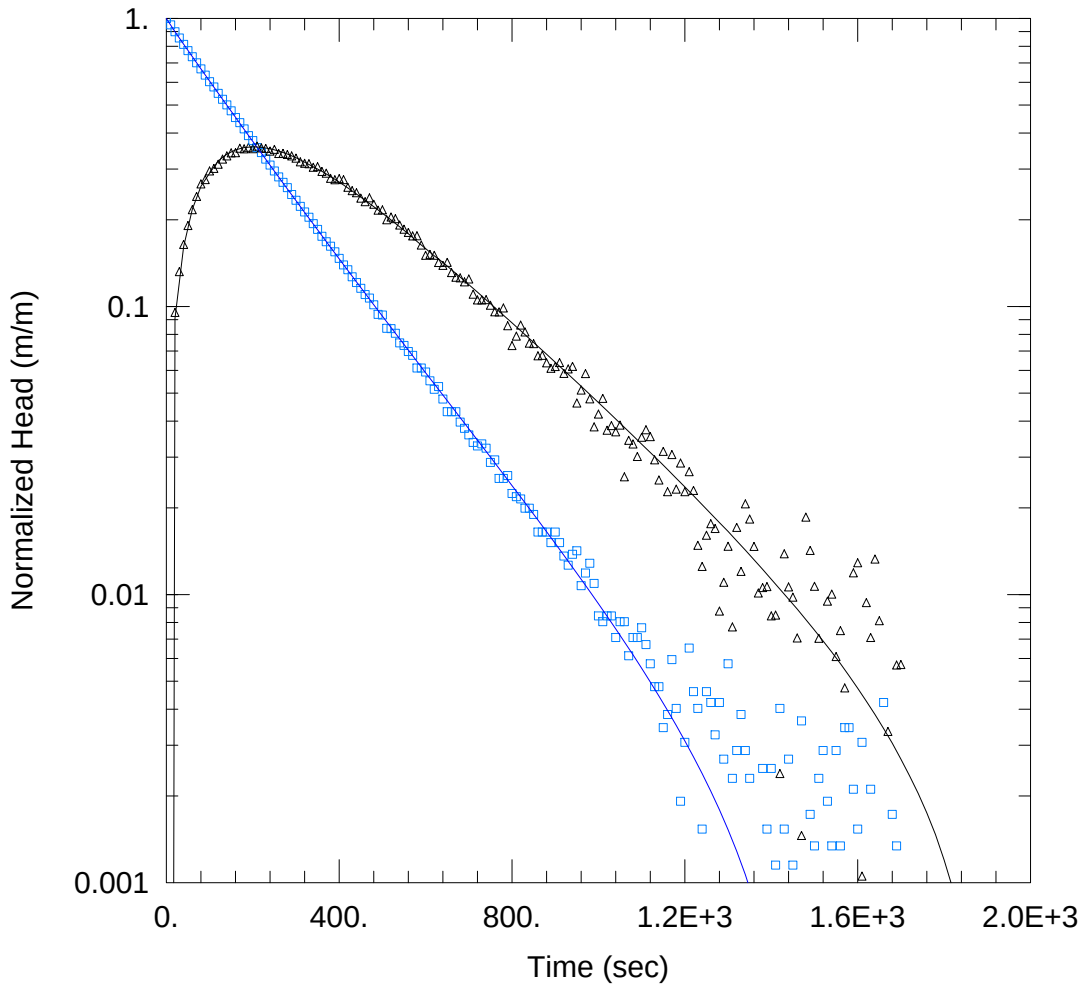
WELL DATA (RAU12HYD09(D) FHT)

Initial Displacement: 5.217 m
Total Well Penetration Depth: 37.63 m
Casing Radius: 0.025 m
Static Water Column Height: 38.13 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.2389 m/day
Kz/Kr = 1.
Ss = 7.94E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD09(D)_FHT_Unc.aqt
Date: 10/22/12 Time: 14:59:52

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 38.13 m

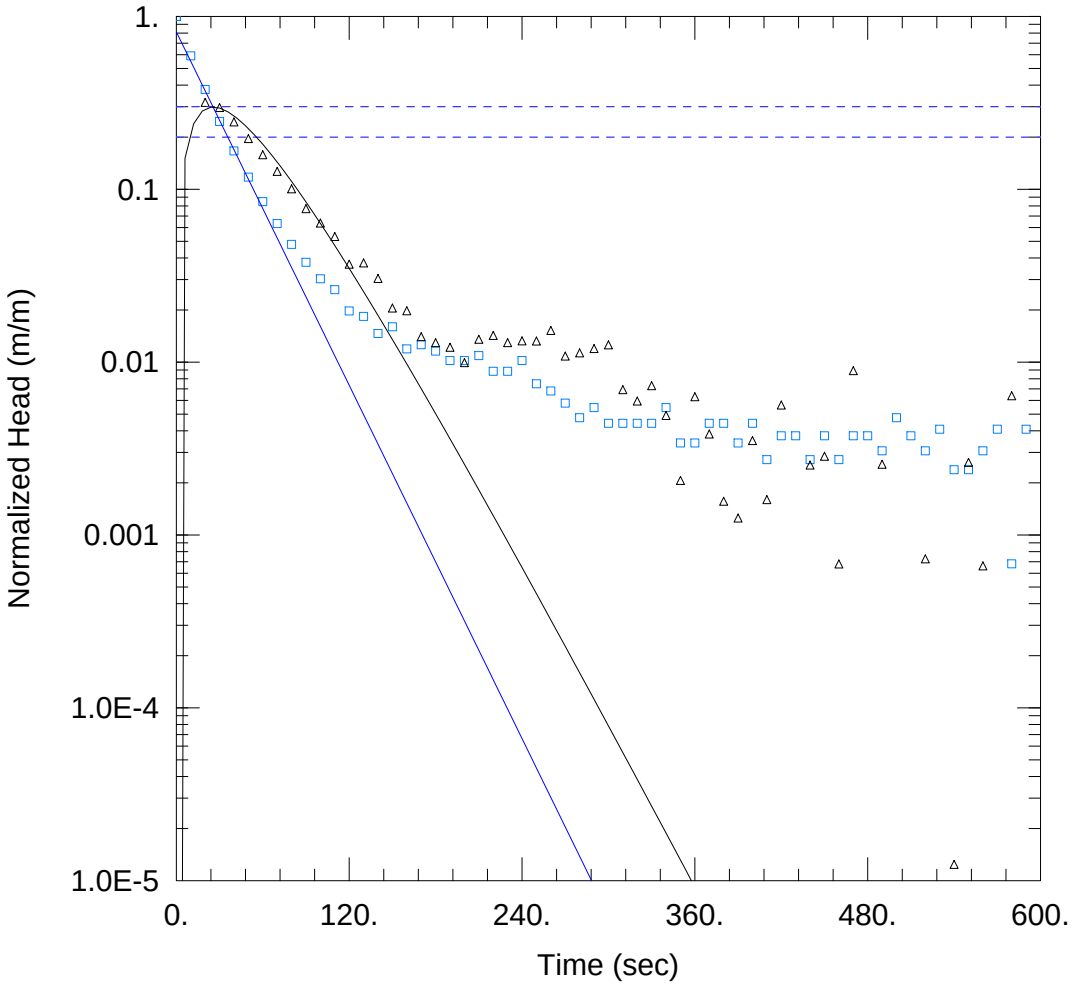
WELL DATA (RAU12HYD09(D) FHT)

Initial Displacement: 5.217 m
Total Well Penetration Depth: 37.63 m
Casing Radius: 0.025 m
Static Water Column Height: 38.13 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.1685 m/day
Kz/Kr = 1.
Ss = 7.73E-7 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD09(S)_FHT.aqt
Date: 10/22/12 Time: 14:59:56

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

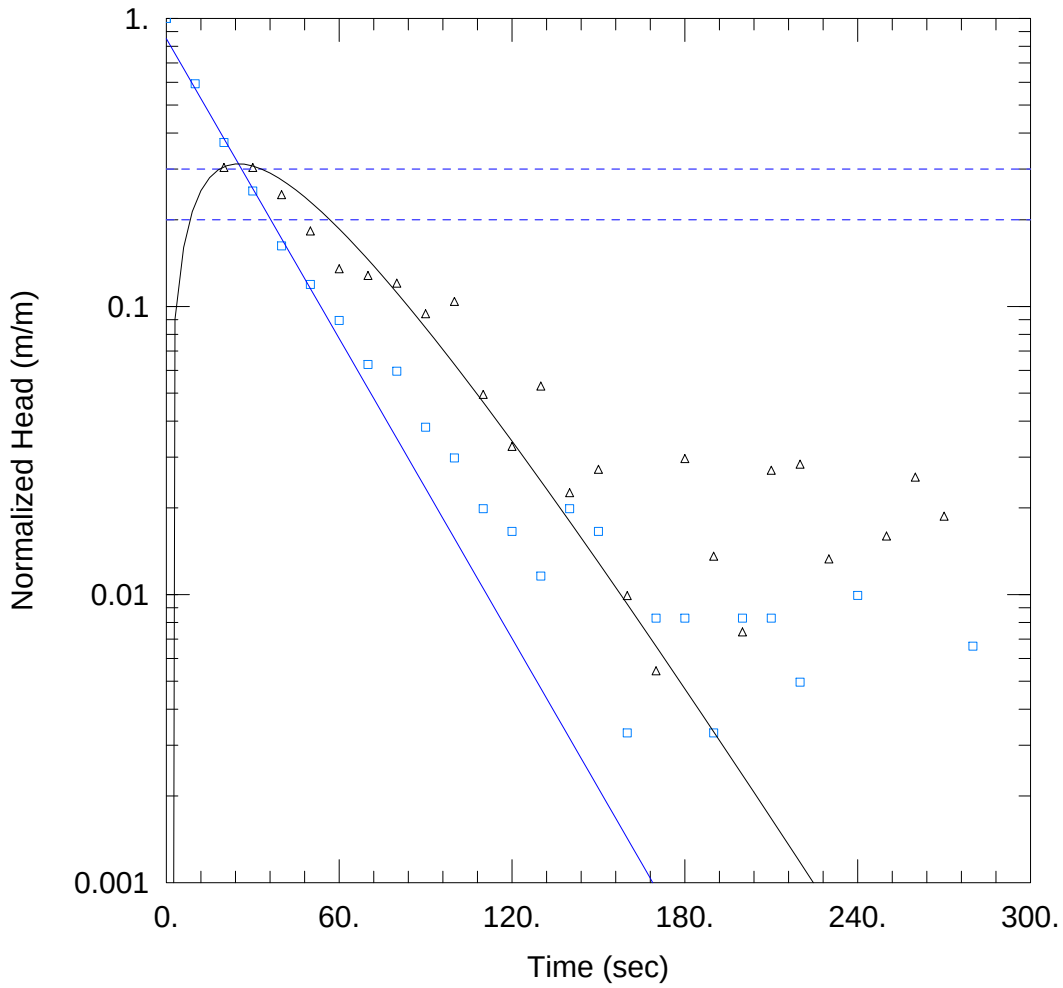
Saturated Thickness: 18. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD09(S) FHT)

Initial Displacement: 2.937 m
Total Well Penetration Depth: 16. m
Casing Radius: 0.025 m
Static Water Column Height: 18. m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.1 m/day
y0 = 2.387 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD09(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:00:01

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

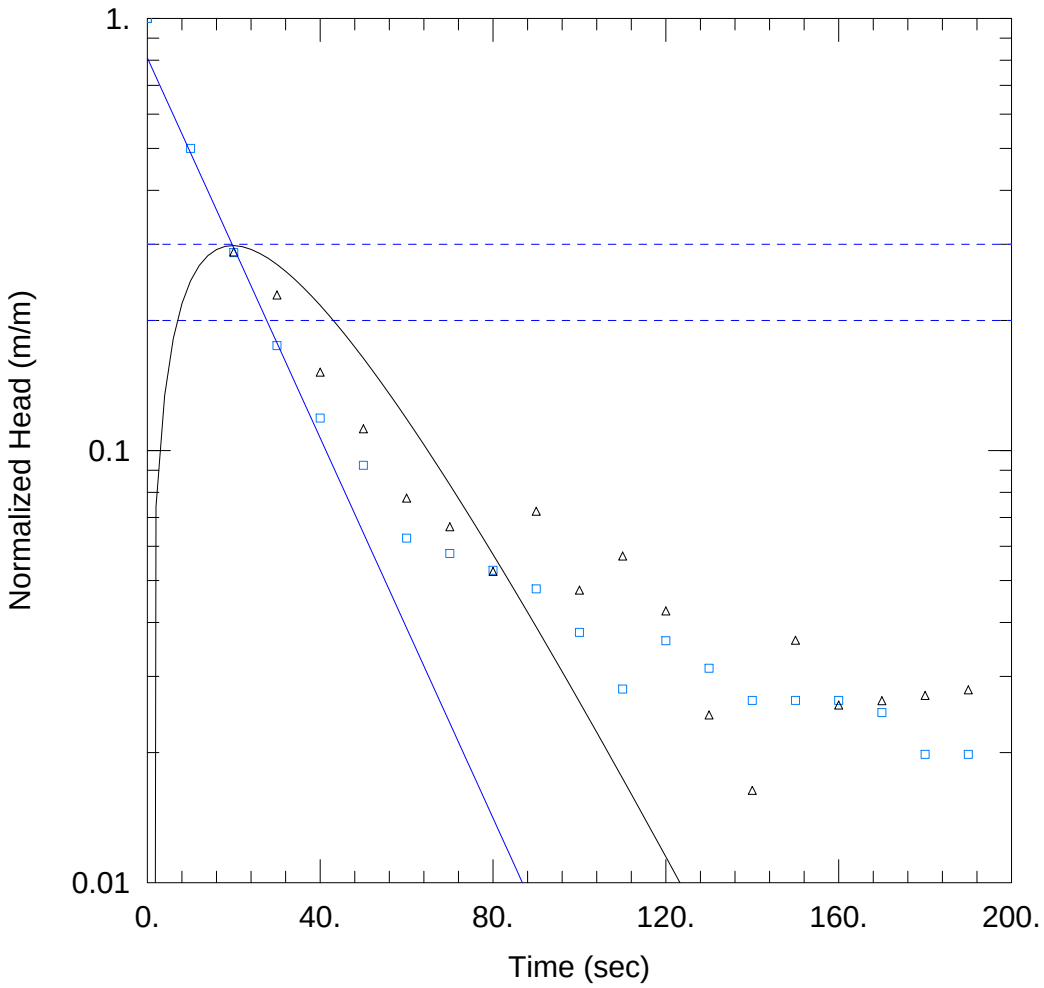
Saturated Thickness: 18. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD09(S) Slug In)

Initial Displacement: 0.604 m
Total Well Penetration Depth: 16. m
Casing Radius: 0.025 m
Static Water Column Height: 18. m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.12 m/day
y0 = 0.5138 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD09(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:00:05

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

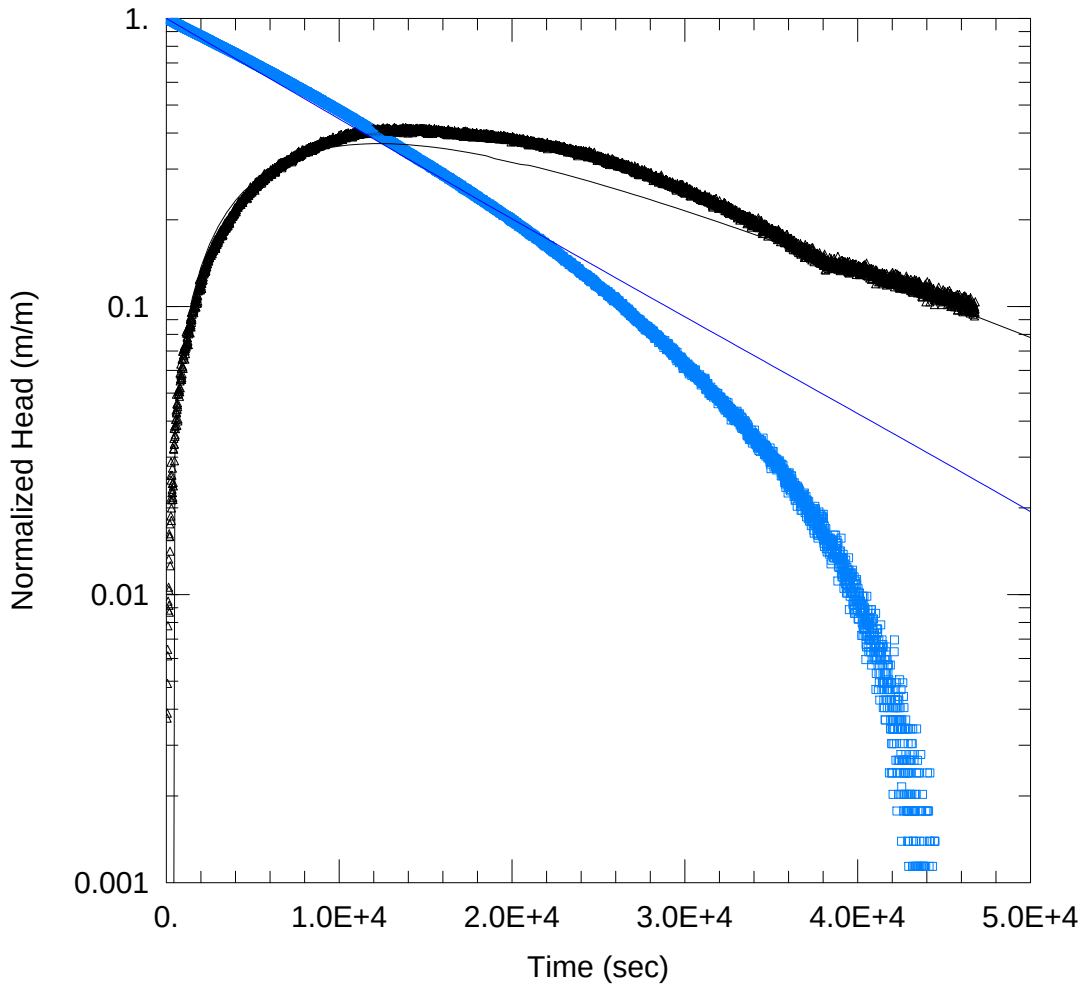
Saturated Thickness: 18. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD09(S) Slug Out)

Initial Displacement: 0.606 m
Total Well Penetration Depth: 16. m
Casing Radius: 0.025 m
Static Water Column Height: 18. m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.42 m/day
y0 = 0.4911 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD10(D)_FHT.aqt
Date: 10/22/12 Time: 15:00:10

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 28.66 m

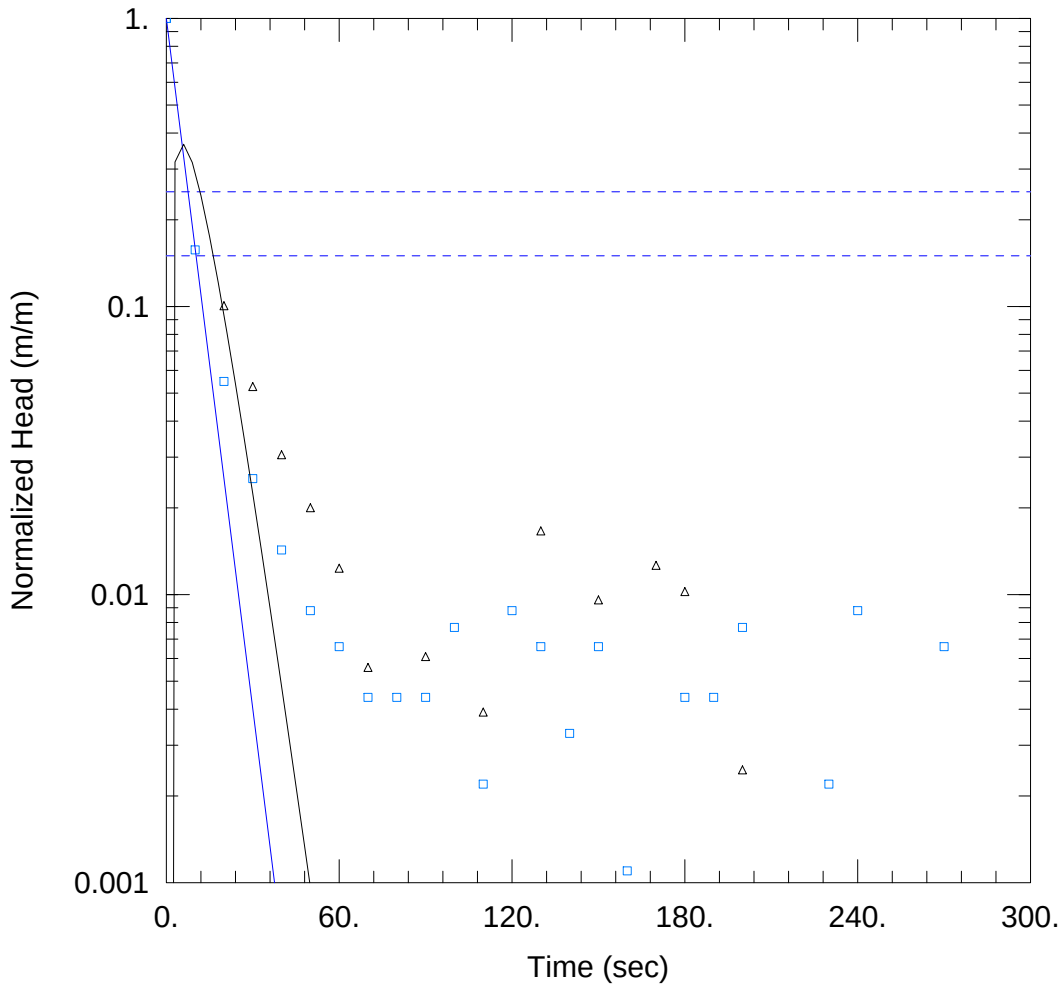
WELL DATA (RAU12HYD10(D) FHT)

Initial Displacement: 7.901 m
Total Well Penetration Depth: 28.16 m
Casing Radius: 0.025 m
Static Water Column Height: 28.66 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.002772 m/day
Kz/Kr = 1.
Ss = 5.541E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD10(S)_FHT.aqt
Date: 10/22/12 Time: 15:00:16

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

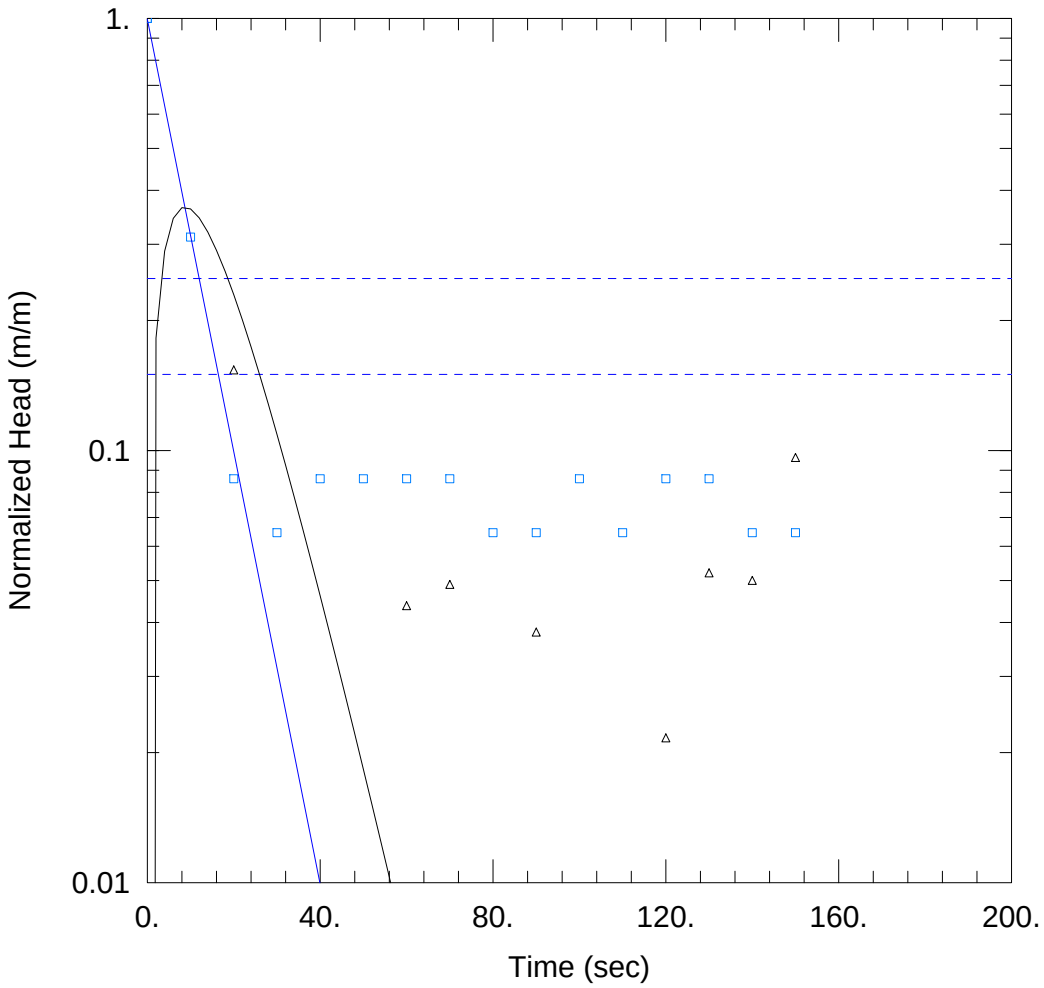
Saturated Thickness: 8.78 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD10(S) FHT)

Initial Displacement: 0.91 m
Total Well Penetration Depth: 6.78 m
Casing Radius: 0.025 m
Static Water Column Height: 8.78 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 5.919 m/day
y0 = 0.9091 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD10(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:00:19

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

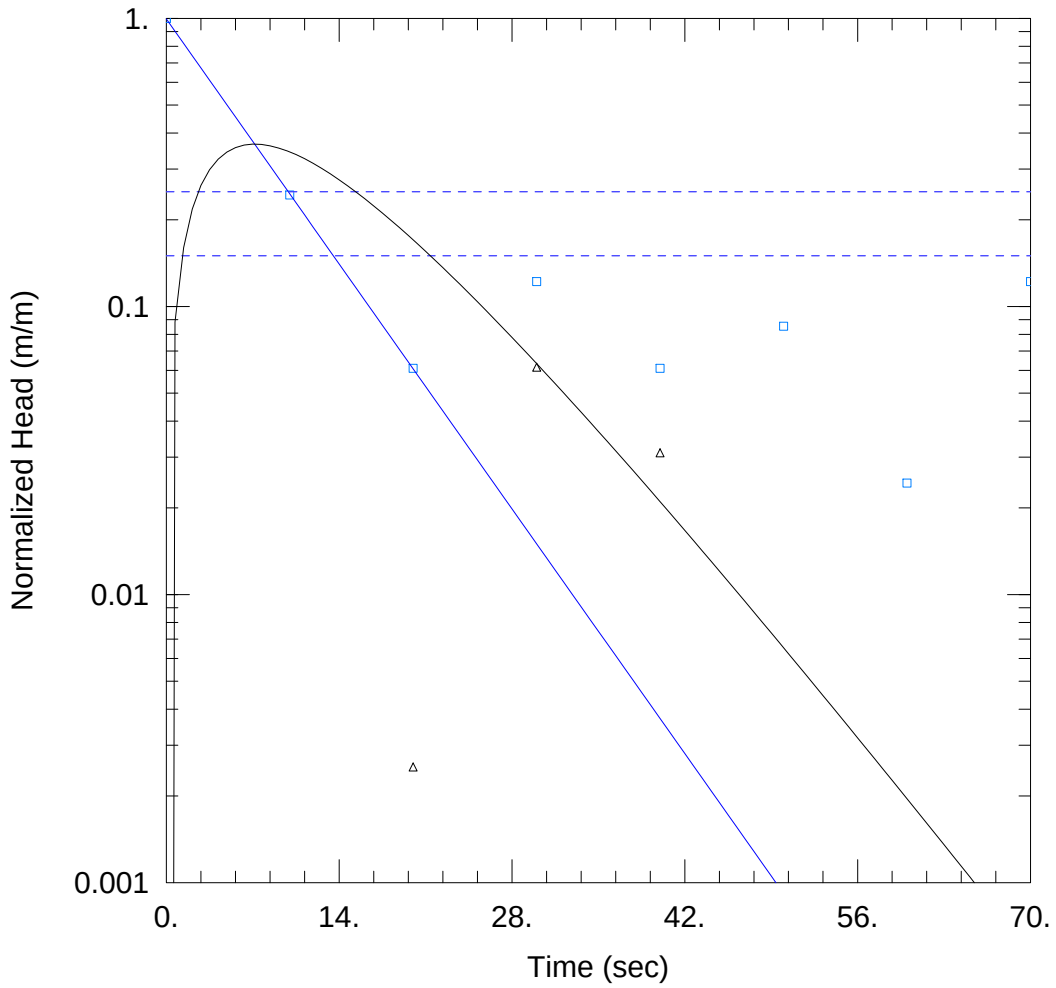
Saturated Thickness: 8.78 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD10(S) Slug in)

Initial Displacement: 0.093 m
Total Well Penetration Depth: 6.78 m
Casing Radius: 0.025 m
Static Water Column Height: 8.78 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 3.709 m/day
y0 = 0.09259 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD10(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:00:23

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

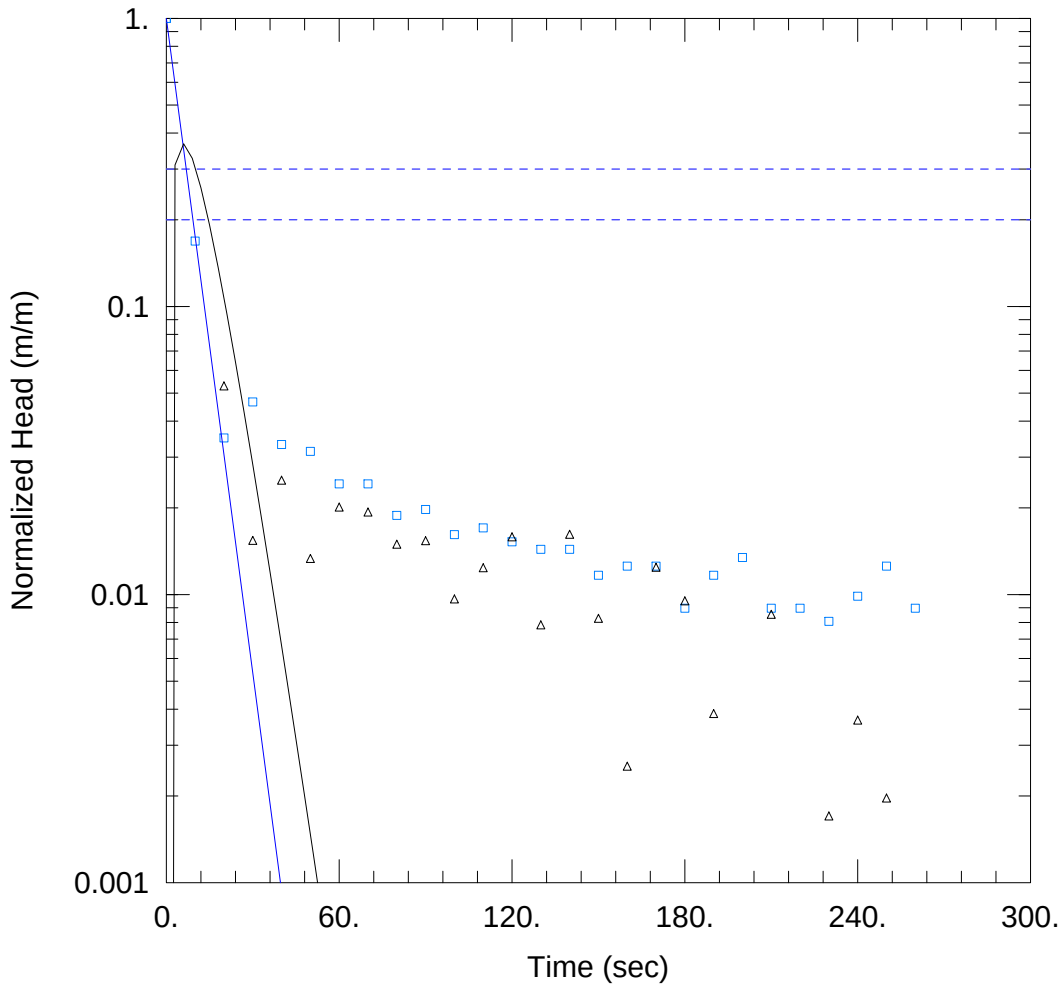
Saturated Thickness: 8.78 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD10(S) Slug out)

Initial Displacement: 0.082 m
Total Well Penetration Depth: 6.78 m
Casing Radius: 0.025 m
Static Water Column Height: 8.78 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 4.5 m/day
y0 = 0.08163 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(D)_FHT1.aqt
Date: 10/22/12 Time: 15:00:29

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

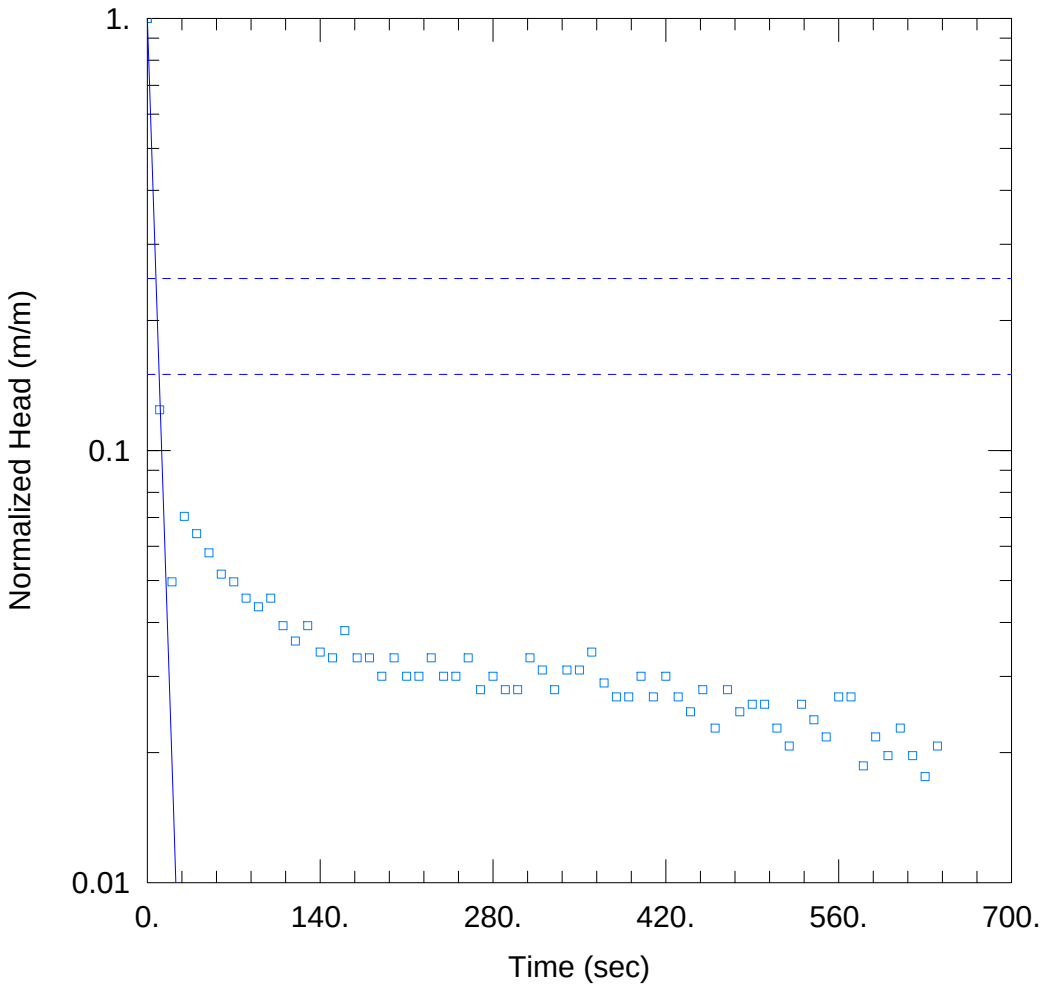
Saturated Thickness: 46.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(D) FHT 1)

Initial Displacement: 1.115 m
Total Well Penetration Depth: 46.02 m
Casing Radius: 0.025 m
Static Water Column Height: 46.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 6.101 m/day
y0 = 1.114 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(D)_FHT2.aqt
Date: 10/22/12 Time: 15:00:33

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

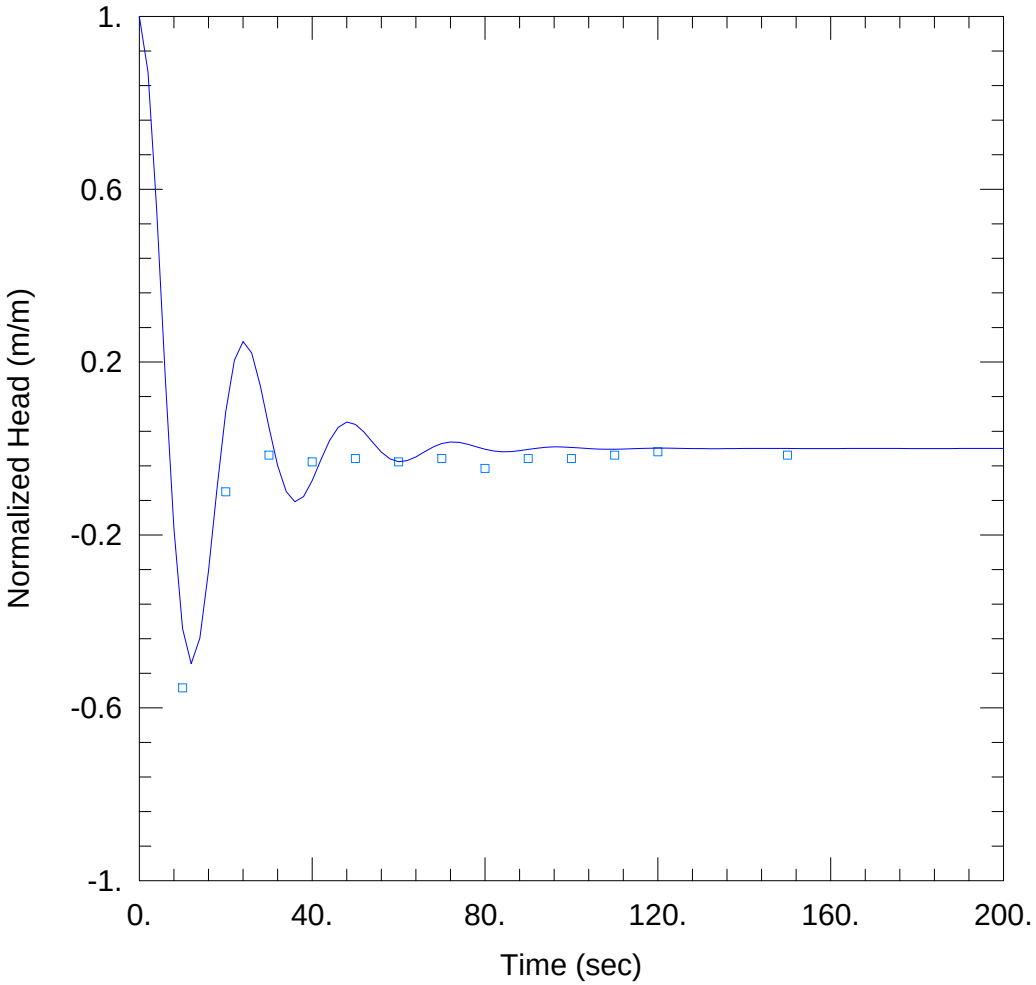
Saturated Thickness: 46.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(D) FHT 2)

Initial Displacement: 0.966 m
Total Well Penetration Depth: 46.02 m
Casing Radius: 0.025 m
Static Water Column Height: 46.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 6.717 m/day
y0 = 0.965 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(D)_Slugin.aqt
Date: 10/22/12 Time: 15:00:37

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

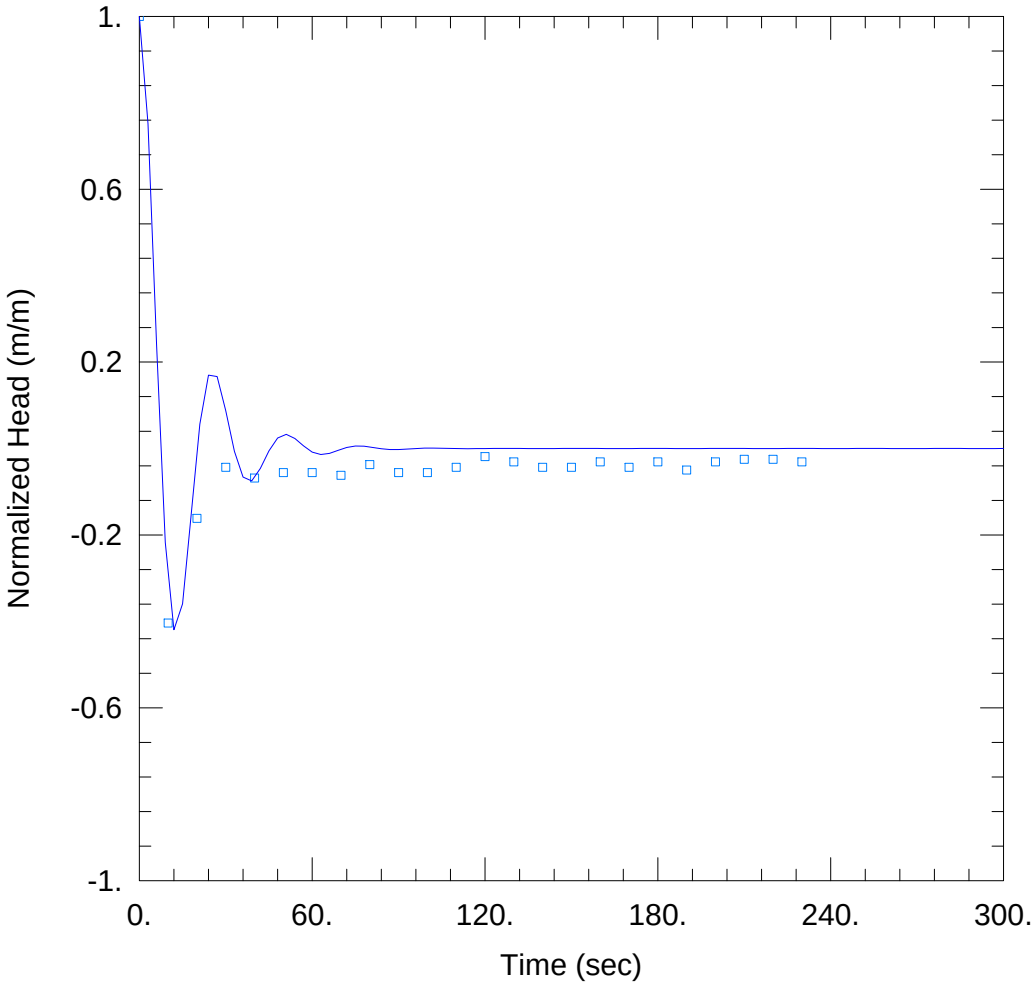
Saturated Thickness: 46.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(D) Slug in)

Initial Displacement: -0.13 m
Total Well Penetration Depth: 46.02 m
Casing Radius: 0.025 m
Static Water Column Height: 46.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 22.45 m/day
Le = 138.3 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:00:41

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

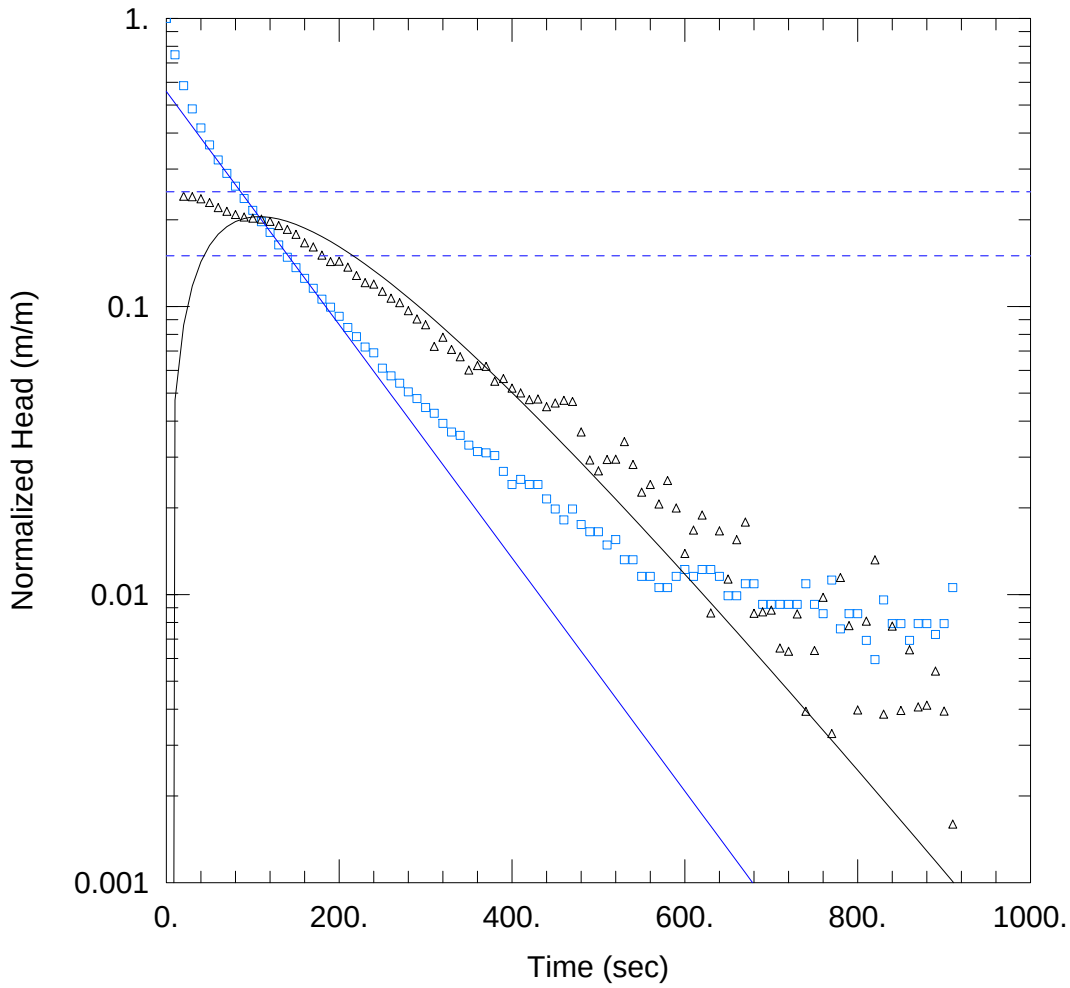
Saturated Thickness: 46.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(D) Slug out)

Initial Displacement: -0.161 m
Total Well Penetration Depth: 46.02 m
Casing Radius: 0.025 m
Static Water Column Height: 46.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 17.73 m/day
Le = 148.7 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(S)_FHT.aqt
Date: 10/22/12 Time: 15:00:44

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

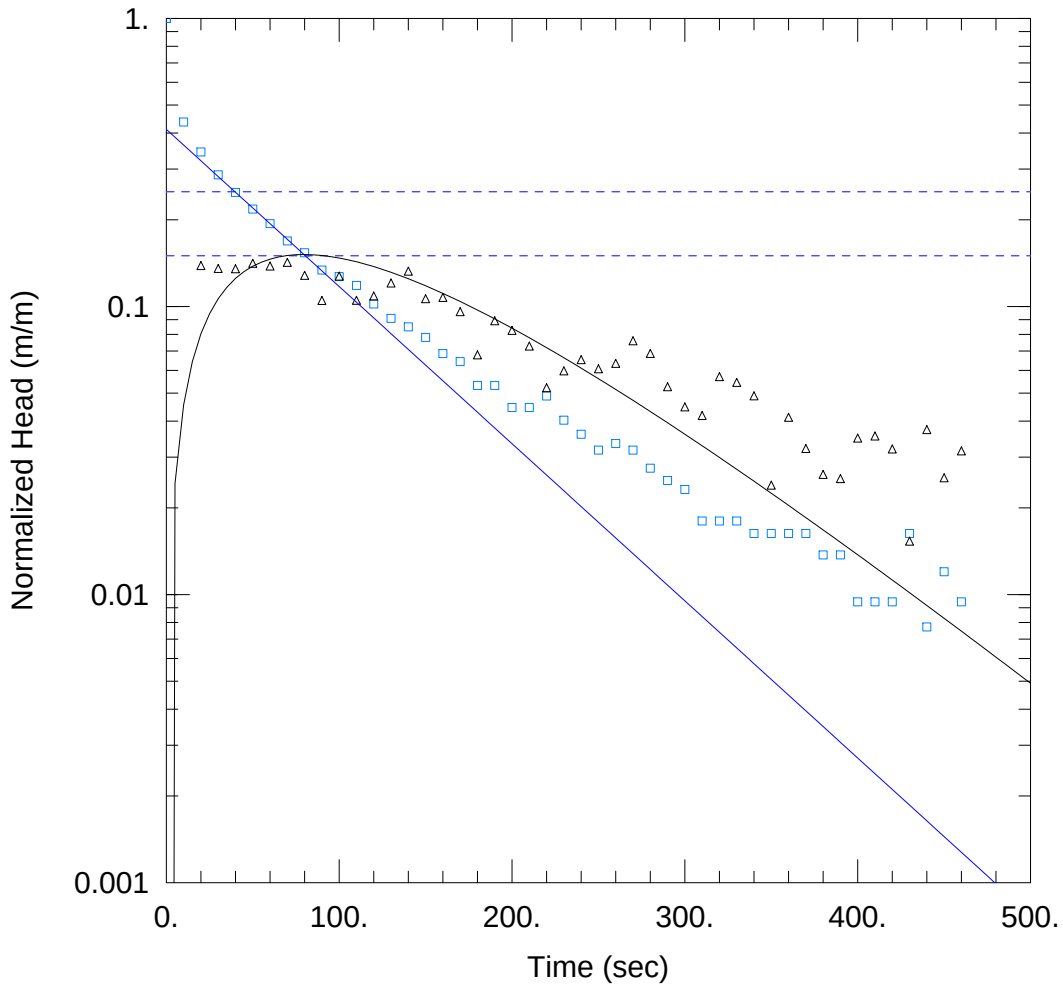
Saturated Thickness: 26.61 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(S) FHT)

Initial Displacement: 3.028 m
Total Well Penetration Depth: 24.61 m
Casing Radius: 0.025 m
Static Water Column Height: 26.61 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.3 m/day
y0 = 1.688 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:00:49

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

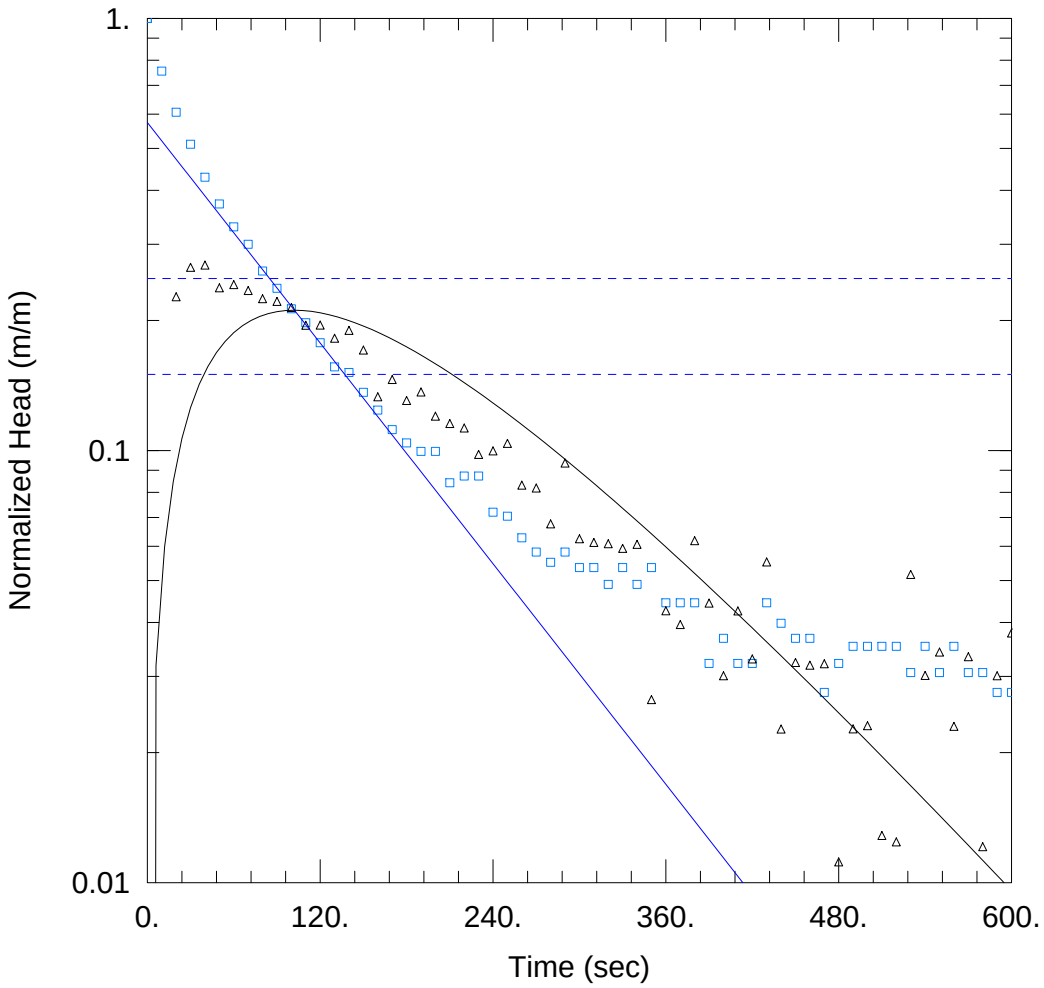
Saturated Thickness: 26.61 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(S) Slug in)

Initial Displacement: 1.166 m
Total Well Penetration Depth: 24.61 m
Casing Radius: 0.025 m
Static Water Column Height: 26.61 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.4043 m/day
y0 = 0.4802 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD11(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:00:54

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

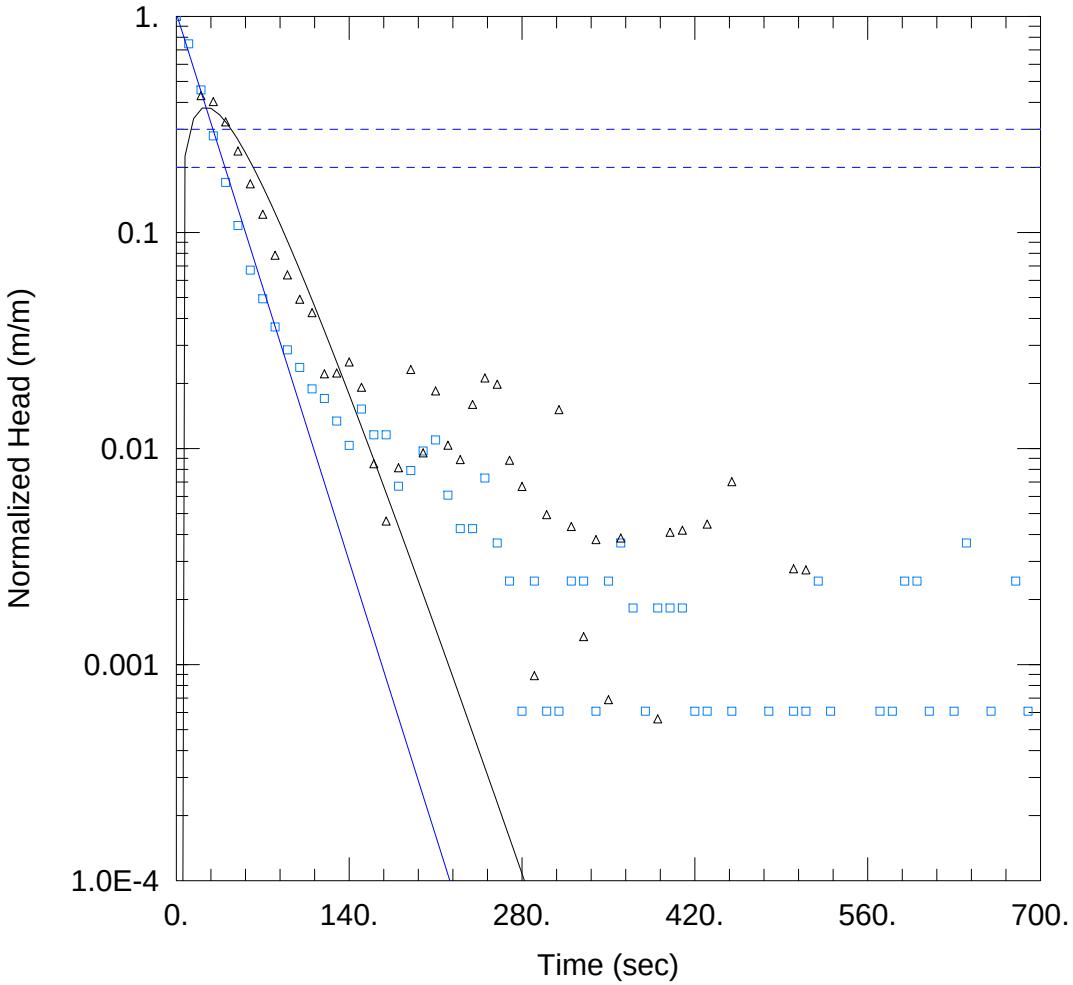
Saturated Thickness: 26.61 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD11(S) Slug out)

Initial Displacement: 0.653 m
Total Well Penetration Depth: 24.61 m
Casing Radius: 0.025 m
Static Water Column Height: 26.61 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.3153 m/day
y0 = 0.375 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(DS)_FHT.aqt
Date: 10/22/12 Time: 15:00:58

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

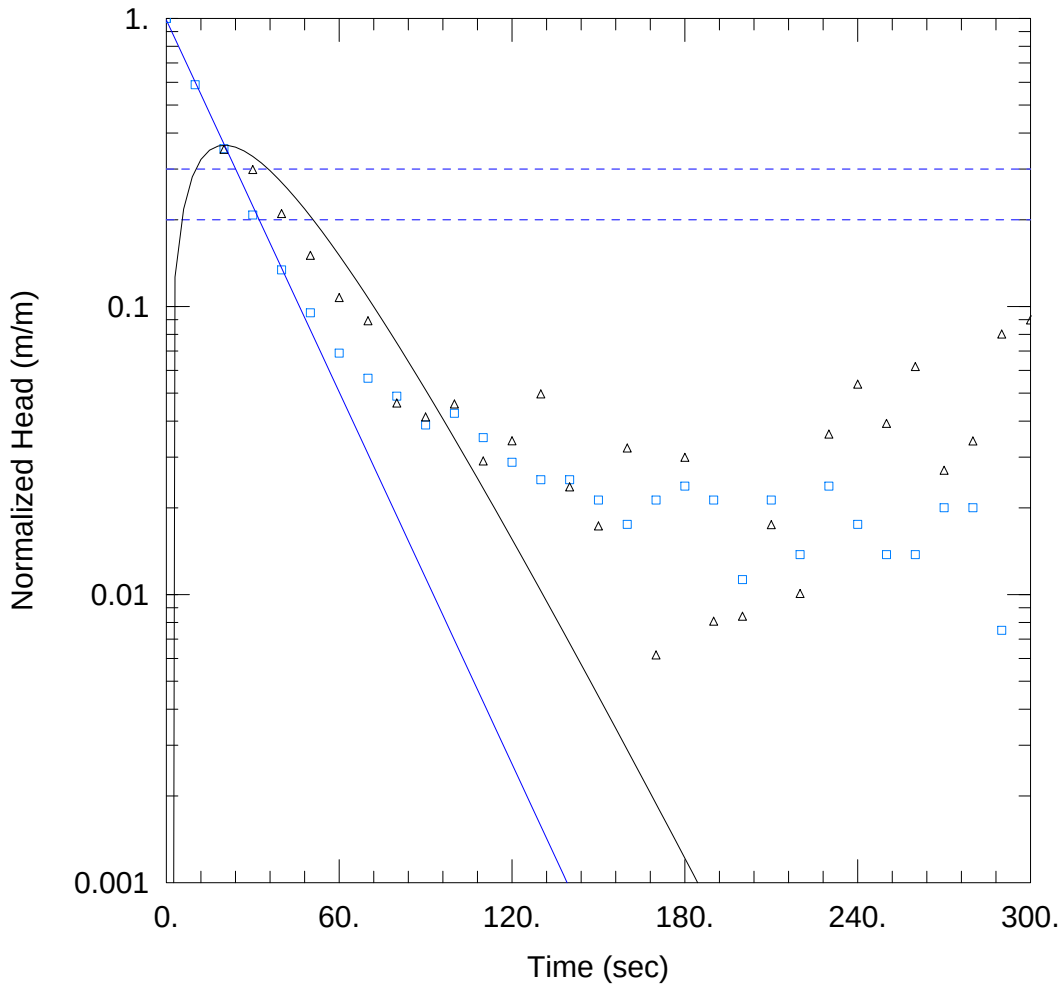
Saturated Thickness: 46.02 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12(D) FHT)

Initial Displacement: 1.643 m
Total Well Penetration Depth: 45.52 m
Casing Radius: 0.025 m
Static Water Column Height: 46.02 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.458 m/day
y0 = 1.698 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(DS)_SlugIn.aqt
Date: 10/22/12 Time: 15:01:01

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

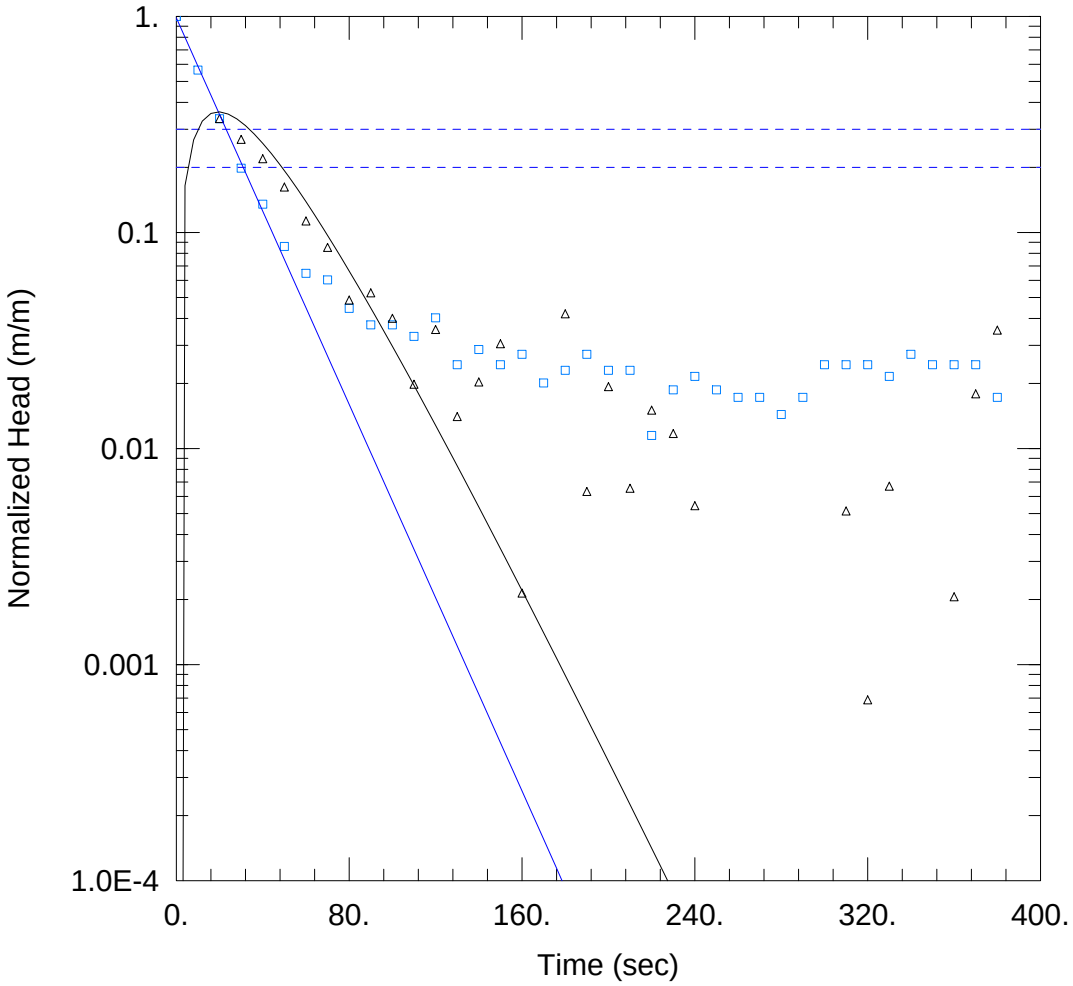
Saturated Thickness: 46.02 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12((D) Slug in)

Initial Displacement: 0.799 m
Total Well Penetration Depth: 45.52 m
Casing Radius: 0.025 m
Static Water Column Height: 46.02 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.732 m/day
y0 = 0.7888 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(DS)_SlugOut.aqt
Date: 10/22/12 Time: 15:01:05

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

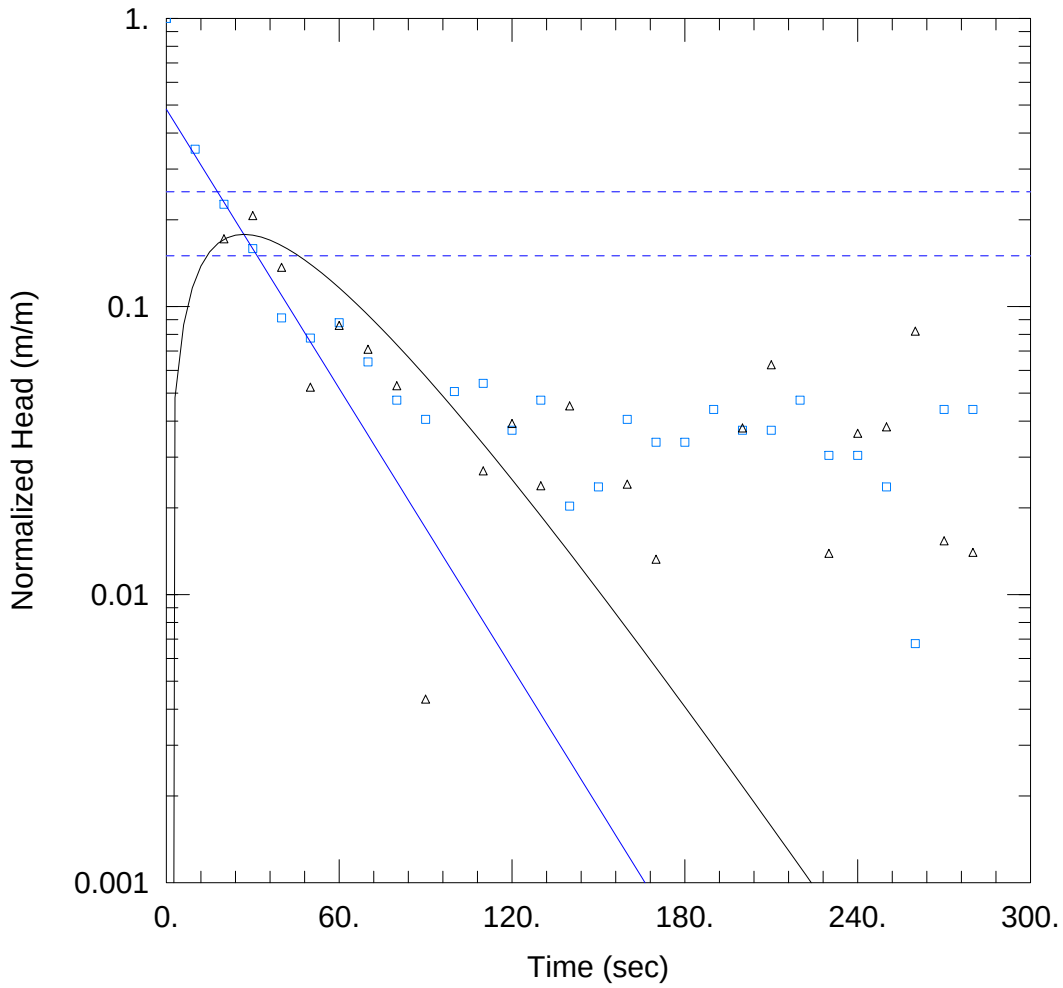
Saturated Thickness: 46.02 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12((D) Slug out)

Initial Displacement: 0.696 m
Total Well Penetration Depth: 45.52 m
Casing Radius: 0.025 m
Static Water Column Height: 46.02 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.8 m/day
y0 = 0.6845 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(S)_FHT.aqt
Date: 10/22/12 Time: 15:01:08

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

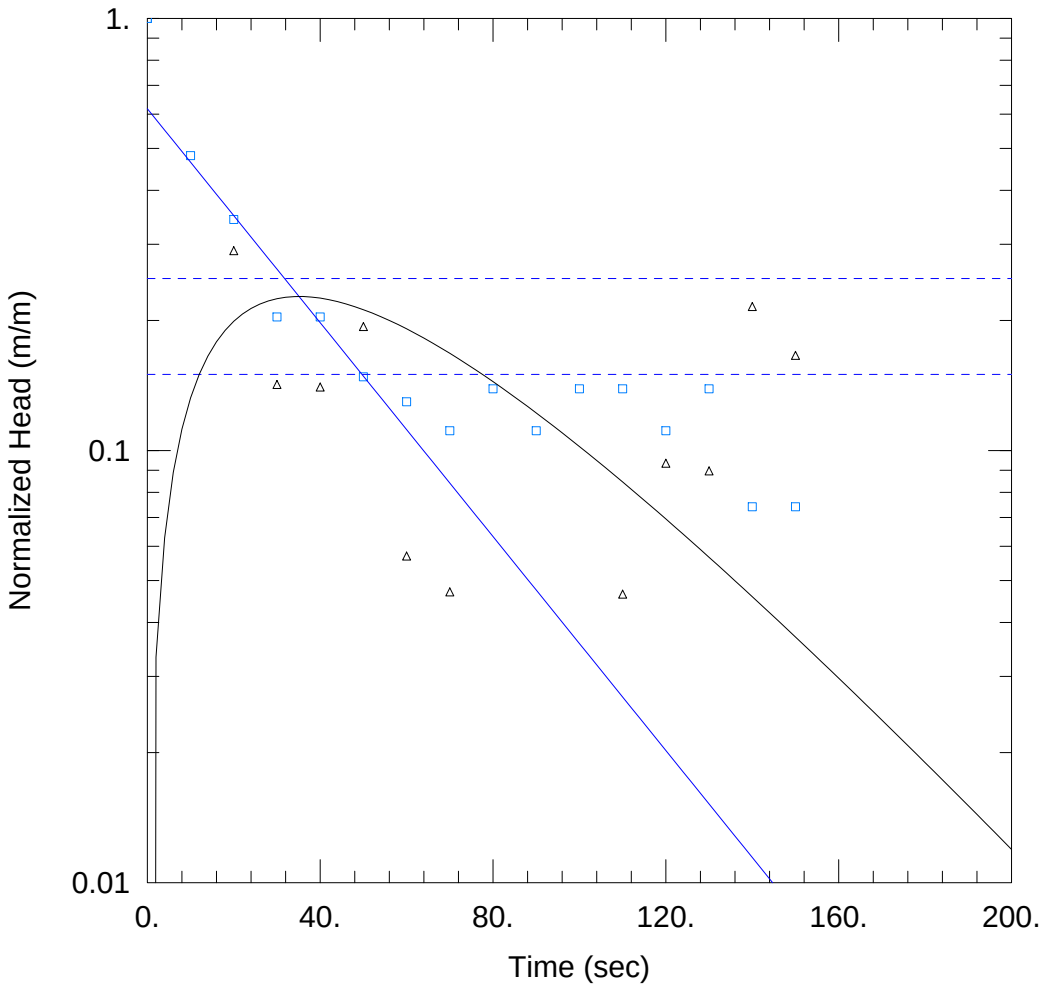
Saturated Thickness: 25.97 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12((S) FHT)

Initial Displacement: 0.296 m
Total Well Penetration Depth: 23.97 m
Casing Radius: 0.025 m
Static Water Column Height: 25.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.197 m/day
y0 = 0.1433 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:01:12

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

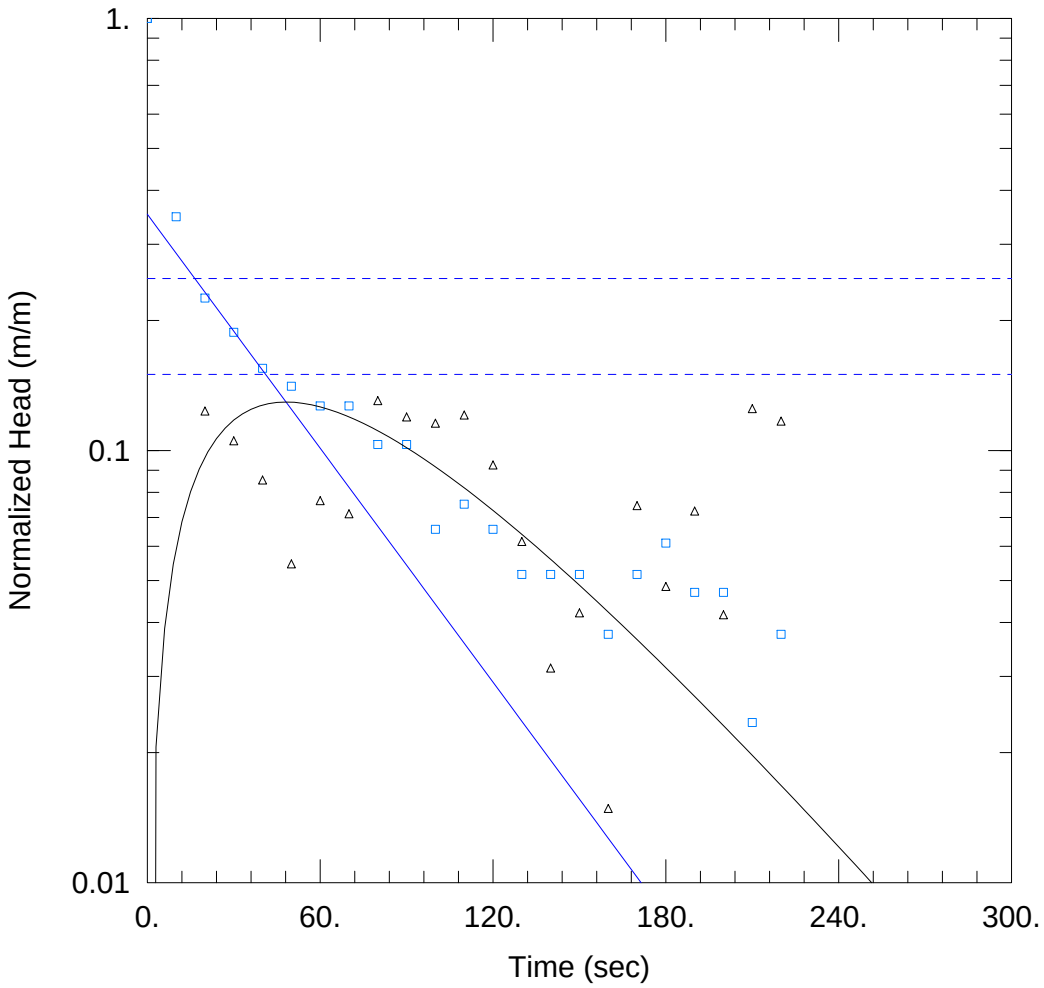
Saturated Thickness: 25.97 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12((S) Slug in)

Initial Displacement: 0.108 m
Total Well Penetration Depth: 23.97 m
Casing Radius: 0.025 m
Static Water Column Height: 25.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.9173 m/day
y0 = 0.06674 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD12(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:01:15

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

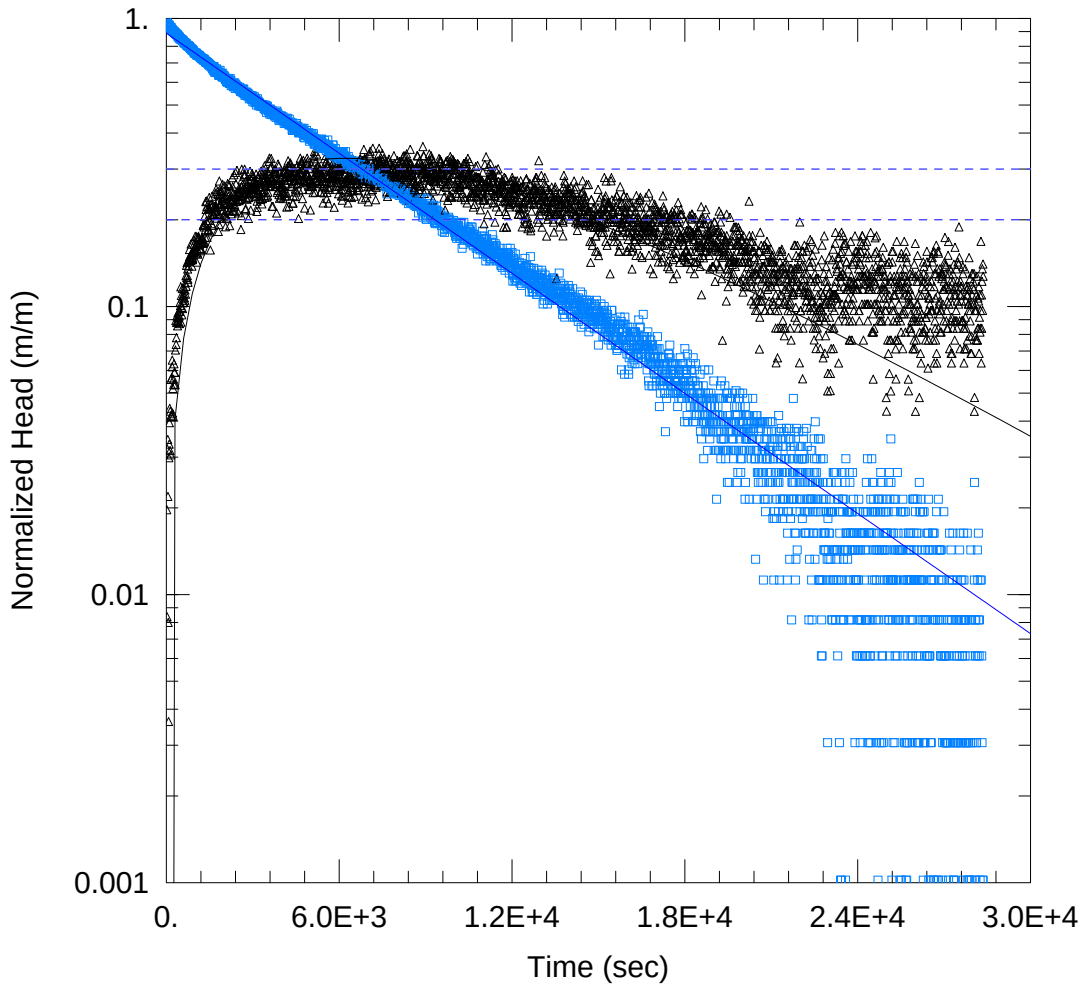
Saturated Thickness: 25.97 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD12((S) Slug out)

Initial Displacement: 0.213 m
Total Well Penetration Depth: 23.97 m
Casing Radius: 0.025 m
Static Water Column Height: 25.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.6688 m/day
y0 = 0.075 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD13(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:01:20

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

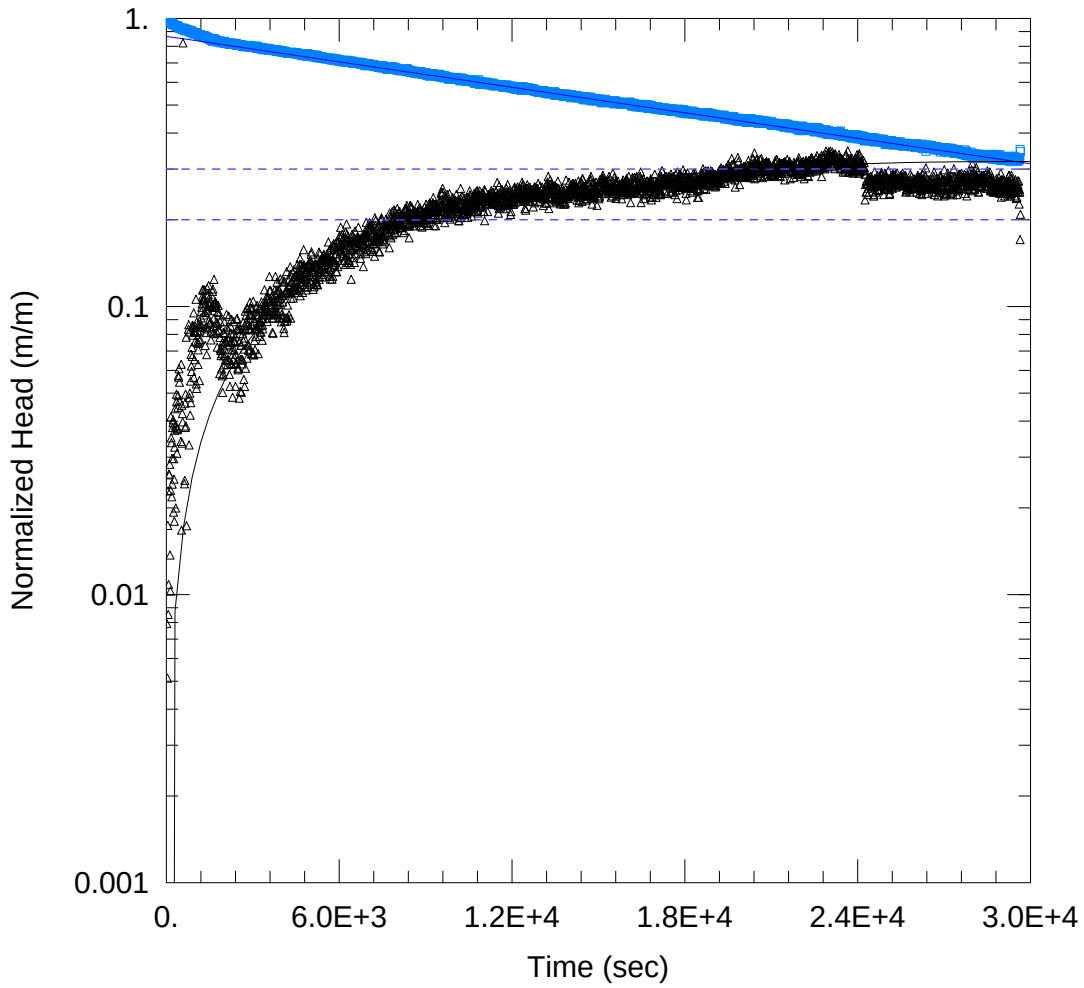
Saturated Thickness: 39.87 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD13(D) Slug in)

Initial Displacement: 0.98 m
Total Well Penetration Depth: 39.37 m
Casing Radius: 0.025 m
Static Water Column Height: 39.87 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.005509 m/day
y0 = 0.871 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD13(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:01:24

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

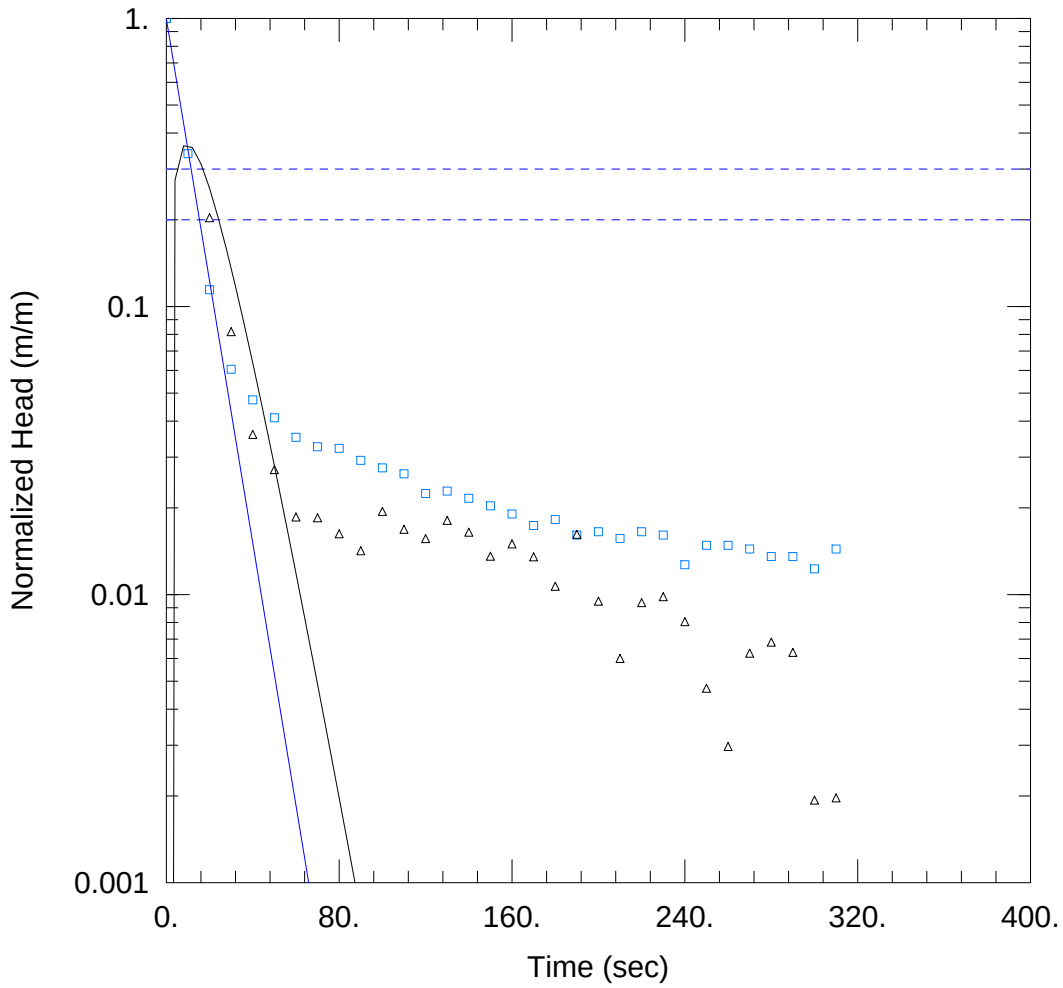
Saturated Thickness: 39.87 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD13(D) Slug out)

Initial Displacement: 0.981 m
Total Well Penetration Depth: 39.37 m
Casing Radius: 0.025 m
Static Water Column Height: 39.87 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.00117 m/day
y0 = 0.85 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD13(S)_FHT.aqt
Date: 10/22/12 Time: 15:01:28

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

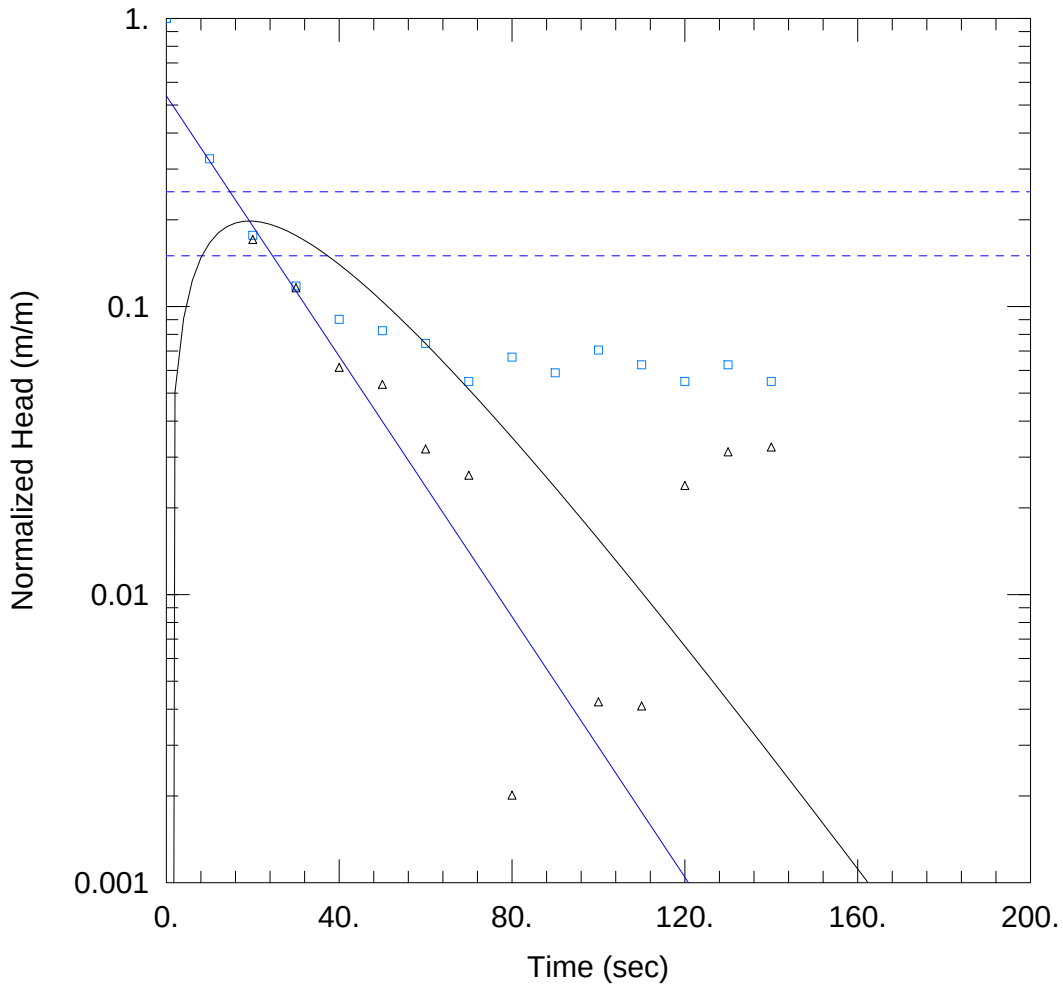
Saturated Thickness: 19.86 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD13(S) FHT)

Initial Displacement: 2.362 m
Total Well Penetration Depth: 17.86 m
Casing Radius: 0.025 m
Static Water Column Height: 19.86 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.979 m/day
y0 = 2.355 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD13(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:01:32

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

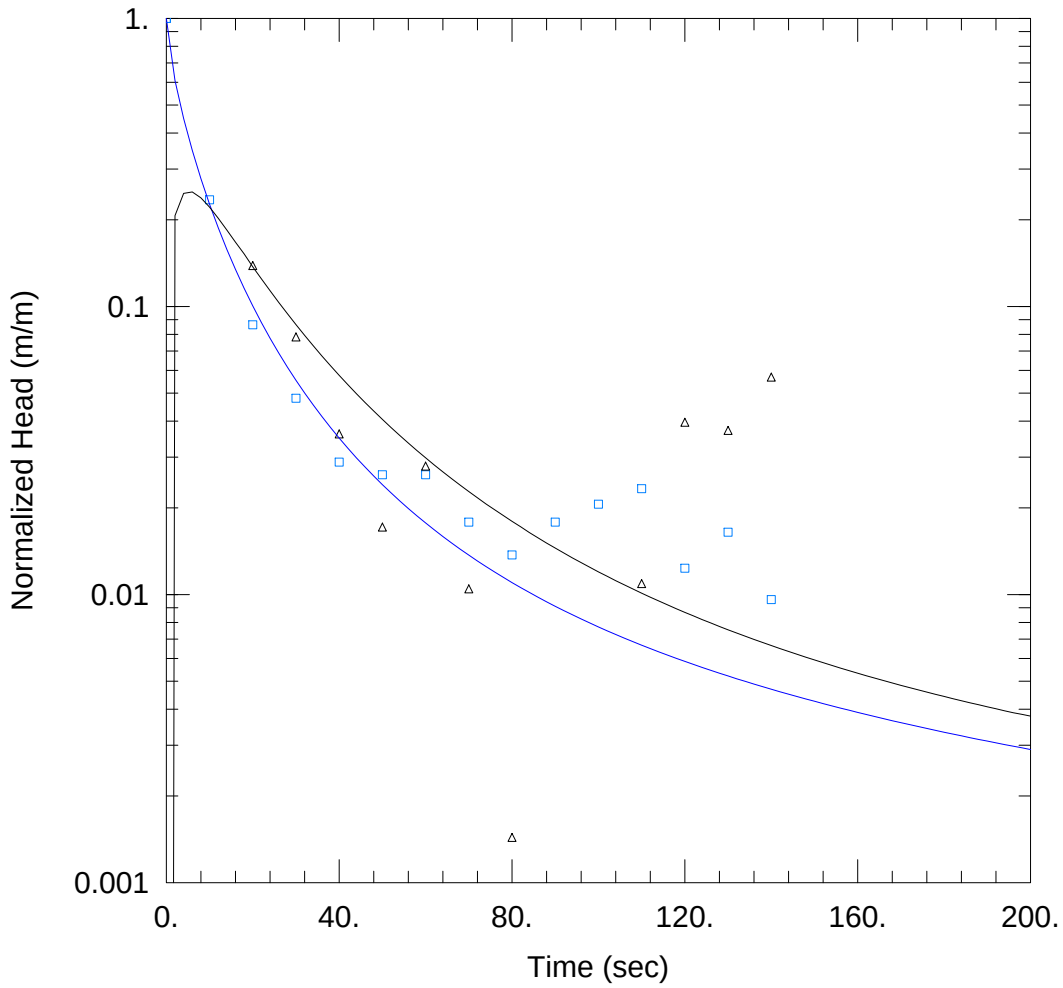
Saturated Thickness: 19.86 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD13(S) slug in)

Initial Displacement: 0.255 m
Total Well Penetration Depth: 17.86 m
Casing Radius: 0.025 m
Static Water Column Height: 19.86 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.675 m/day
y0 = 0.1373 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD13(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:01:36

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 19.86 m

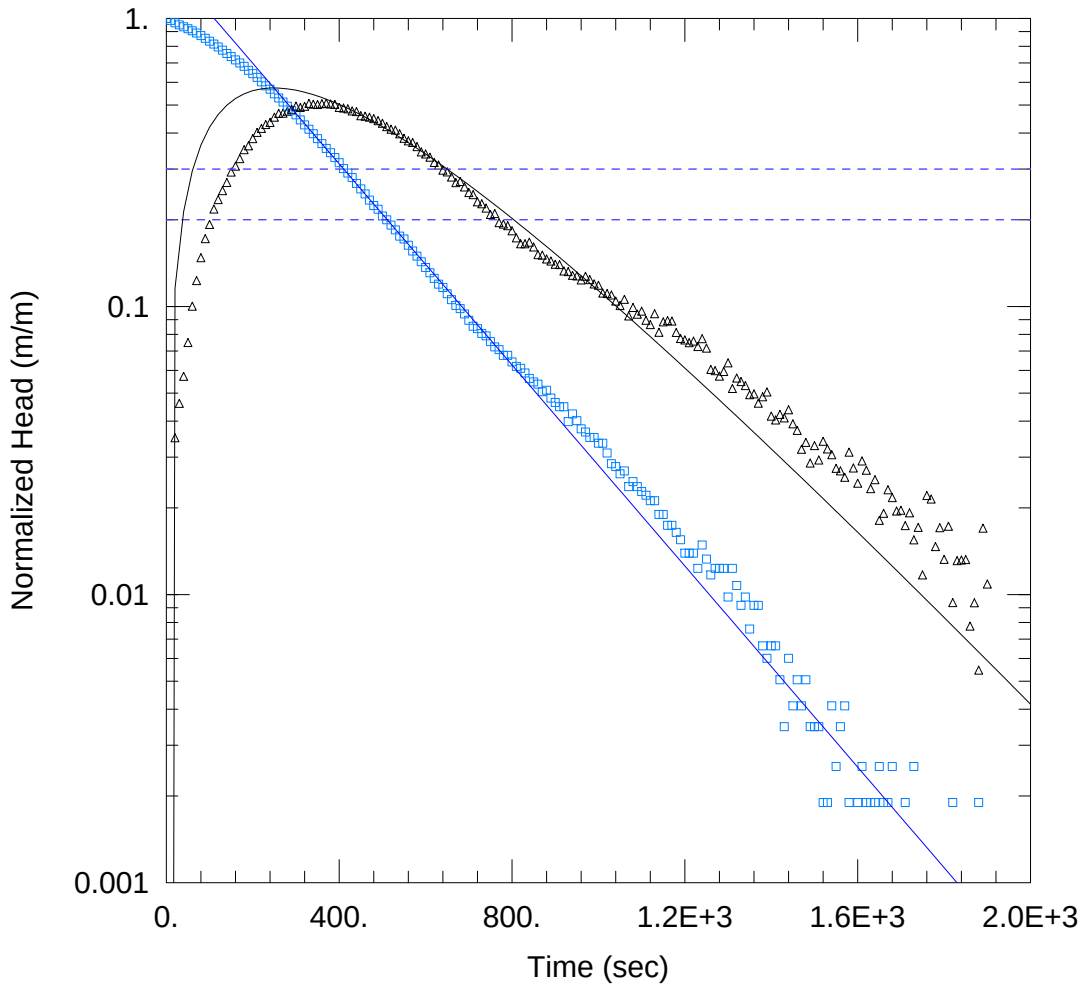
WELL DATA (RAU12HYD13(S) slug out)

Initial Displacement: 0.729 m
Total Well Penetration Depth: 17.86 m
Casing Radius: 0.025 m
Static Water Column Height: 19.86 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 3.154 m/day
Kz/Kr = 1.
Ss = 0.001056 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(D)_FHT.aqt
Date: 10/22/12 Time: 15:01:39

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

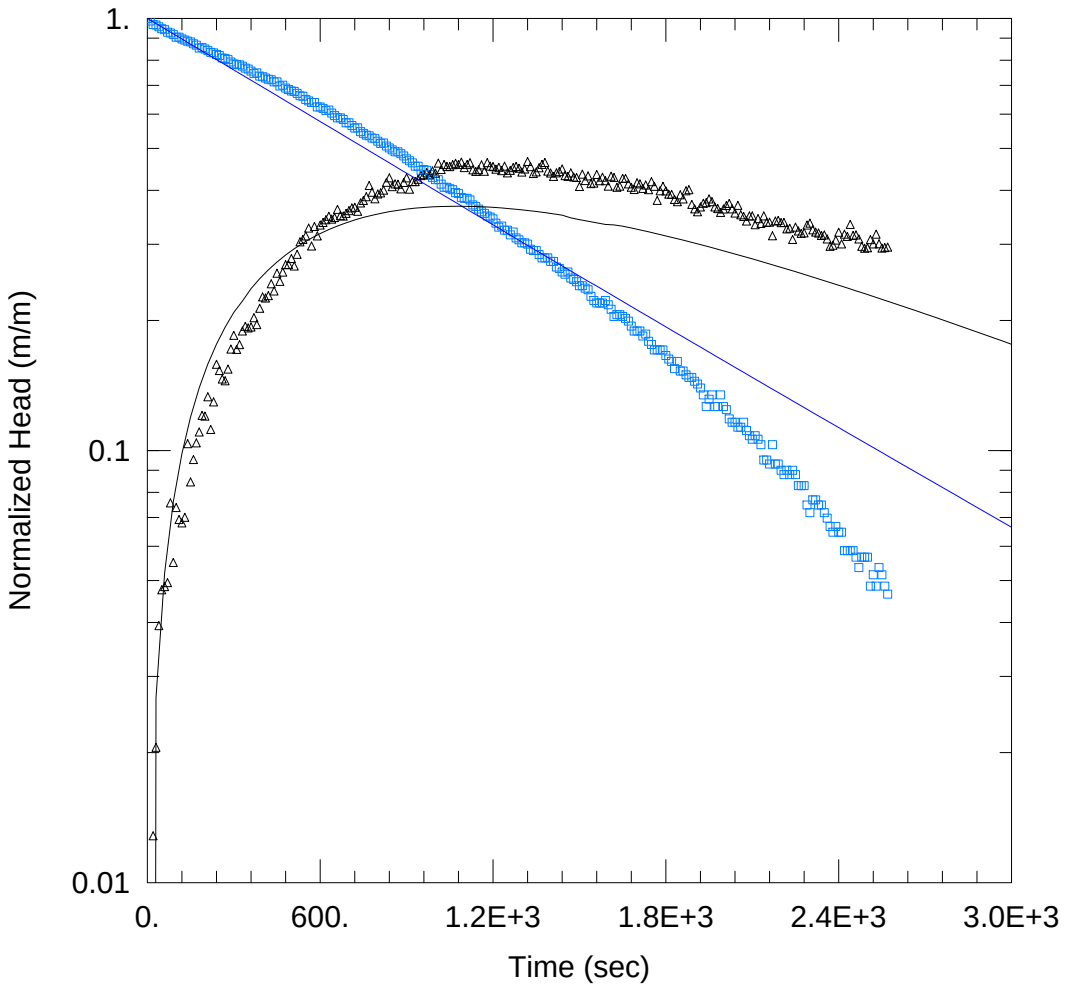
Saturated Thickness: 23.42 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD14(D) FHT)

Initial Displacement: 3.163 m
Total Well Penetration Depth: 22.92 m
Casing Radius: 0.025 m
Static Water Column Height: 23.42 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.1303 m/day
y0 = 4.934 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:01:43

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 23.42 m

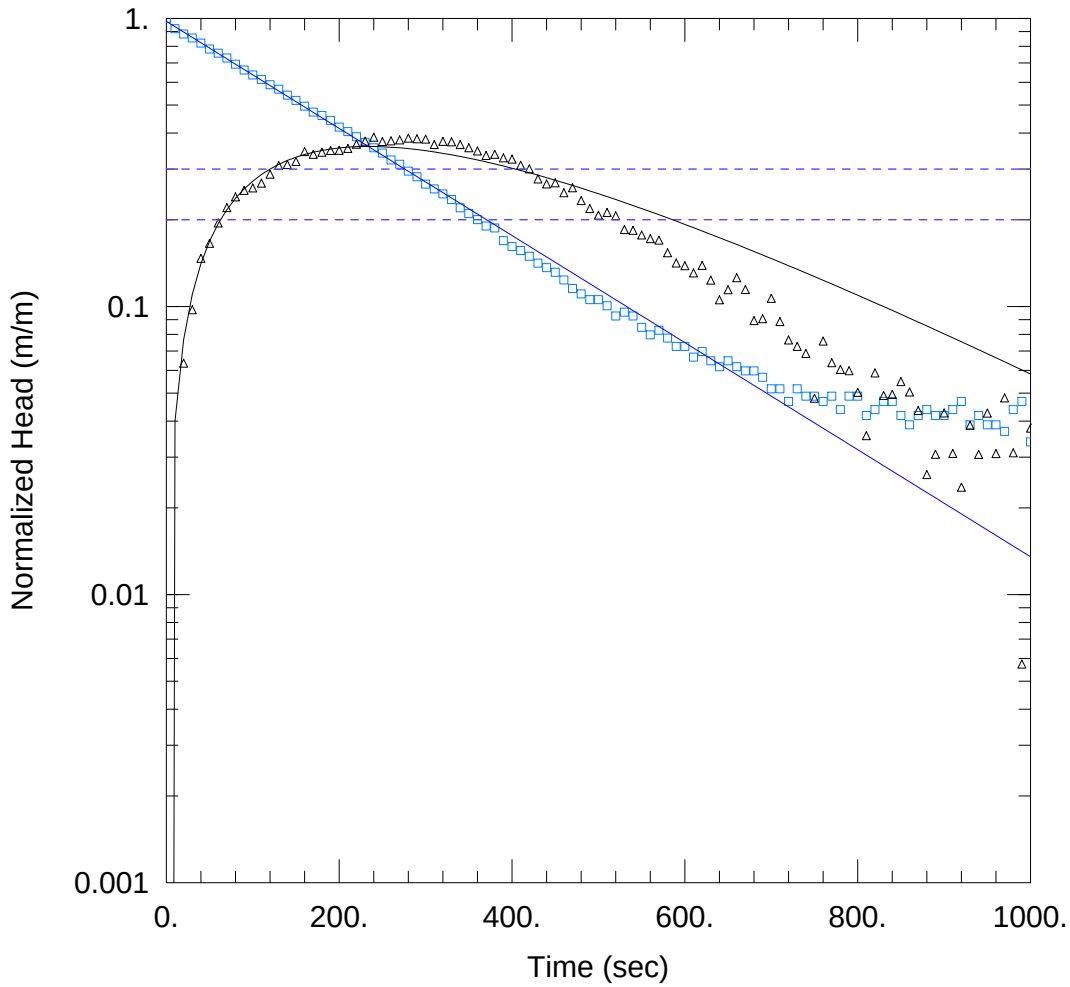
WELL DATA (RAU12HYD14(D) slug in)

Initial Displacement: 0.989 m
Total Well Penetration Depth: 22.92 m
Casing Radius: 0.025 m
Static Water Column Height: 23.42 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.03148 m/day
Kz/Kr = 1.
Ss = 4.27E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:01:47

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

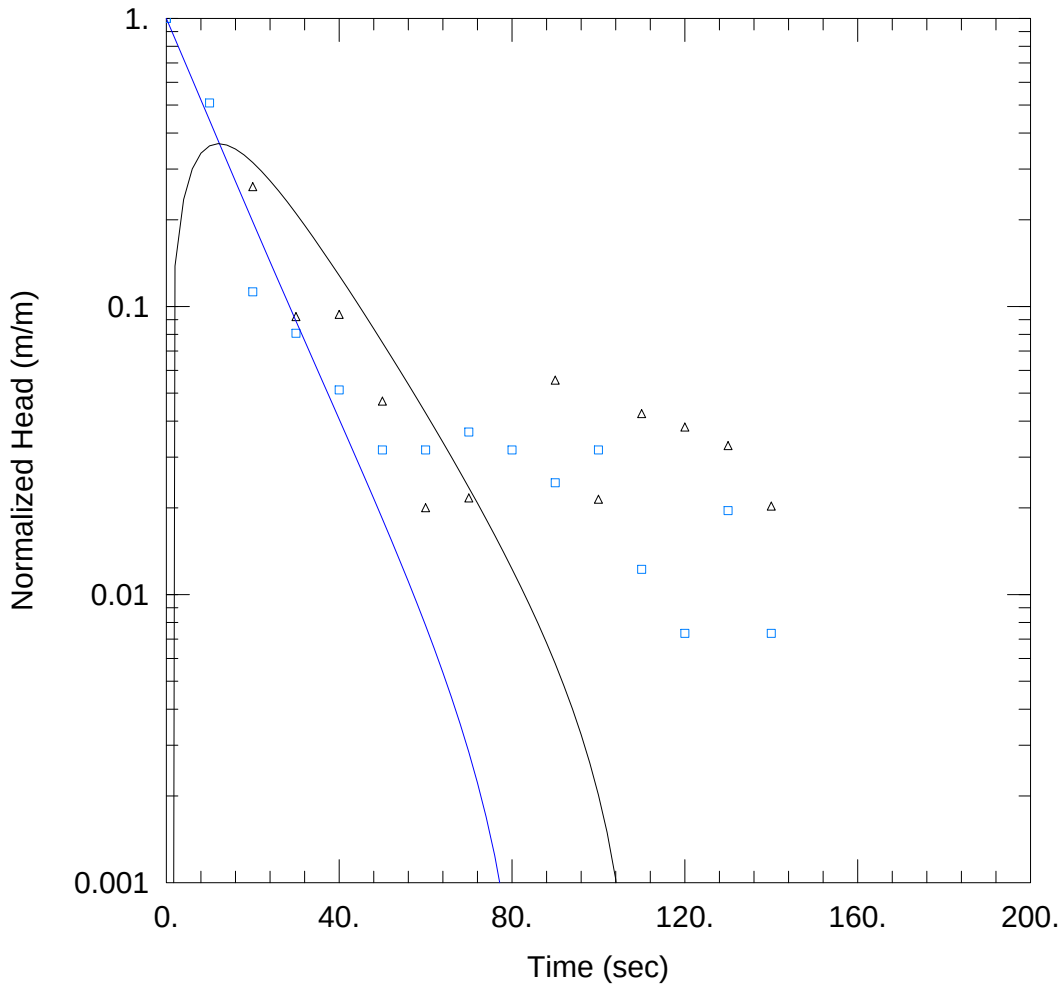
Saturated Thickness: 23.42 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD14(D) slug out)

Initial Displacement: 1.004 m
Total Well Penetration Depth: 22.92 m
Casing Radius: 0.025 m
Static Water Column Height: 23.42 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.1387 m/day
y0 = 0.9806 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(S)_FHT1.aqt
Date: 10/22/12 Time: 15:01:53

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 3.31 m

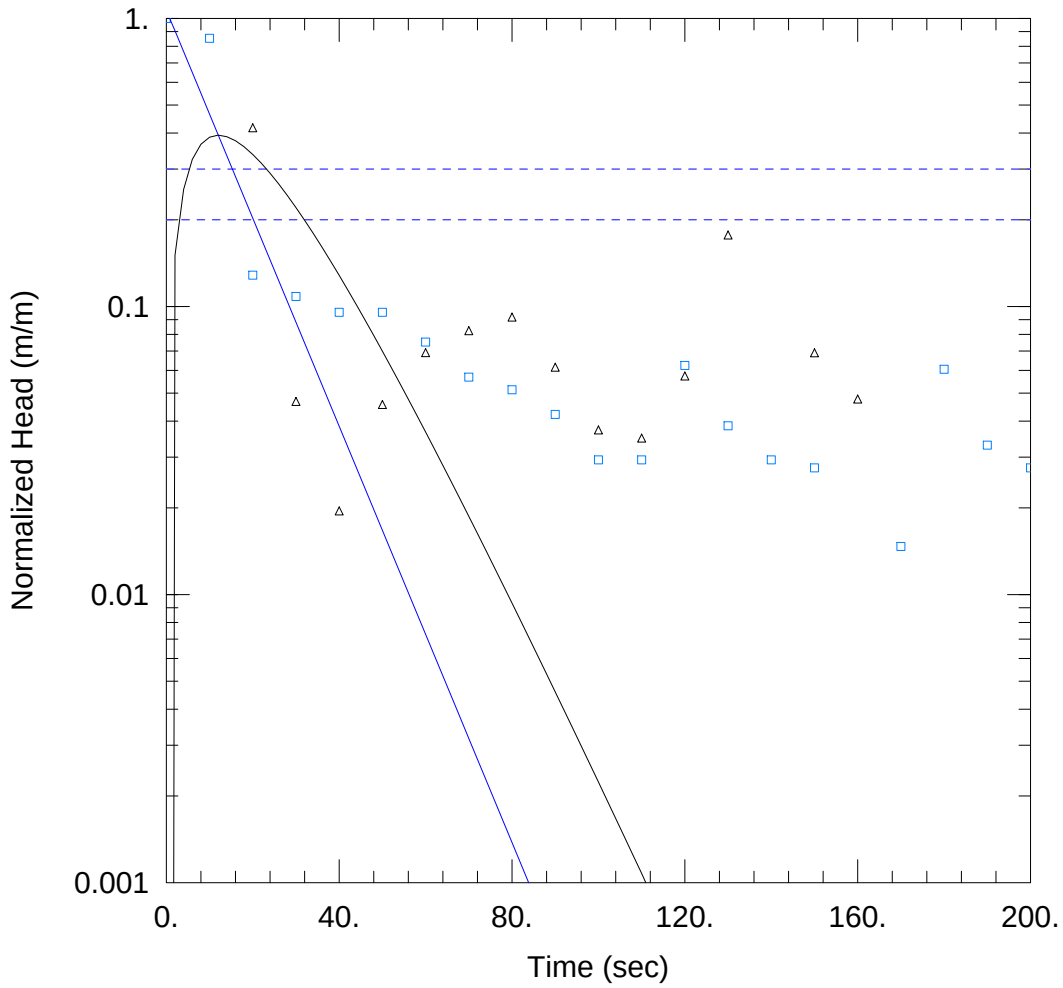
WELL DATA (RAU12HYD14(S) FHT 1)

Initial Displacement: 0.409 m
Total Well Penetration Depth: 1.81 m
Casing Radius: 0.025 m
Static Water Column Height: 3.31 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.738 m/day
Kz/Kr = 1.
Ss = 7.141E-16 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(S)_FHT2.aqt
Date: 10/22/12 Time: 15:01:58

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

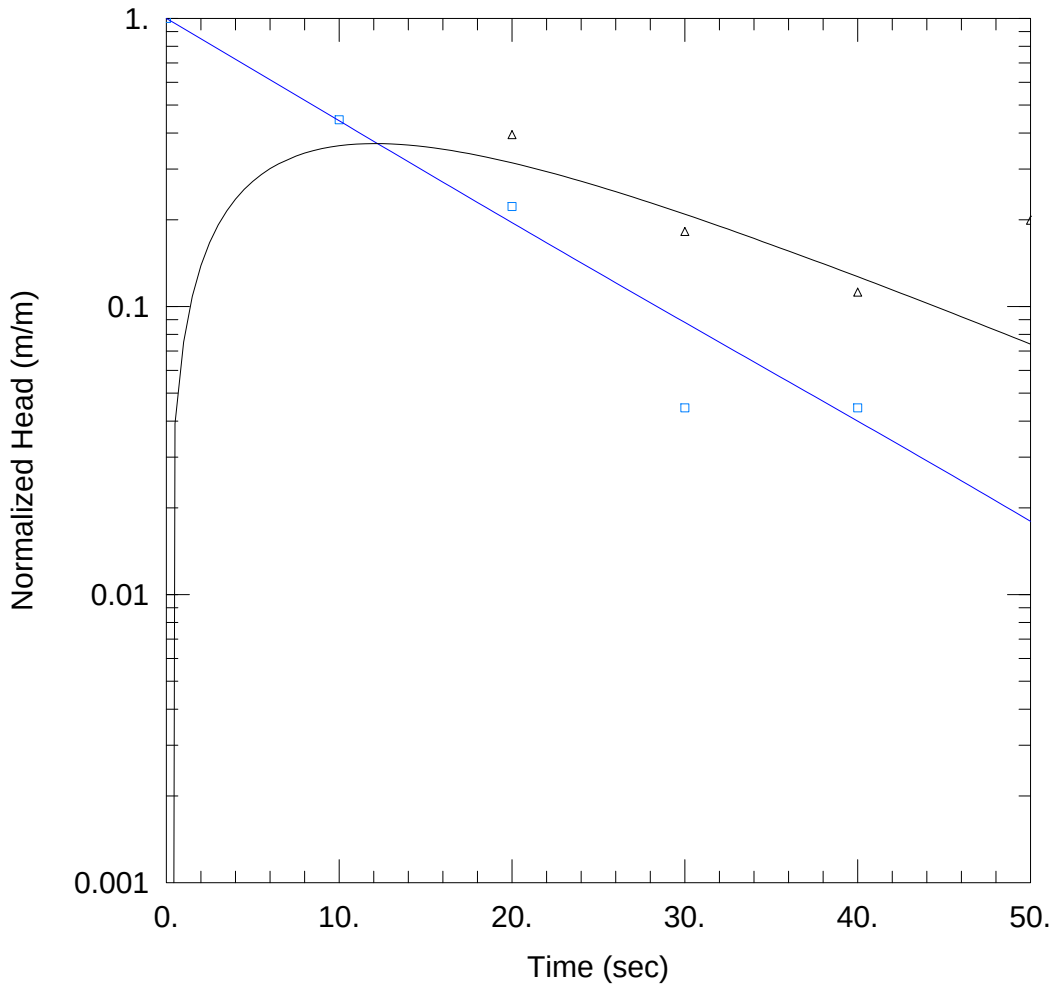
Saturated Thickness: 3.31 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD14(S) FHT 2)

Initial Displacement: 0.545 m
Total Well Penetration Depth: 1.81 m
Casing Radius: 0.025 m
Static Water Column Height: 3.31 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 3.813 m/day
y0 = 0.5826 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:02:02

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 3.31 m

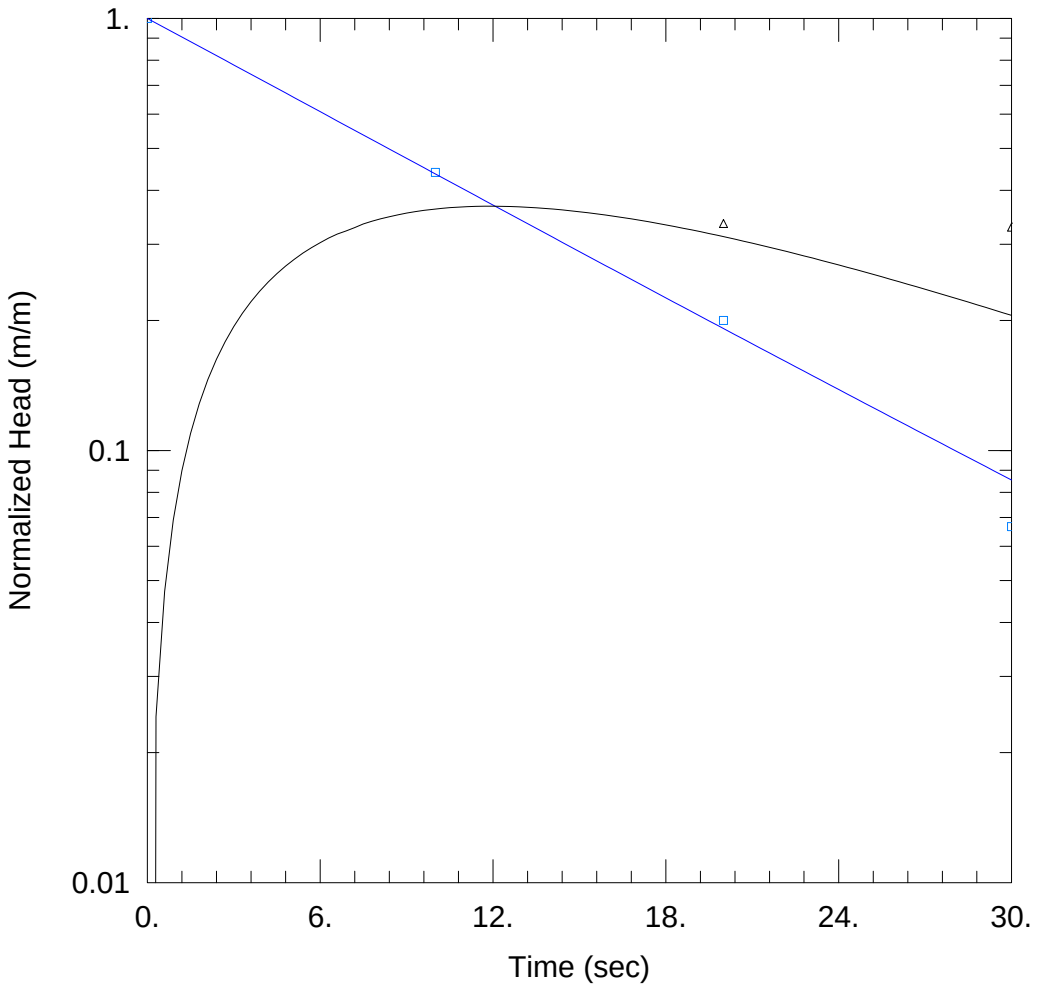
WELL DATA (RAU12HYD14(S) Slug In)

Initial Displacement: 0.045 m
Total Well Penetration Depth: 1.81 m
Casing Radius: 0.025 m
Static Water Column Height: 3.31 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.761 m/day
Kz/Kr = 1.
Ss = 1.798E-14 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD14(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:02:07

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 3.31 m

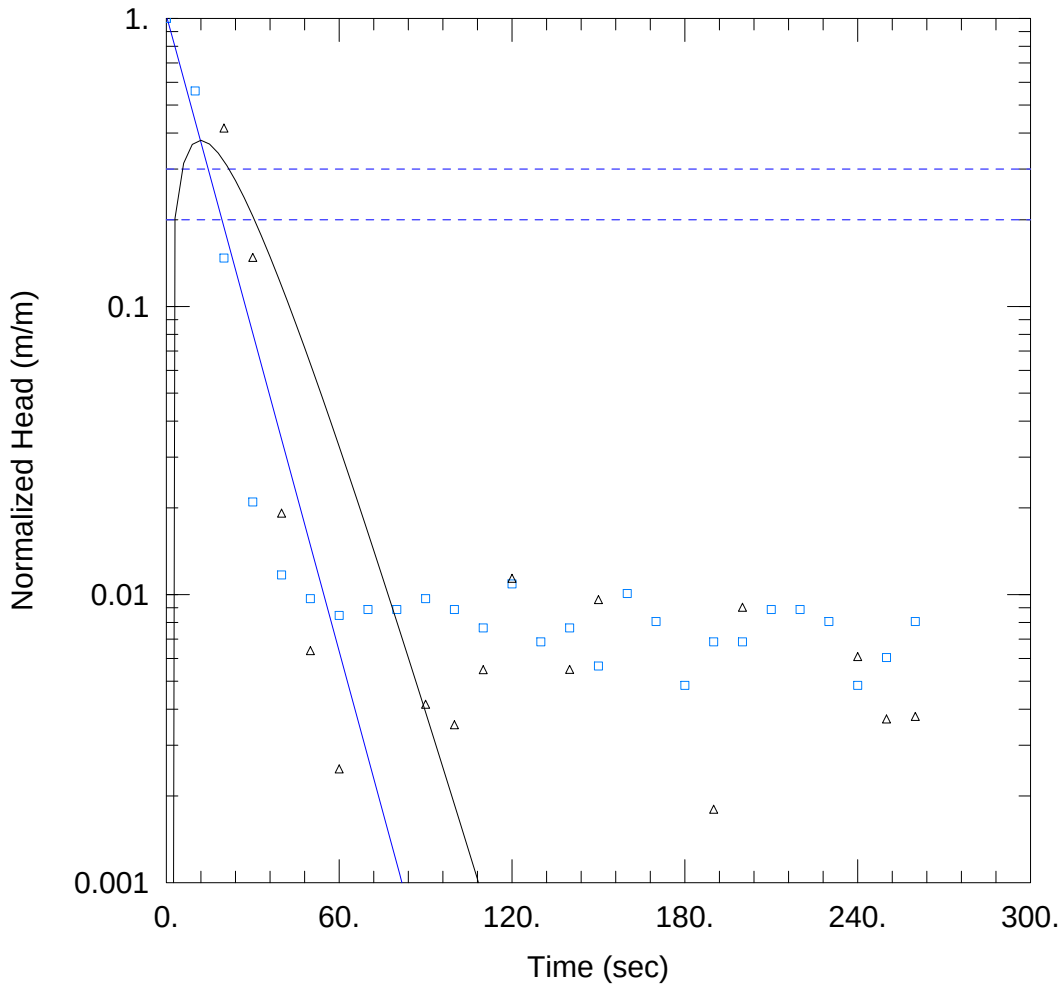
WELL DATA (RAU12HYD14(S) Slug Out)

Initial Displacement: 0.075 m
Total Well Penetration Depth: 1.81 m
Casing Radius: 0.025 m
Static Water Column Height: 3.31 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.82 m/day
Kz/Kr = 1.
Ss = 7.531E-15 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(D)_FHT1.aqt
Date: 10/22/12 Time: 15:02:51

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

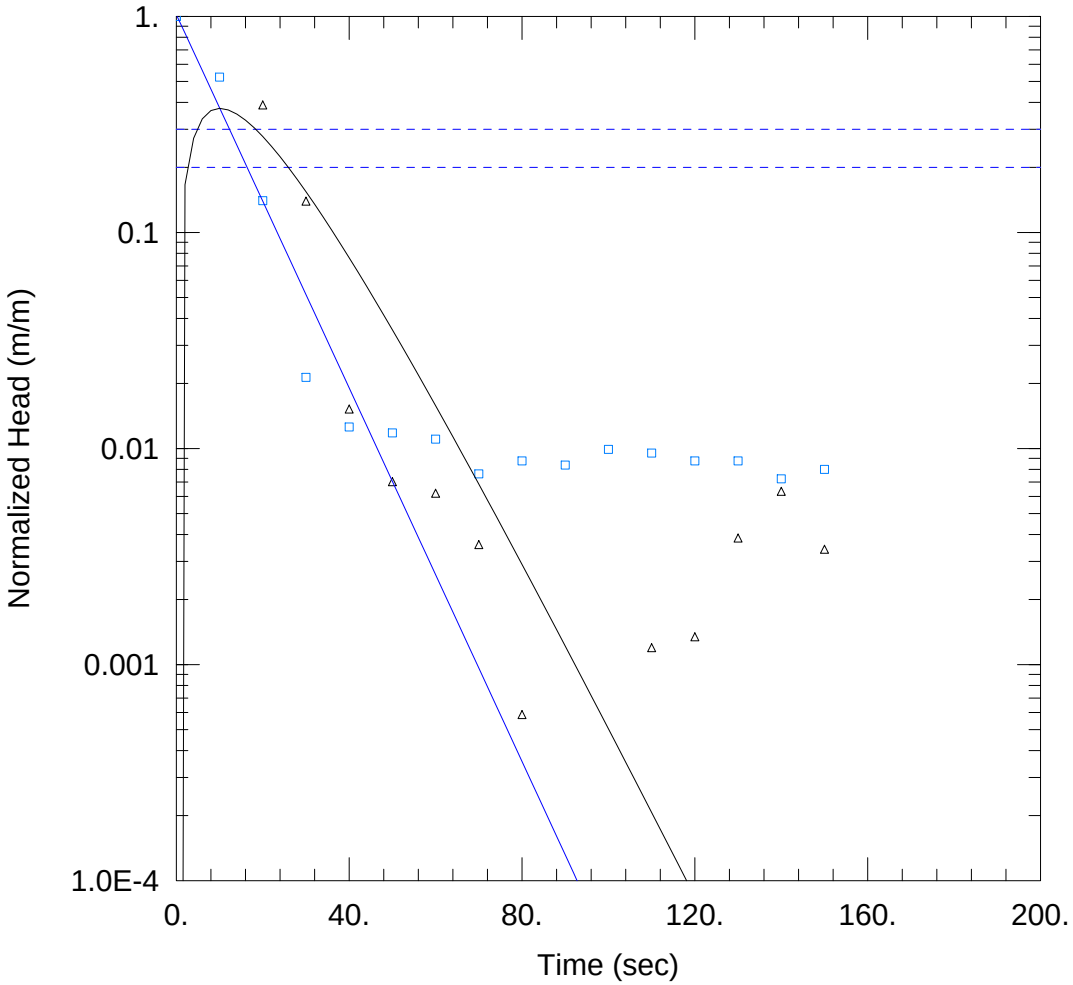
Saturated Thickness: 29.68 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(D) FHT 1)

Initial Displacement: 2.48 m
Total Well Penetration Depth: 29.18 m
Casing Radius: 0.025 m
Static Water Column Height: 29.68 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.825 m/day
y0 = 2.547 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(D)_FHT2.aqt
Date: 10/22/12 Time: 15:02:57

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

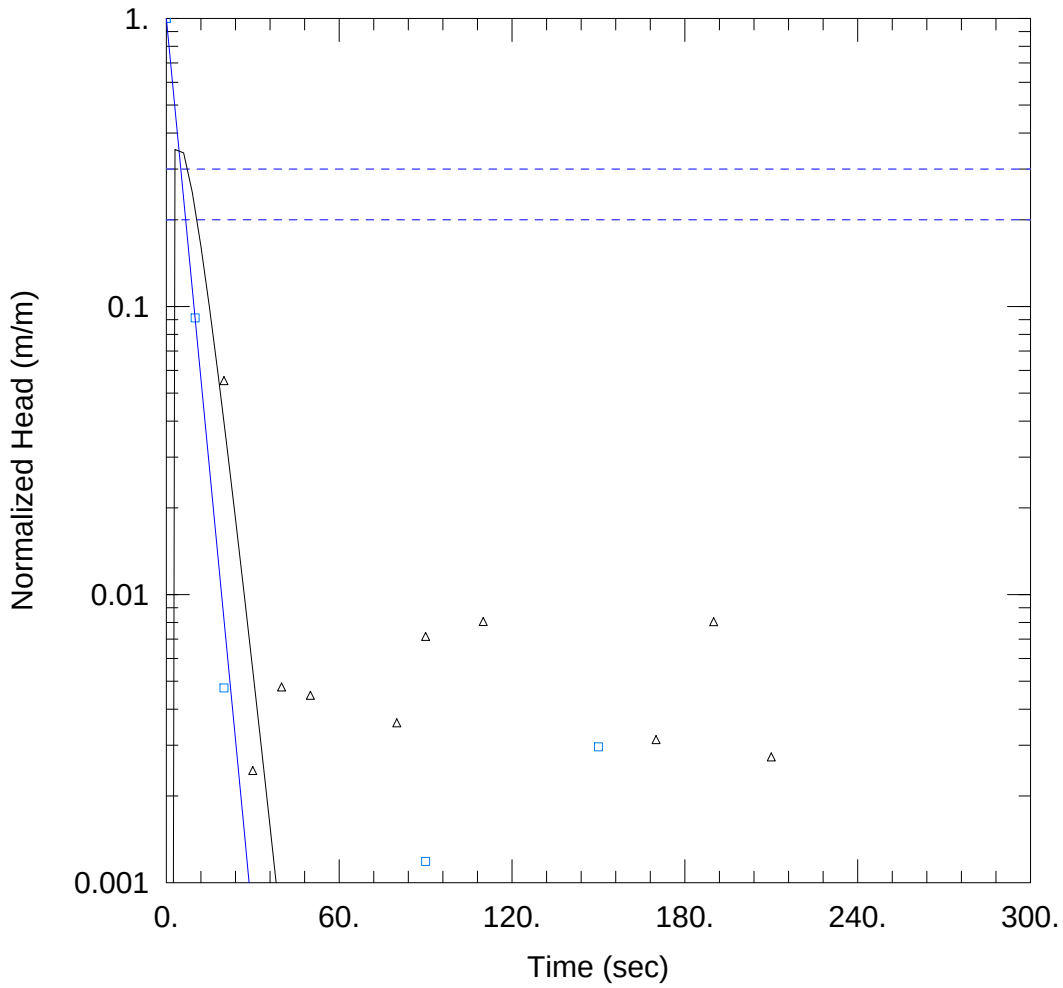
Saturated Thickness: 29.68 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(D) FHT 2)

Initial Displacement: 2.623 m
Total Well Penetration Depth: 29.18 m
Casing Radius: 0.025 m
Static Water Column Height: 29.68 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 3.317 m/day
y0 = 2.678 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:03:02

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

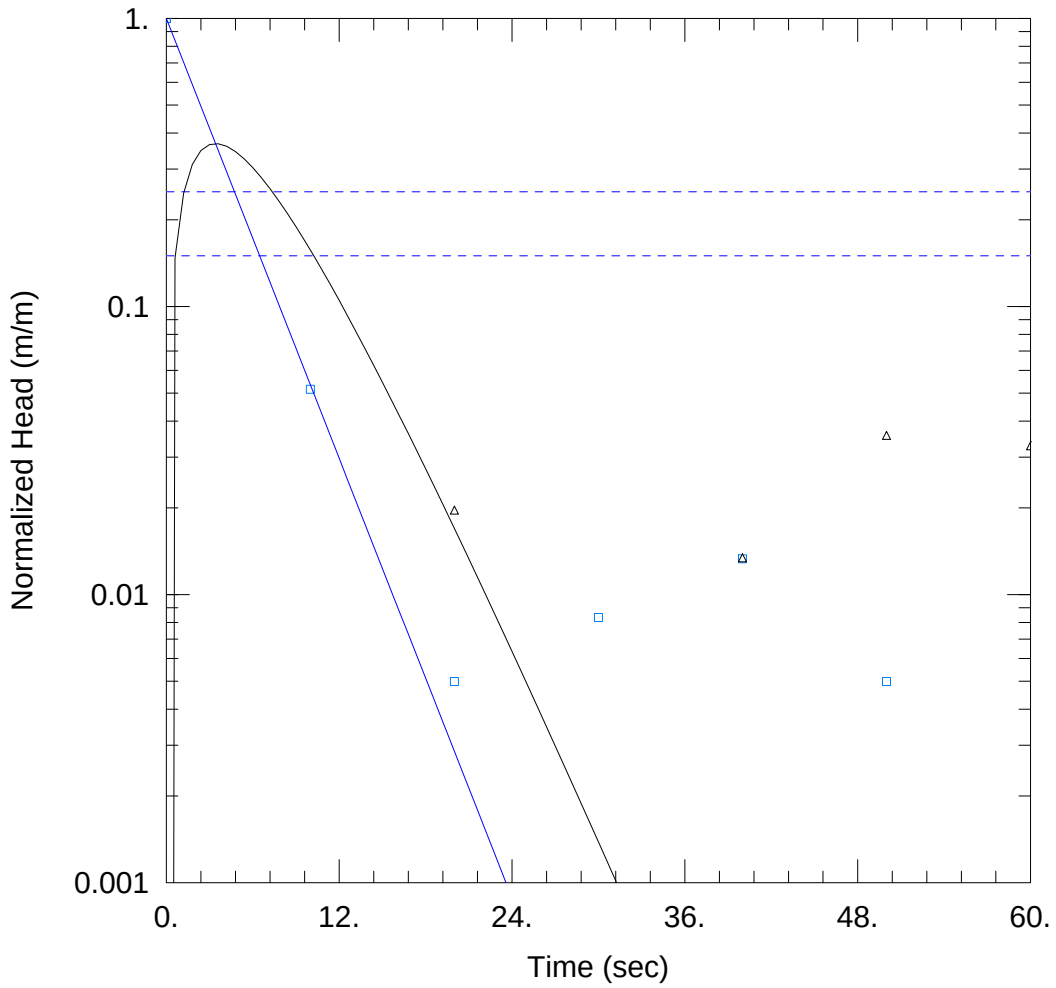
Saturated Thickness: 29.68 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(D) Slug in)

Initial Displacement: 1.688 m
Total Well Penetration Depth: 29.18 m
Casing Radius: 0.025 m
Static Water Column Height: 29.68 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 8.005 m/day
y0 = 1.688 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:03:08

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

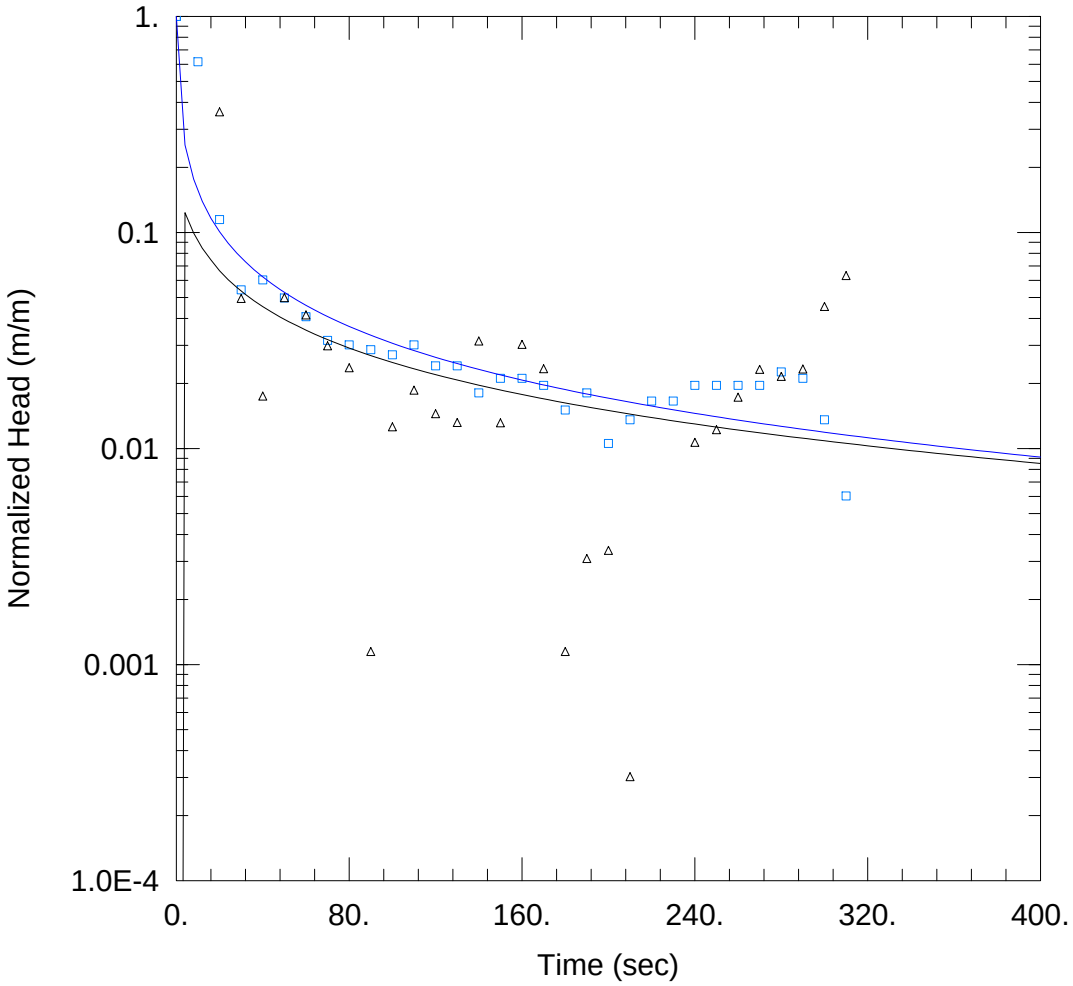
Saturated Thickness: 29.68 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(D) Slug out)

Initial Displacement: 0.601 m
Total Well Penetration Depth: 29.18 m
Casing Radius: 0.025 m
Static Water Column Height: 29.68 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 9.908 m/day
y0 = 0.601 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(S)_FHT1.aqt
Date: 10/22/12 Time: 15:03:17

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 9.57 m

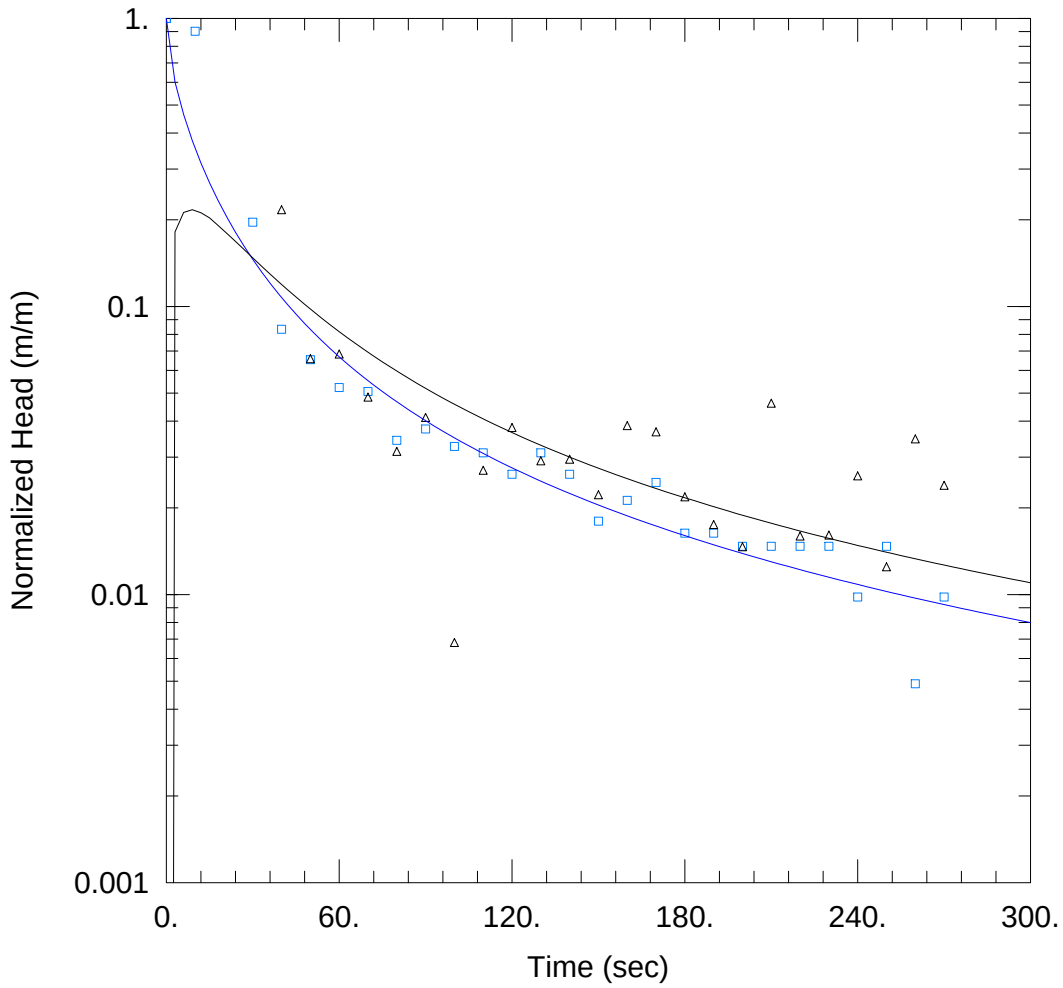
WELL DATA (RAU12HYD15(S) FHT 1)

Initial Displacement: 0.663 m
Total Well Penetration Depth: 7.75 m
Casing Radius: 0.025 m
Static Water Column Height: 9.57 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.9649 m/day
Kz/Kr = 1.
Ss = 0.1045 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(S)_FHT2.aqt
Date: 10/22/12 Time: 15:03:22

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 9.57 m

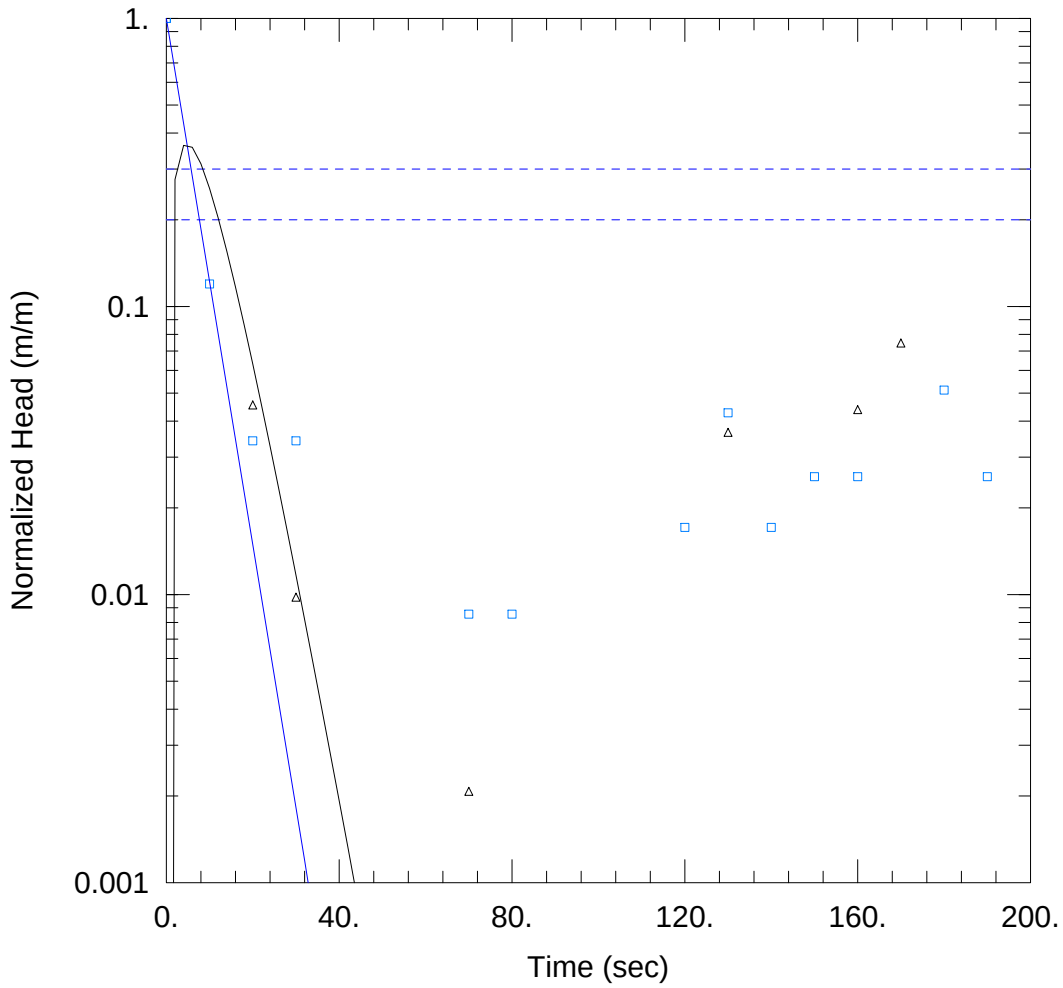
WELL DATA (RAU12HYD15(S) FHT 2)

Initial Displacement: 0.612 m
Total Well Penetration Depth: 7.75 m
Casing Radius: 0.025 m
Static Water Column Height: 9.57 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 1.29 m/day
Kz/Kr = 1.
Ss = 0.003794 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:03:28

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

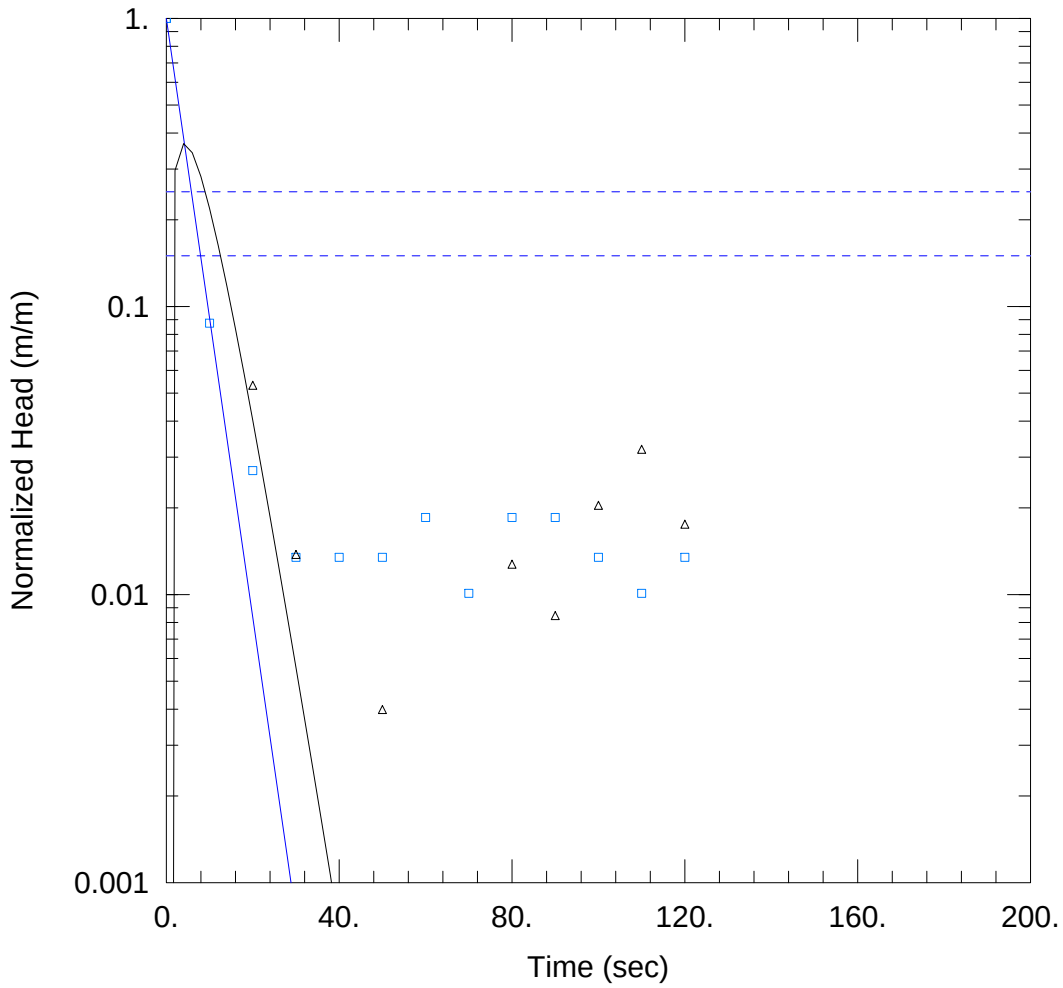
Saturated Thickness: 9.57 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(S) Slug in)

Initial Displacement: 0.117 m
Total Well Penetration Depth: 7.75 m
Casing Radius: 0.025 m
Static Water Column Height: 9.57 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 5.356 m/day
y0 = 0.117 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD15(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:03:33

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

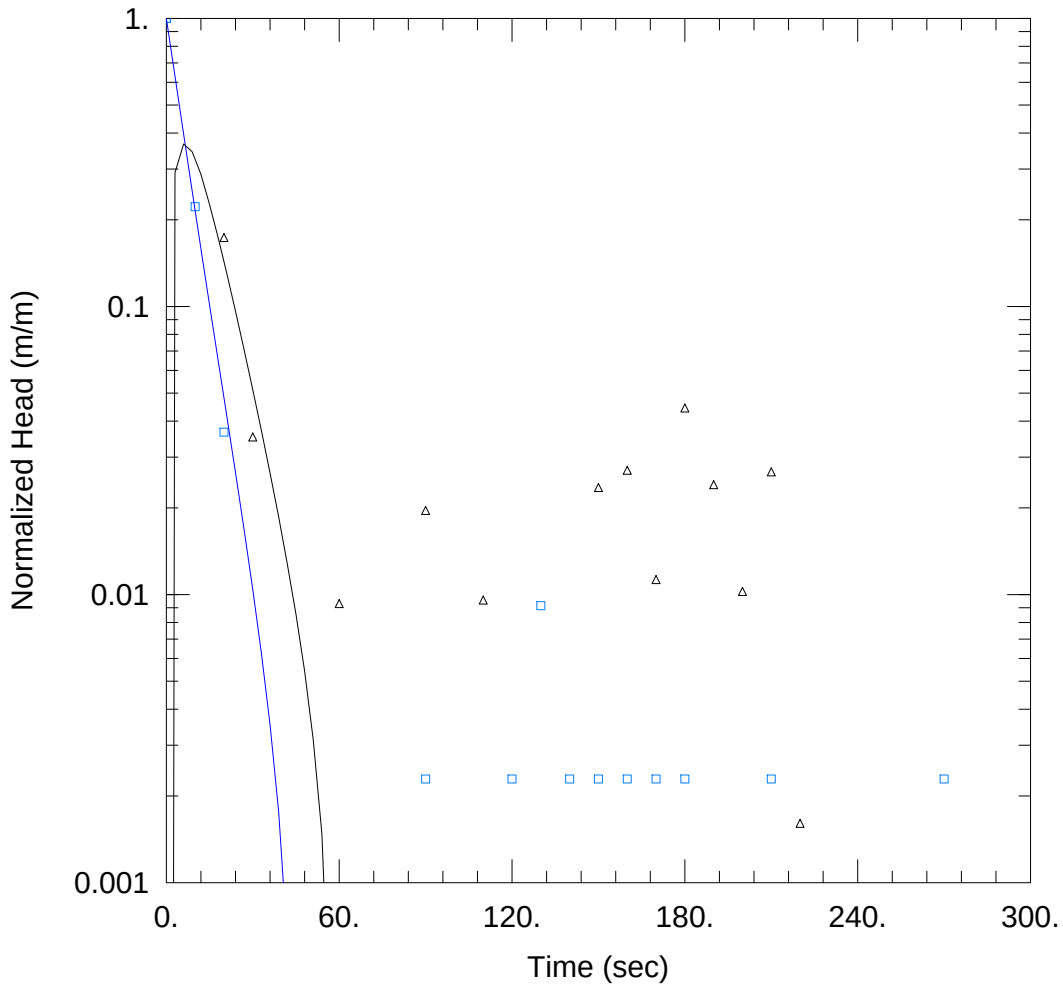
Saturated Thickness: 9.57 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD15(S) Slug out)

Initial Displacement: 0.594 m
Total Well Penetration Depth: 7.75 m
Casing Radius: 0.025 m
Static Water Column Height: 9.57 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 7.705 m/day
y0 = 0.5939 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(D)_FHT1.aqt
Date: 10/22/12 Time: 15:03:38

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 32.59 m

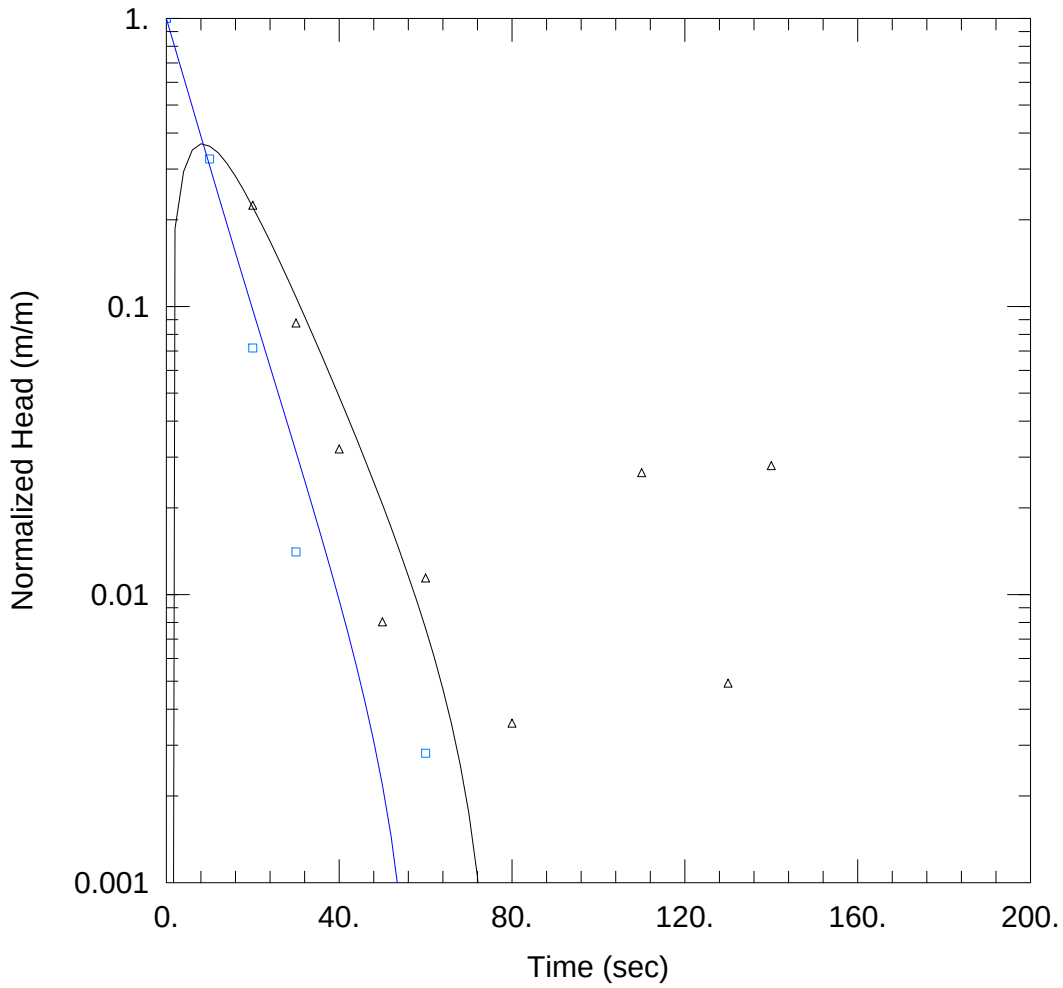
WELL DATA (RAU12HYD16(D) FHT 1)

Initial Displacement: 0.437 m
Total Well Penetration Depth: 32.09 m
Casing Radius: 0.025 m
Static Water Column Height: 32.59 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 5.331 m/day
Kz/Kr = 1.
Ss = 3.068E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(D)_FHT2.aqt
Date: 10/22/12 Time: 15:03:42

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 32.59 m

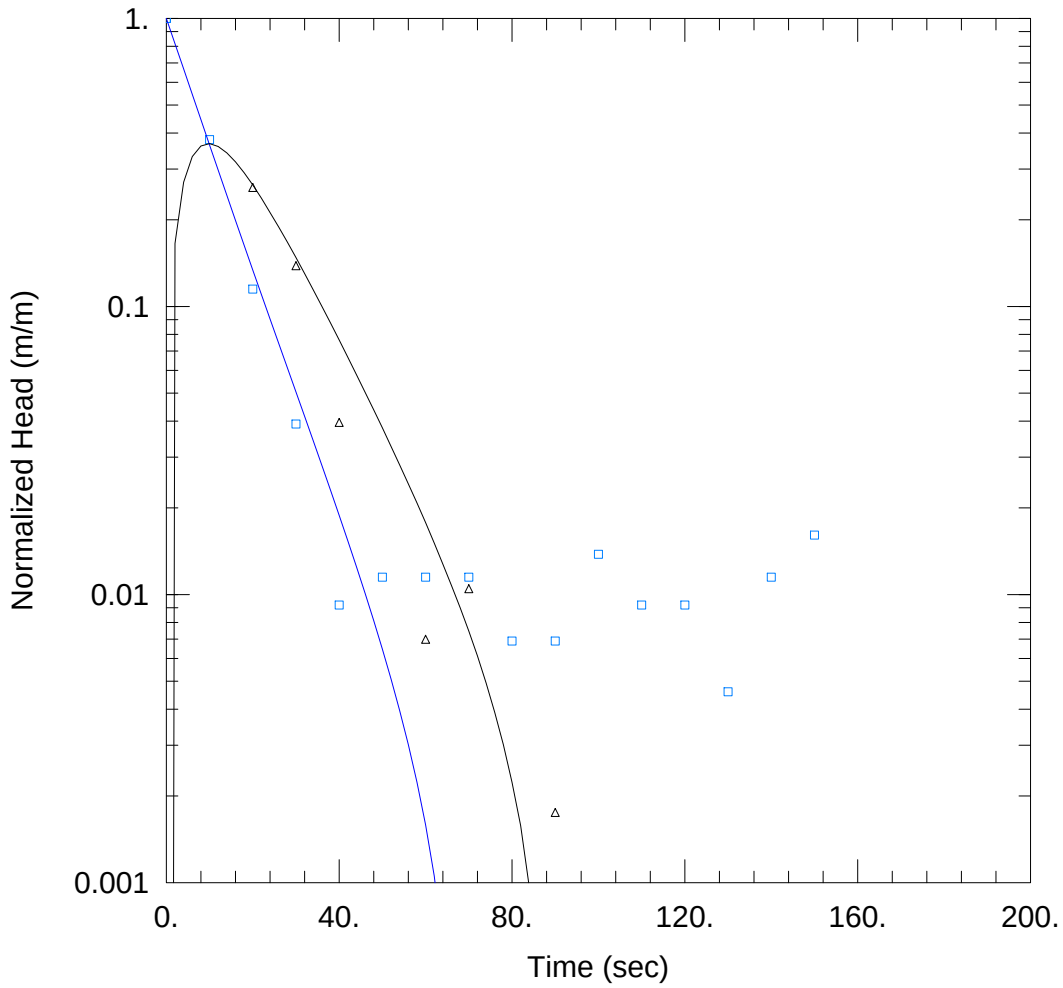
WELL DATA (RAU12HYD16(D) FHT 2)

Initial Displacement: 0.711 m
Total Well Penetration Depth: 32.09 m
Casing Radius: 0.025 m
Static Water Column Height: 32.59 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.068 m/day
Kz/Kr = 1.
Ss = 3.068E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:03:48

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 32.59 m

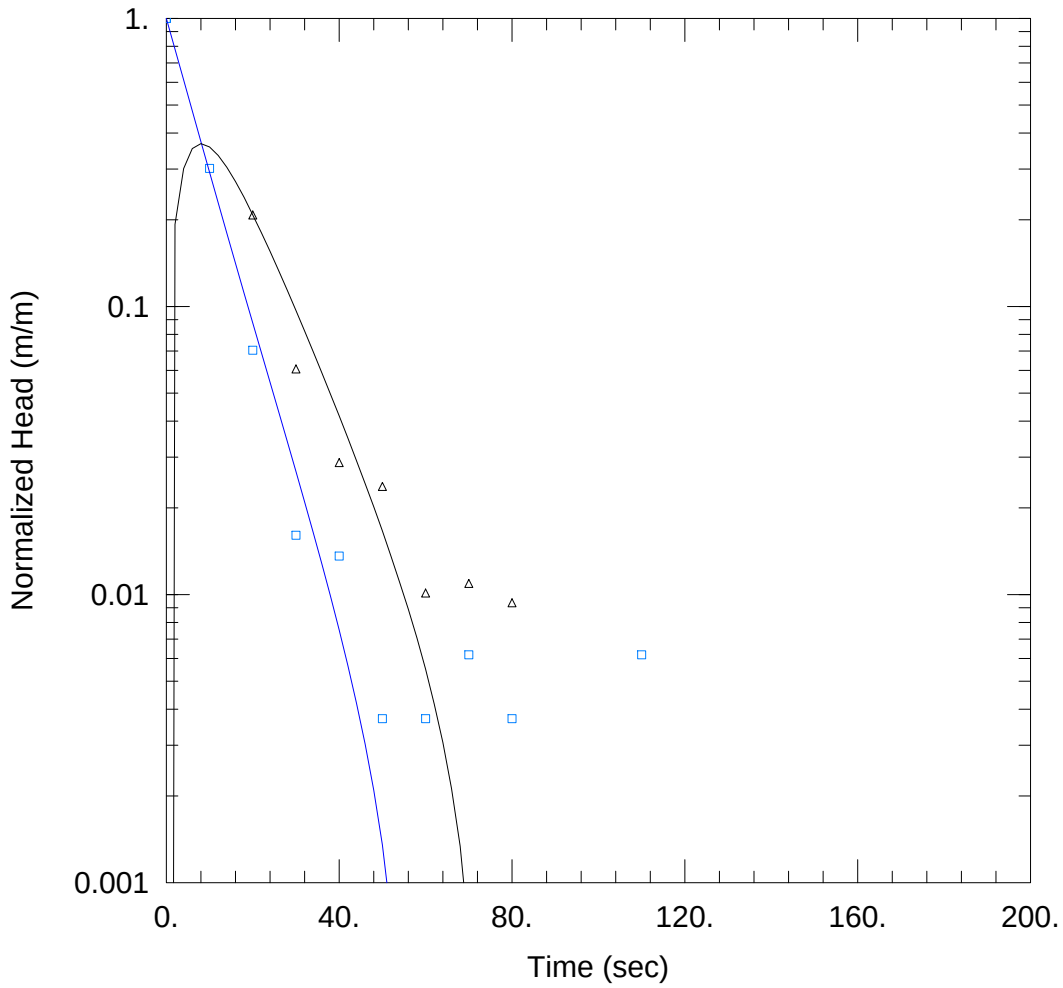
WELL DATA (RAU12HYD16(D) Slug in)

Initial Displacement: 0.435 m
Total Well Penetration Depth: 32.09 m
Casing Radius: 0.025 m
Static Water Column Height: 32.59 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 3.498 m/day
Kz/Kr = 1.
Ss = 3.068E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:03:52

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 32.59 m

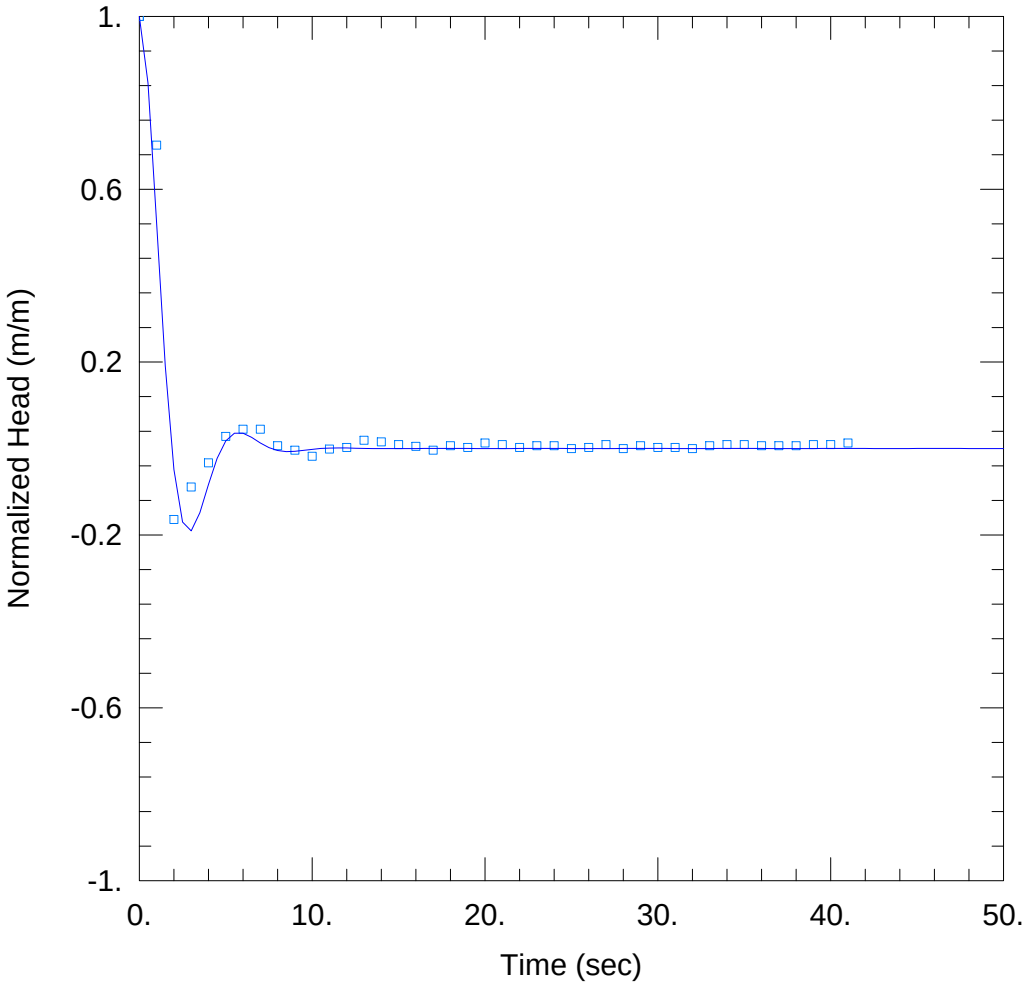
WELL DATA (RAU12HYD16(D) Slug out)

Initial Displacement: 0.809 m
Total Well Penetration Depth: 32.09 m
Casing Radius: 0.025 m
Static Water Column Height: 32.59 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.256 m/day
Kz/Kr = 1.
Ss = 3.068E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(S)_SlugIn2.aqt
Date: 10/22/12 Time: 15:03:56

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

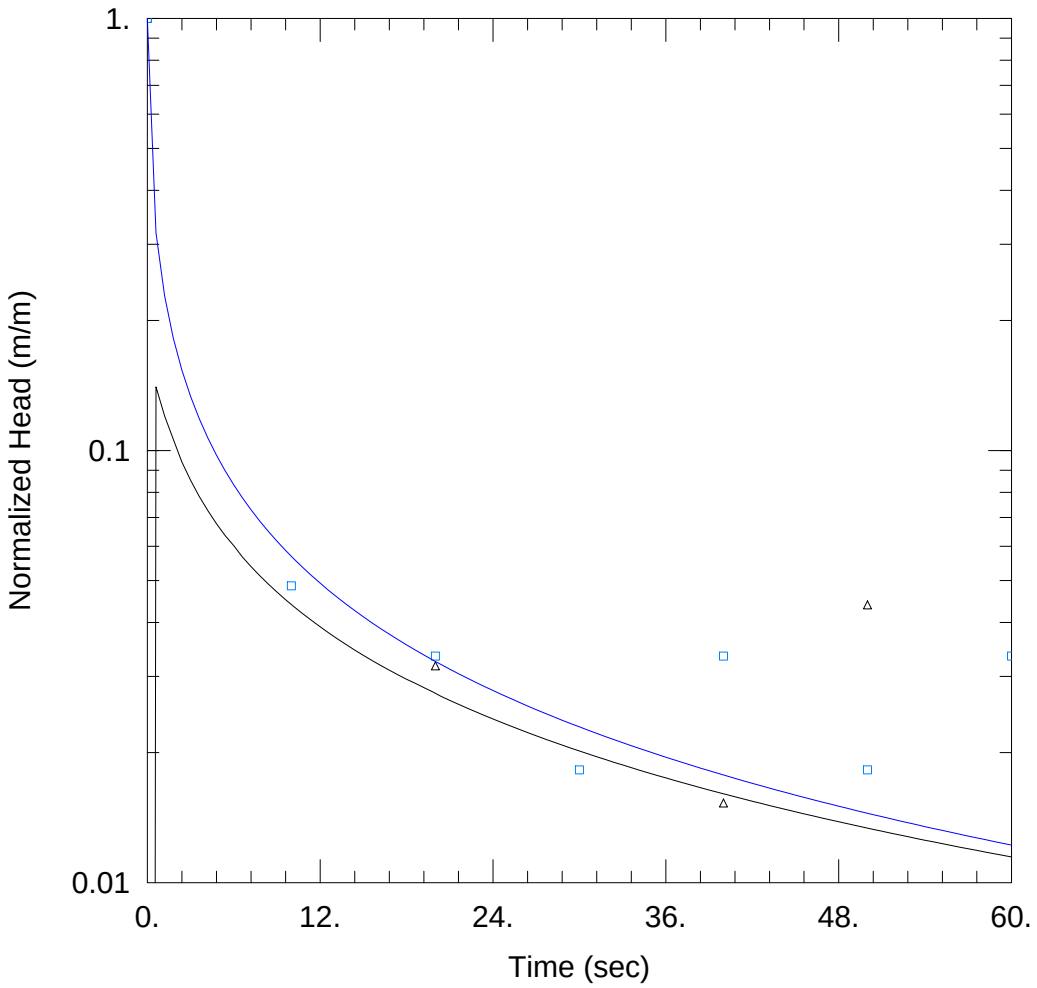
Saturated Thickness: 12.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD16(S) Slug in 2)

Initial Displacement: 0.785 m
Total Well Penetration Depth: 10.52 m
Casing Radius: 0.025 m
Static Water Column Height: 12.52 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 36.06 m/day
Le = 6.424 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(S)_SlugOut1.aqt
Date: 10/22/12 Time: 15:04:01

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 12.52 m

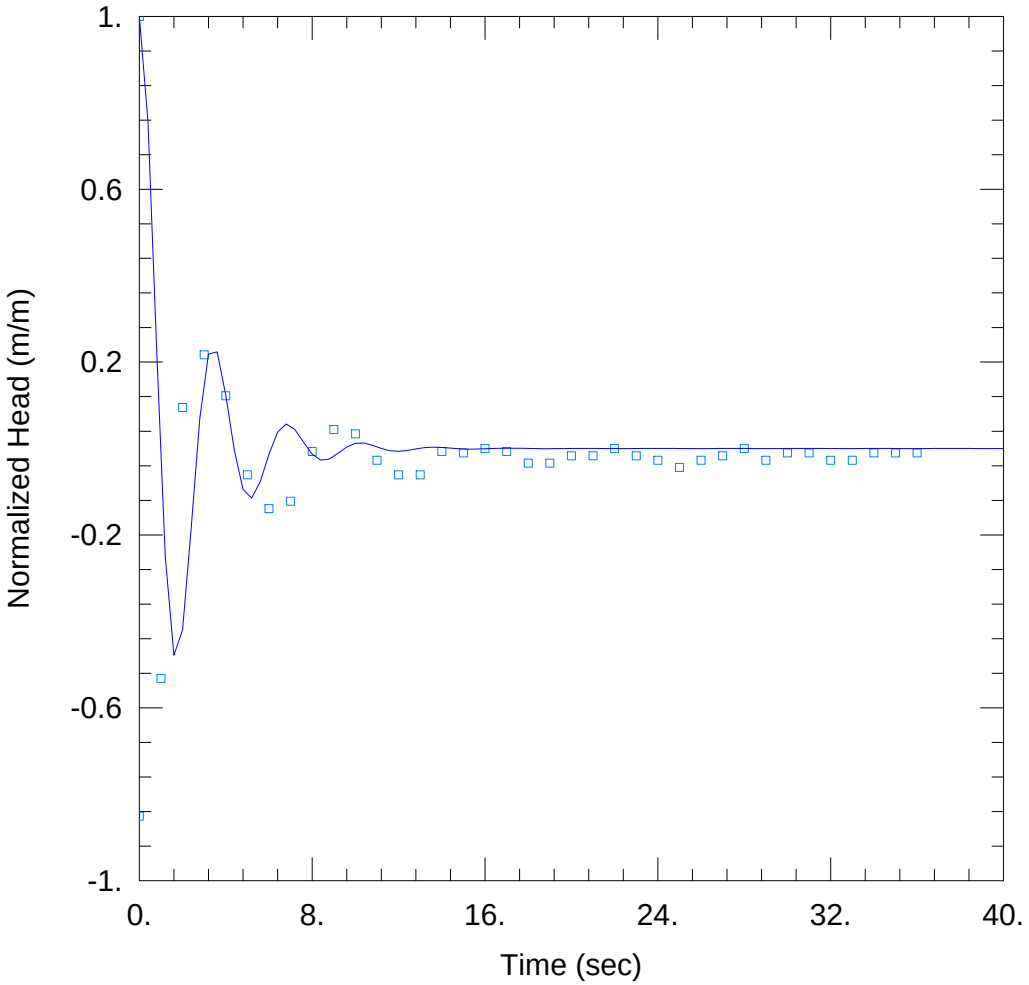
WELL DATA (RAU12HYD16(S) Slug out)

Initial Displacement: 0.329 m
Total Well Penetration Depth: 10.52 m
Casing Radius: 0.025 m
Static Water Column Height: 12.52 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.856 m/day
Kz/Kr = 1.
Ss = 0.07987 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD16(S)_SlugOut2.aqt
Date: 10/22/12 Time: 15:04:06

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

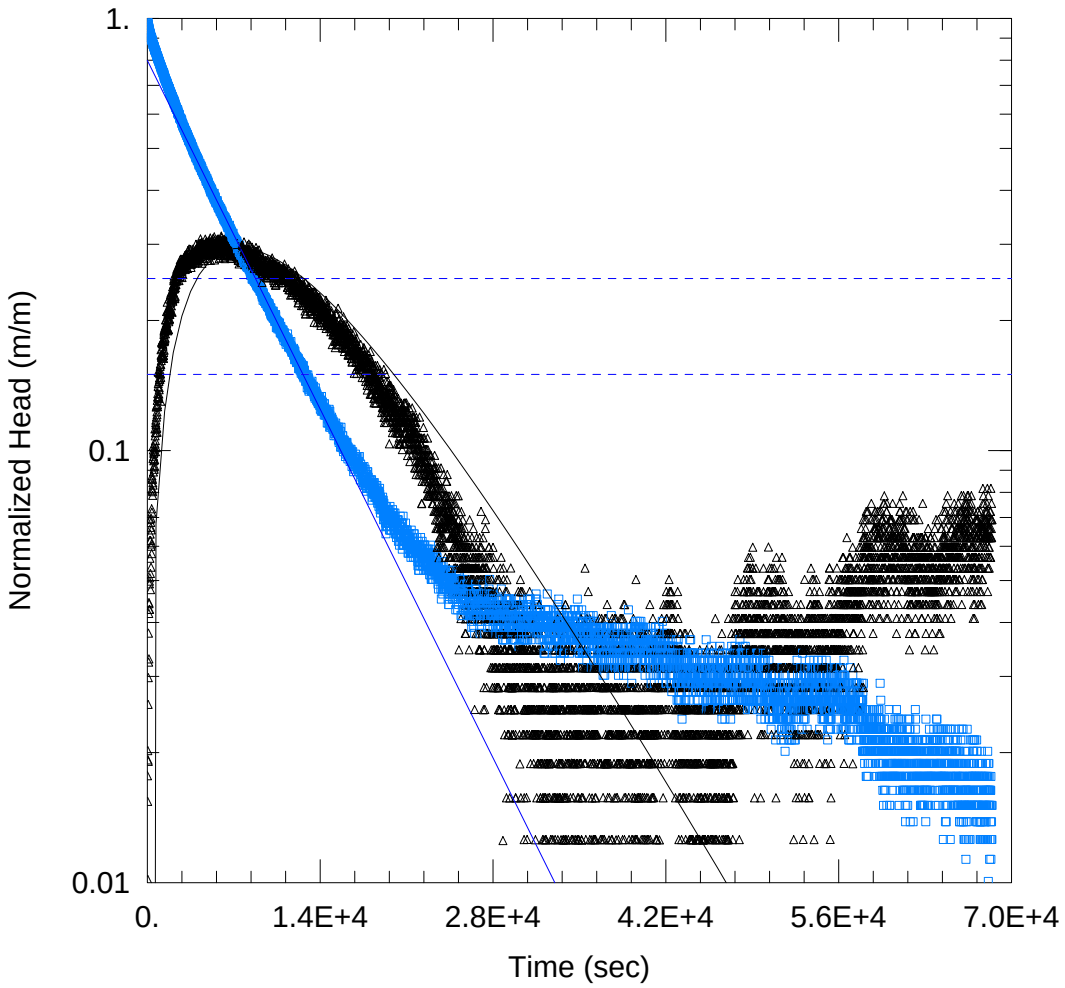
Saturated Thickness: 12.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD16(S) Slug out 2)

Initial Displacement: 0.295 m
Total Well Penetration Depth: 10.52 m
Casing Radius: 0.025 m
Static Water Column Height: 12.52 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 120.3 m/day
Le = 2.744 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12Geotech16_FHT.aqt
Date: 10/22/12 Time: 14:52:45

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

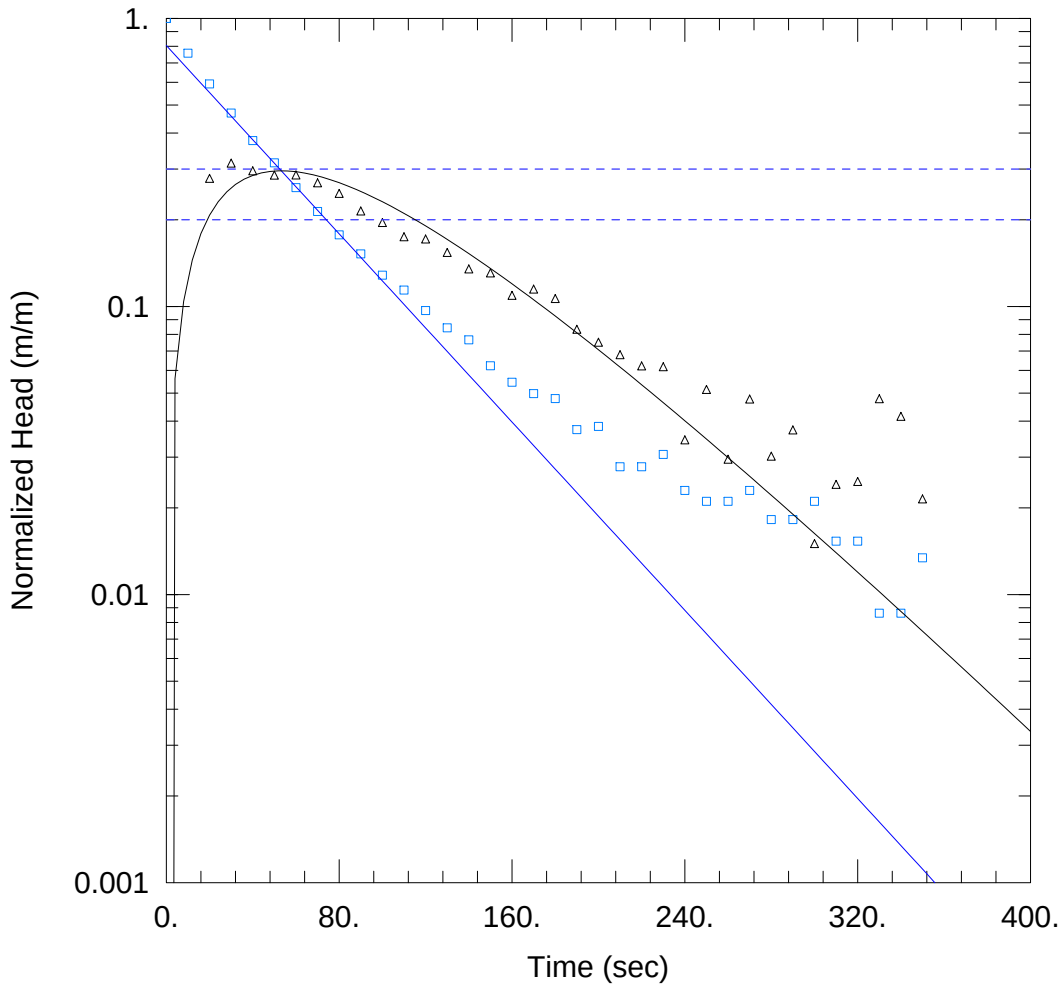
Saturated Thickness: 6.46 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12geotech16 FHT)

Initial Displacement: 0.795 m
Total Well Penetration Depth: 6.46 m
Casing Radius: 0.025 m
Static Water Column Height: 6.46 m
Screen Length: 0.01 m
Well Radius: 0.025 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.1398 m/day
y0 = 0.6356 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(D)_FHT.aqt
Date: 10/22/12 Time: 15:04:15

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

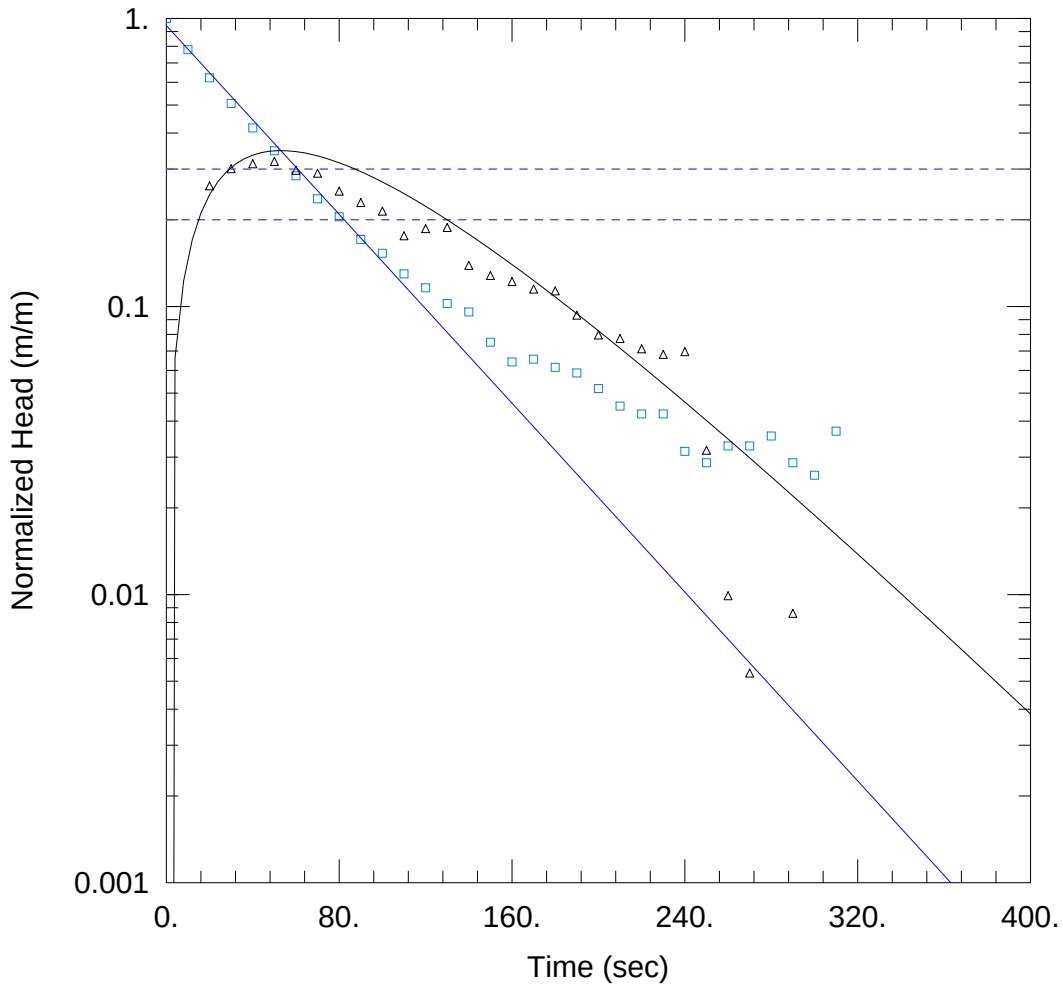
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD17(D) FHT)

Initial Displacement: 1.044 m
Total Well Penetration Depth: 34.58 m
Casing Radius: 0.025 m
Static Water Column Height: 35.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.7258 m/day
y0 = 0.84 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:04:20

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

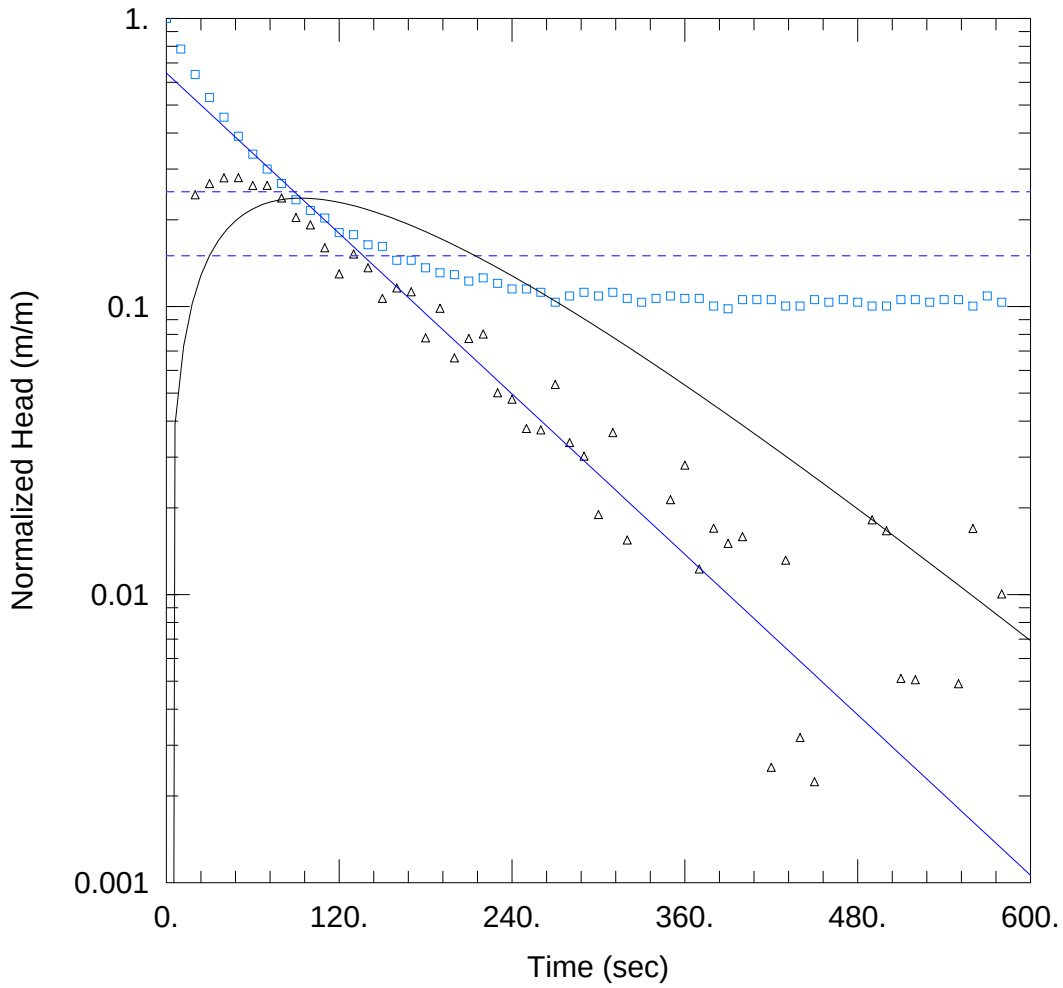
WELL DATA (RAU12HYD17(D) Slug In)

Initial Displacement: 0.732 m
Total Well Penetration Depth: 34.58 m
Casing Radius: 0.025 m
Static Water Column Height: 35.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.7283 m/day
y0 = 0.6919 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:04:24

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

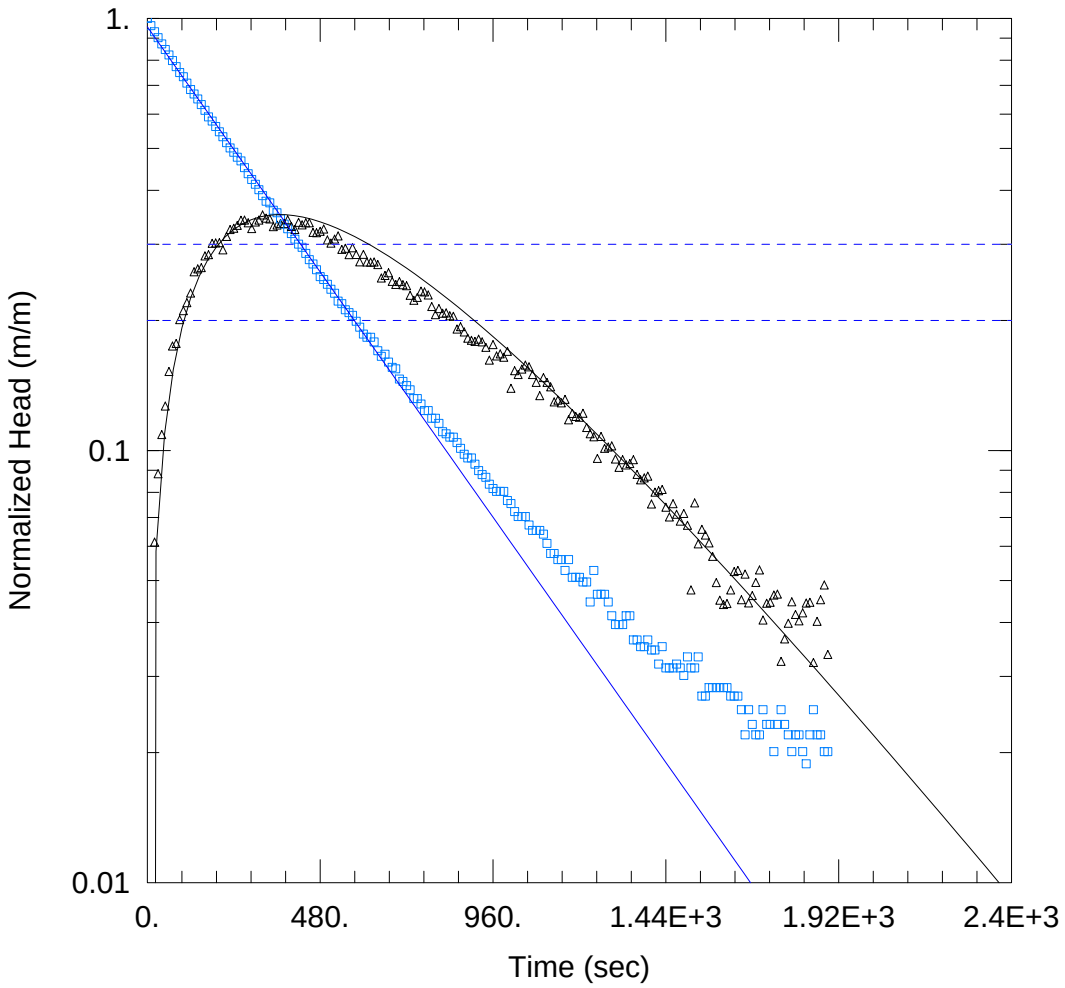
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD17(D) Slug out)

Initial Displacement: 0.947 m
Total Well Penetration Depth: 34.58 m
Casing Radius: 0.025 m
Static Water Column Height: 35.08 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.4282 m/day
y0 = 0.6121 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(S)_FHT.aqt
Date: 10/22/12 Time: 15:04:28

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

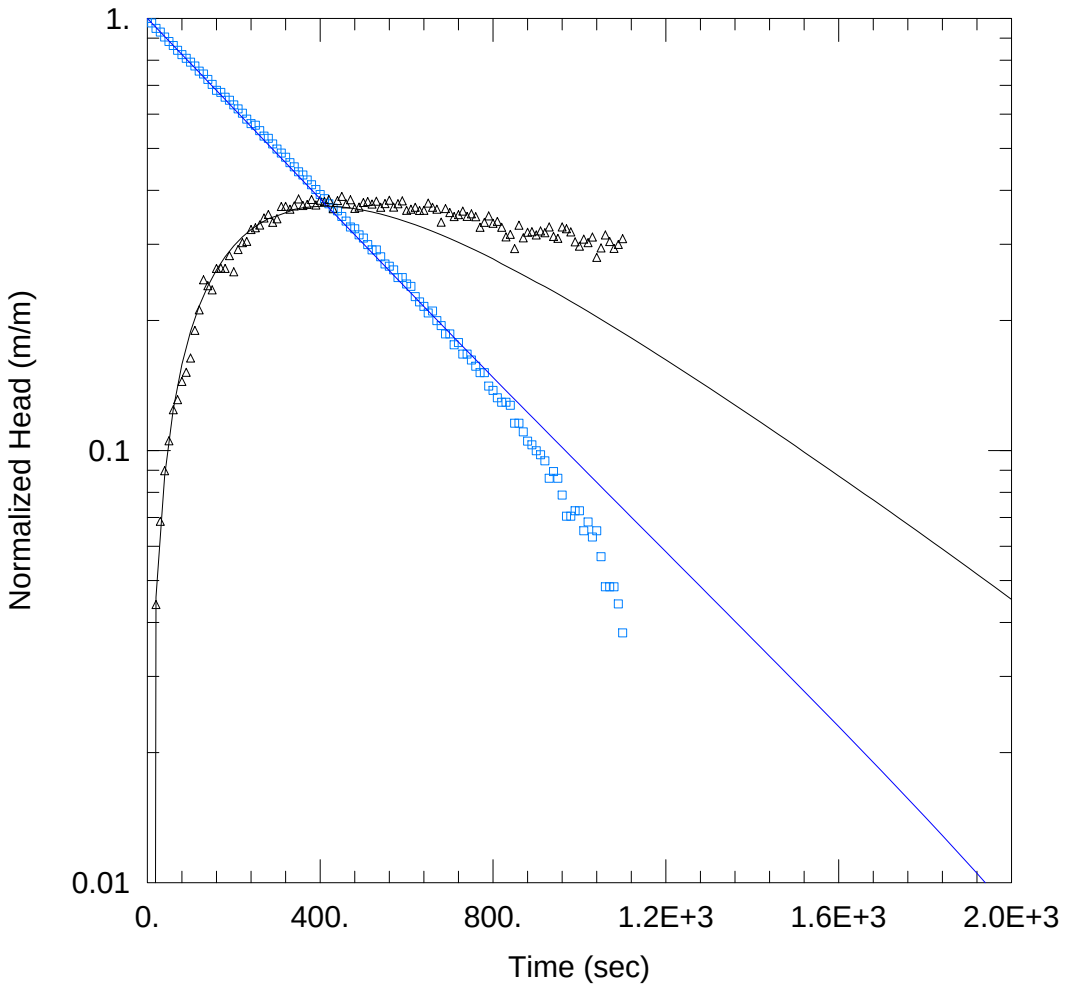
Saturated Thickness: 14.82 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD17(S) FHT)

Initial Displacement: 1.592 m
Total Well Penetration Depth: 12.82 m
Casing Radius: 0.025 m
Static Water Column Height: 14.82 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.07421 m/day
y0 = 1.522 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:04:32

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

Saturated Thickness: 14.82 m

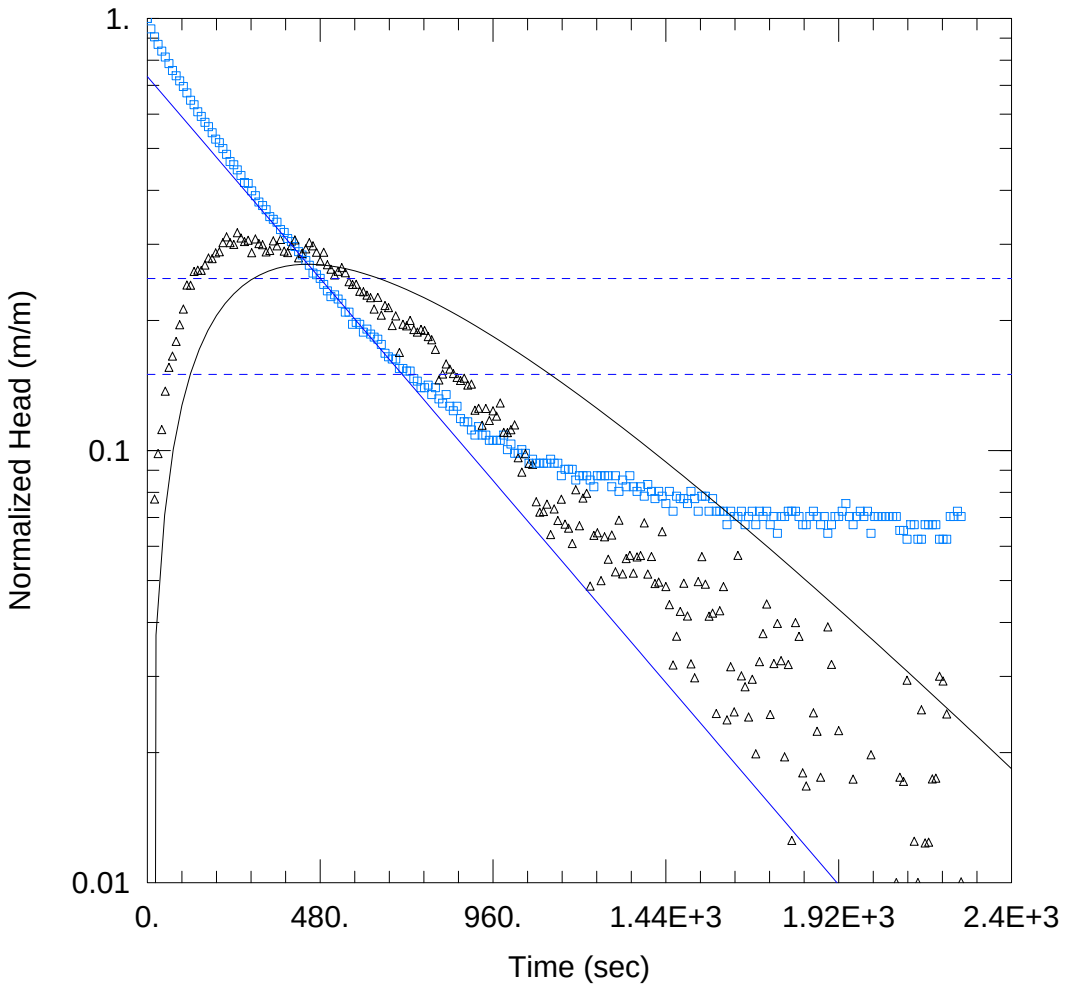
WELL DATA (RAU12HYD17(S) Slug in)

Initial Displacement: 0.951 m
Total Well Penetration Depth: 12.82 m
Casing Radius: 0.025 m
Static Water Column Height: 14.82 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.07338 m/day
Kz/Kr = 1.
Ss = 6.748E-12 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD17(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:04:36

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD01(D)
Test Date: 8/6/2012

AQUIFER DATA

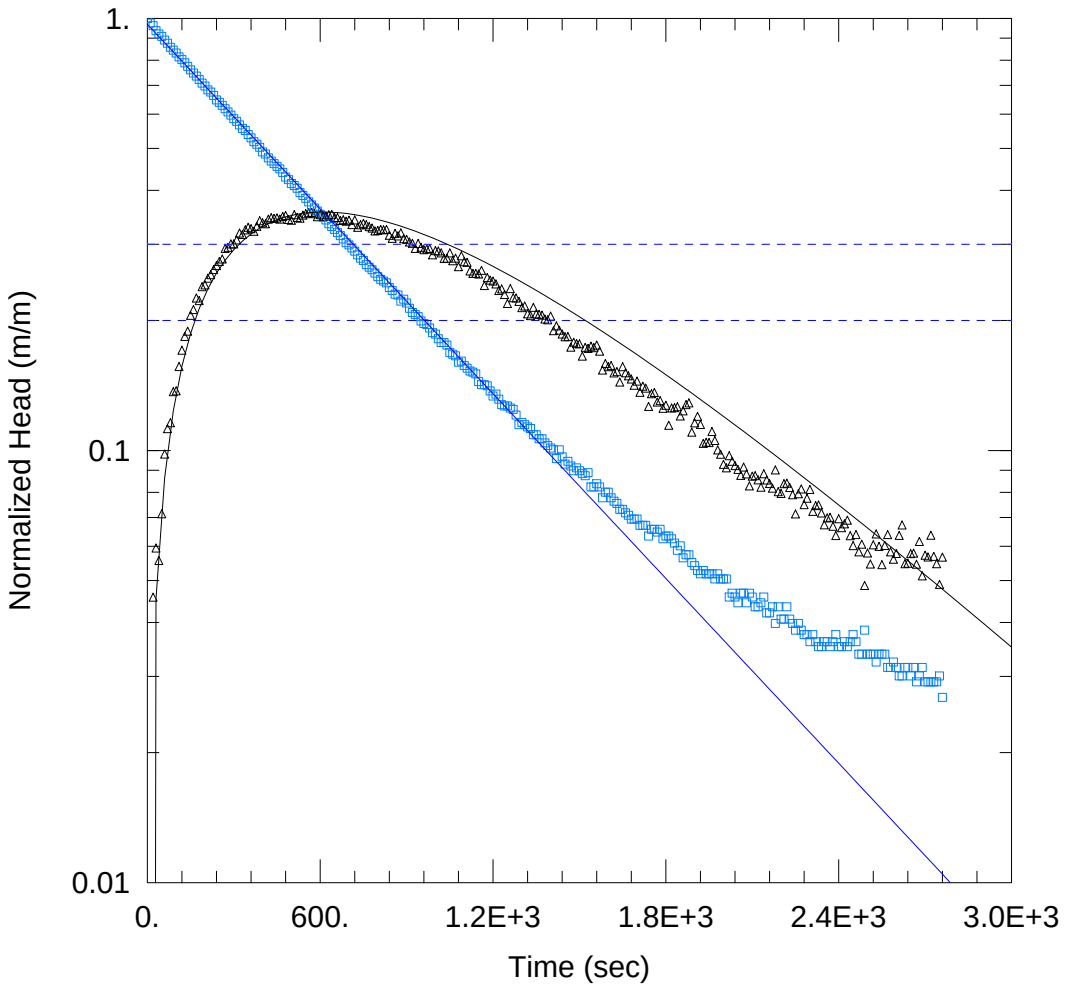
Saturated Thickness: 14.82 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD17(S) Slug out)

Initial Displacement: 0.995 m
Total Well Penetration Depth: 12.82 m
Casing Radius: 0.025 m
Static Water Column Height: 14.82 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.07219 m/day
y0 = 0.73 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(D)_FHT.aqt
Date: 10/22/12 Time: 15:04:40

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

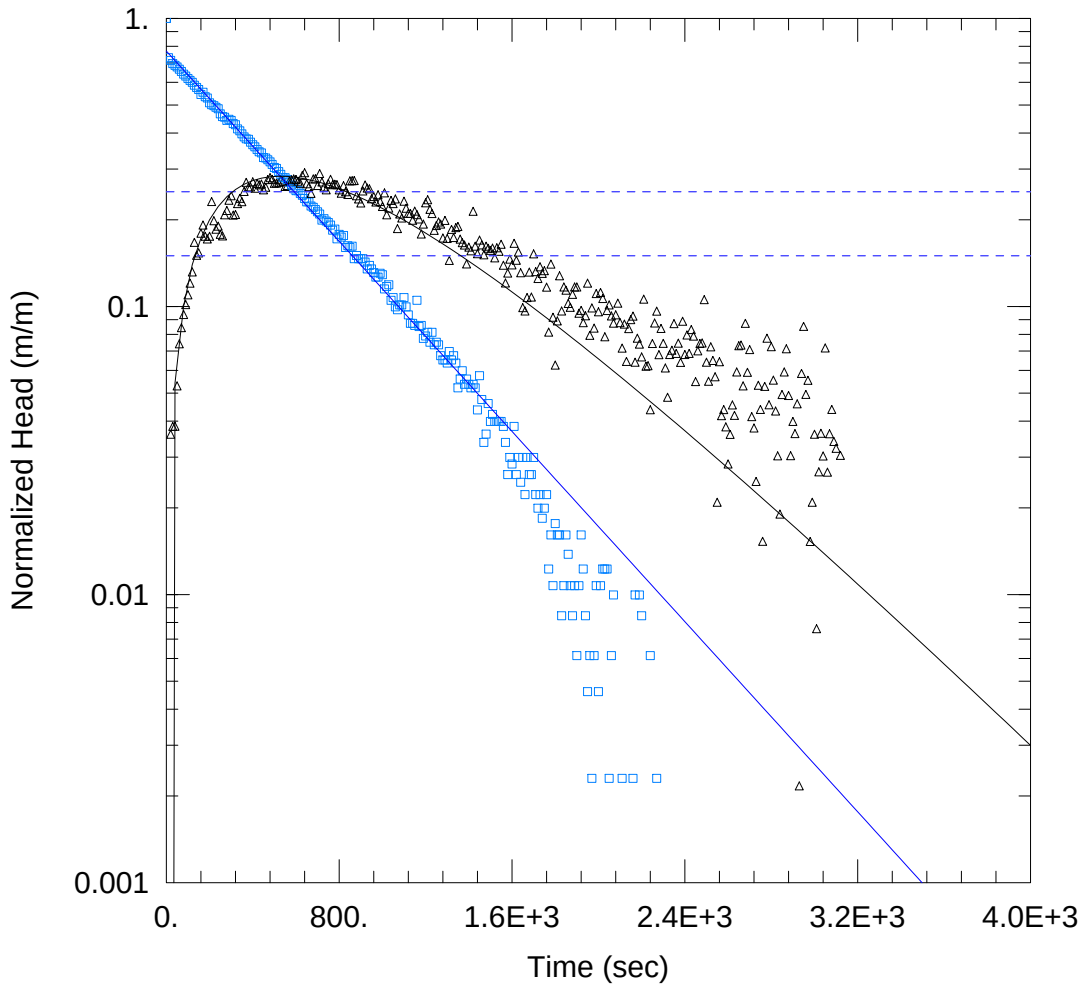
Saturated Thickness: 21.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(D) FHT)

Initial Displacement: 2.161 m
Total Well Penetration Depth: 21.02 m
Casing Radius: 0.025 m
Static Water Column Height: 21.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.05265 m/day
y0 = 2.095 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:04:44

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

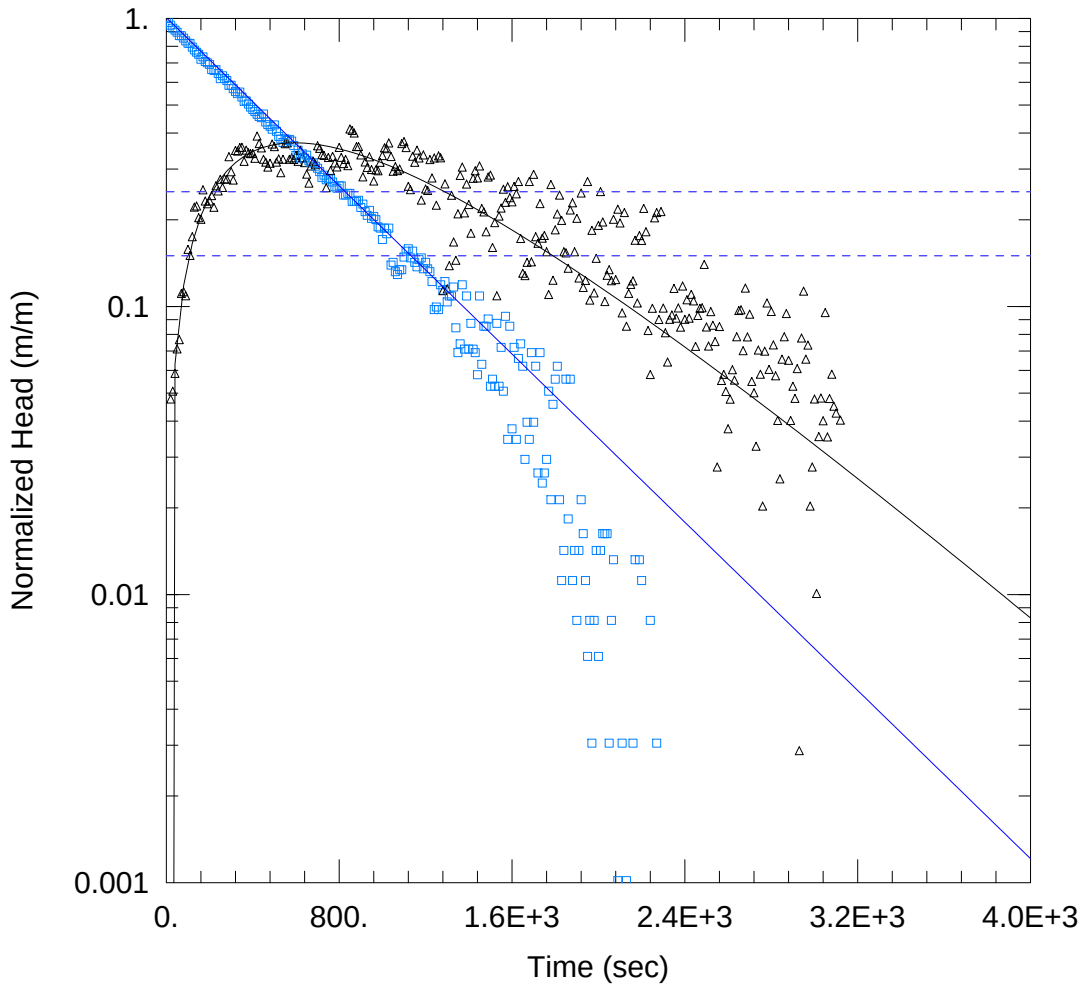
Saturated Thickness: 21.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(D) Slug in)

Initial Displacement: 1.304 m
Total Well Penetration Depth: 21.02 m
Casing Radius: 0.025 m
Static Water Column Height: 21.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.06427 m/day
y0 = 1.004 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:04:48

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

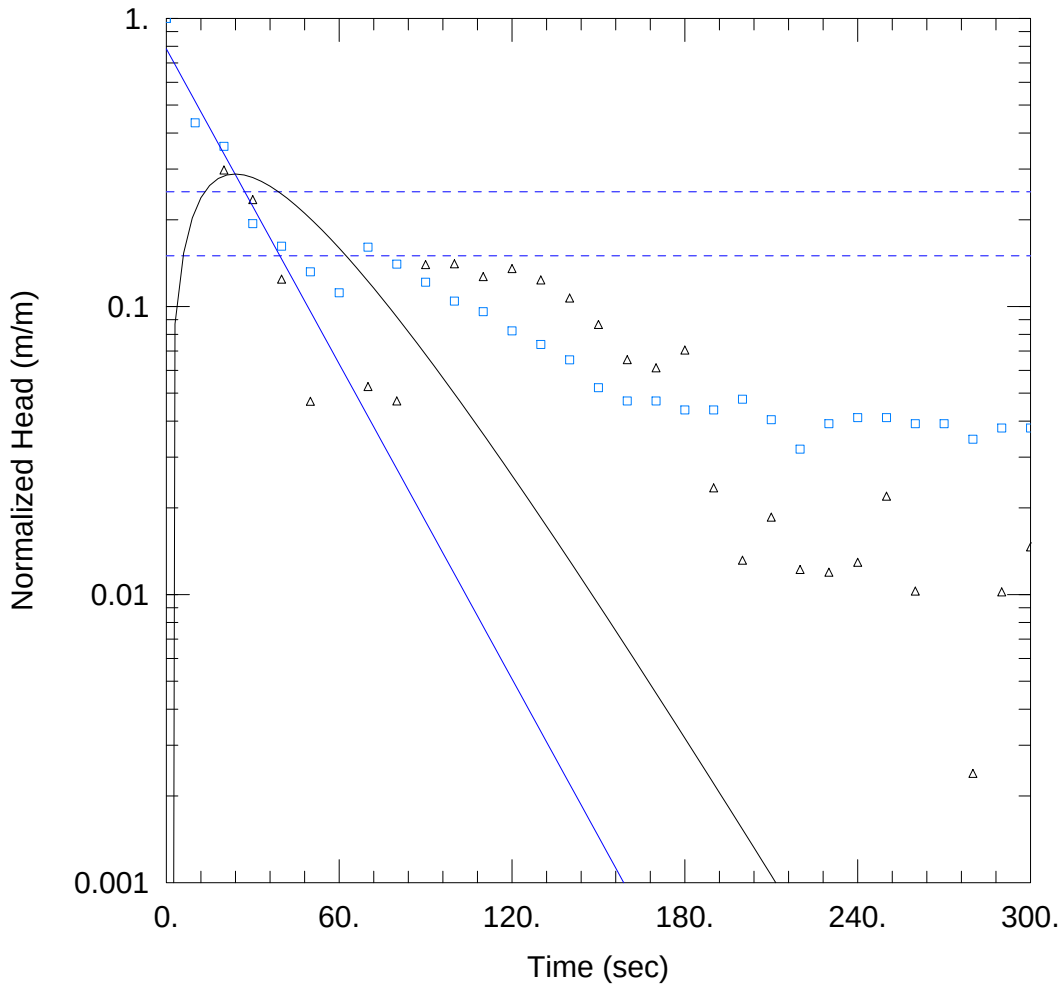
Saturated Thickness: 21.52 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(D) Slug out)

Initial Displacement: 0.984 m
Total Well Penetration Depth: 21.02 m
Casing Radius: 0.025 m
Static Water Column Height: 21.52 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.05685 m/day
y0 = 0.9897 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(S)_FHT.aqt
Date: 10/22/12 Time: 15:04:52

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

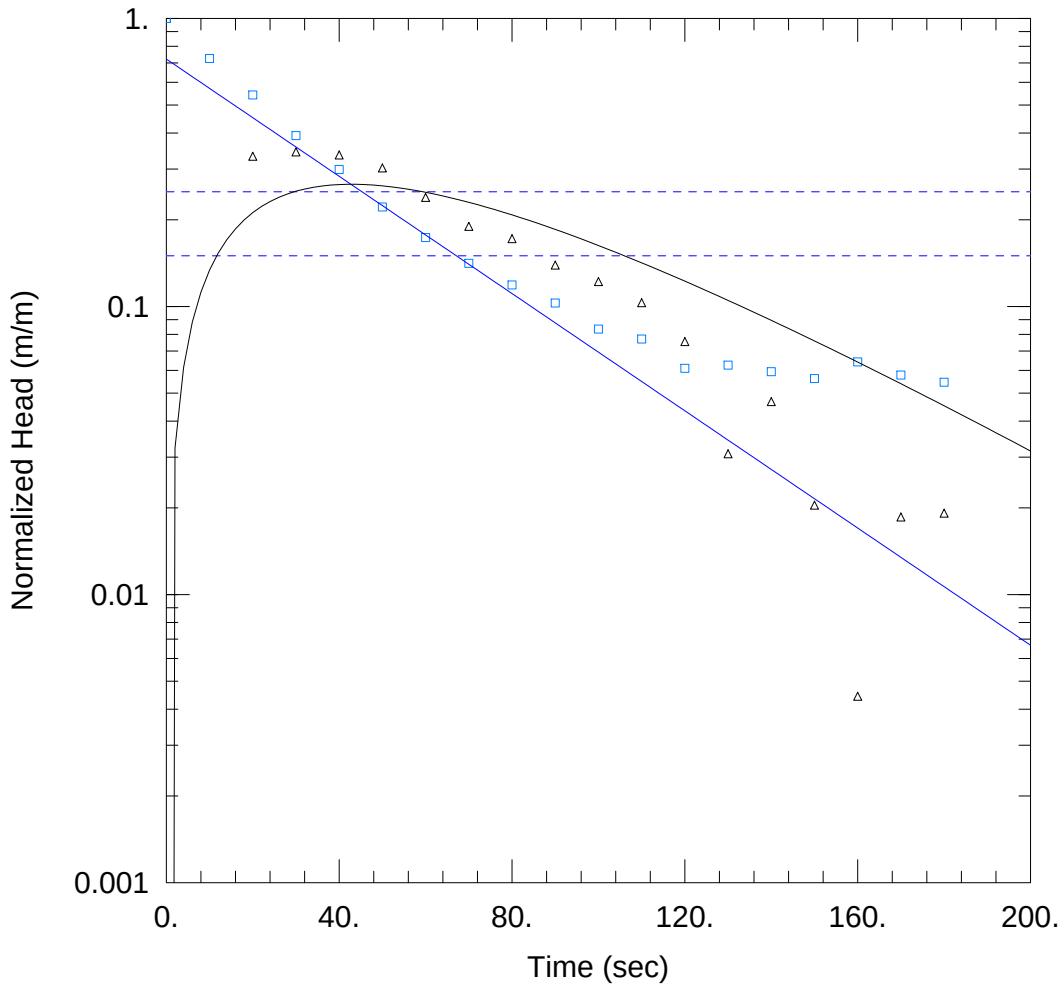
Saturated Thickness: 2.16 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(S) FHT)

Initial Displacement: 1.532 m
Total Well Penetration Depth: 2.41 m
Casing Radius: 0.025 m
Static Water Column Height: 2.16 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 3.594 m/day
y0 = 1.201 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:04:56

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

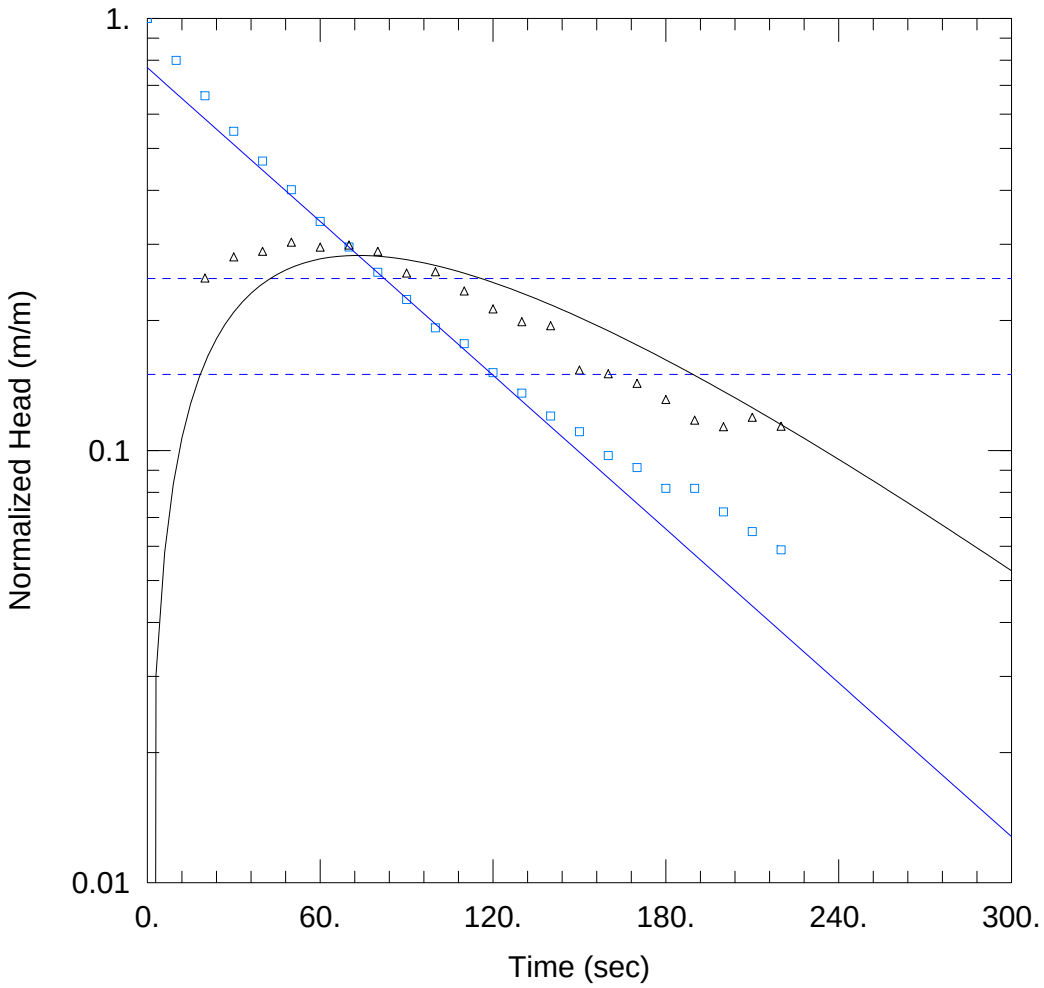
Saturated Thickness: 2.16 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(S) slug in)

Initial Displacement: 0.623 m
Total Well Penetration Depth: 2.41 m
Casing Radius: 0.025 m
Static Water Column Height: 2.16 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 2.006 m/day
y0 = 0.45 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD18(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:05:01

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

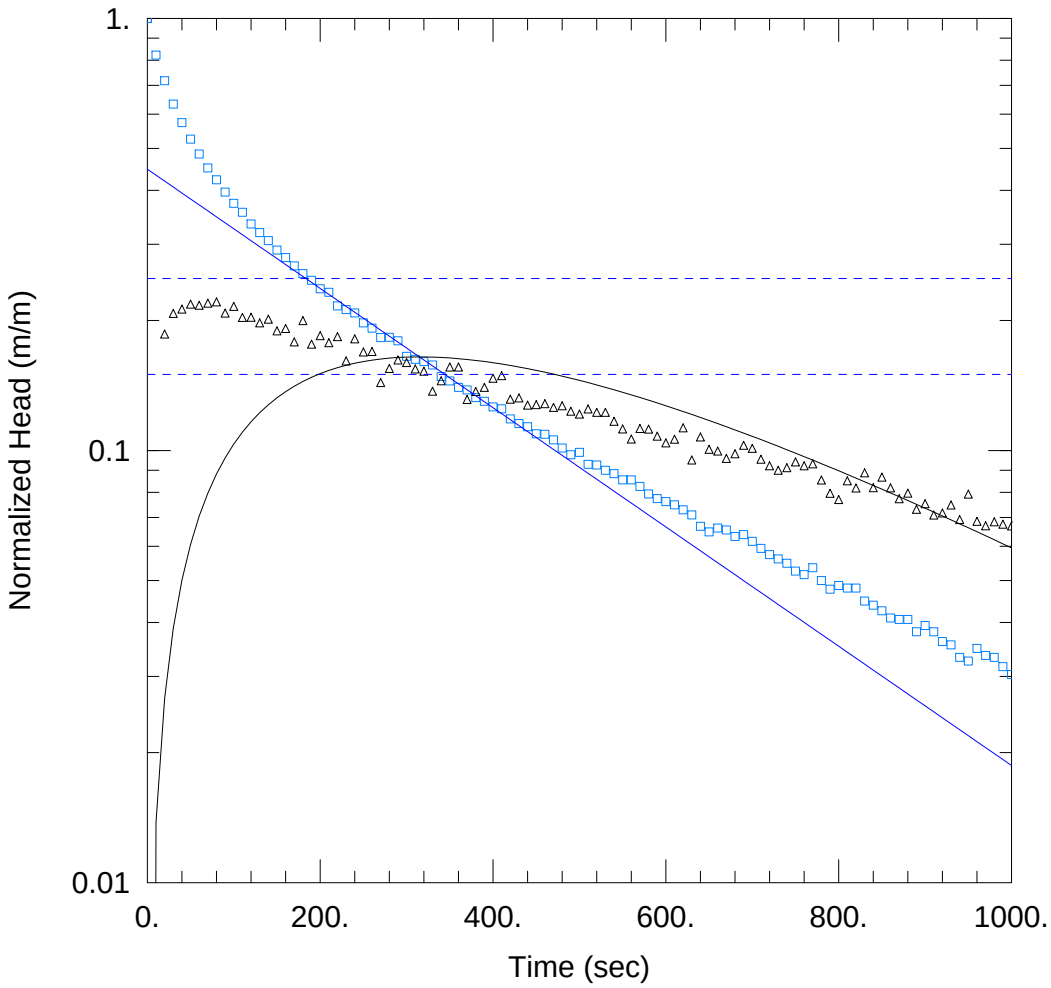
Saturated Thickness: 2.16 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD18(S) slug out)

Initial Displacement: 0.832 m
Total Well Penetration Depth: 2.41 m
Casing Radius: 0.025 m
Static Water Column Height: 2.16 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.17 m/day
y0 = 0.6398 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD19(D)_FHT.aqt
Date: 10/22/12 Time: 15:05:04

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

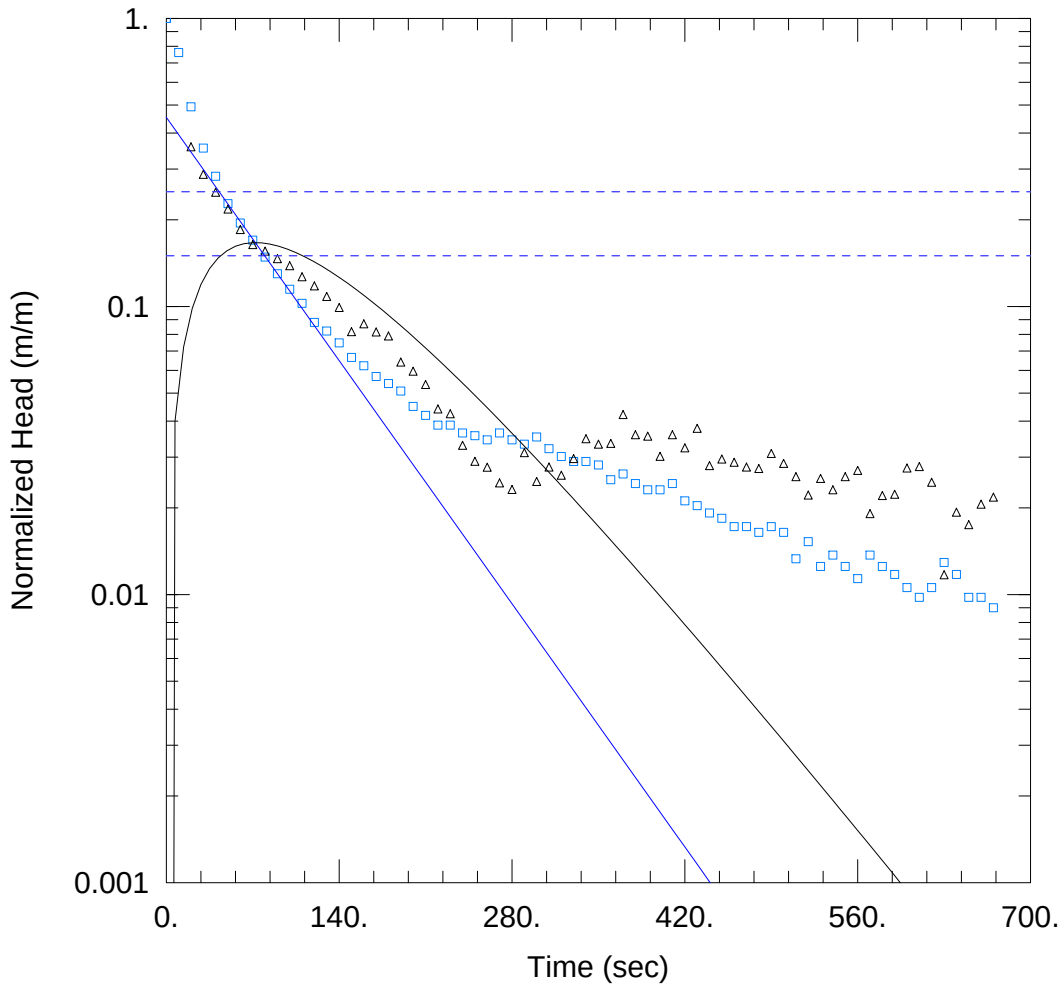
Saturated Thickness: 36.69 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD19(D) FHT)

Initial Displacement: 3.1 m
Total Well Penetration Depth: 36.19 m
Casing Radius: 0.025 m
Static Water Column Height: 36.69 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.1075 m/day
y0 = 1.388 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD19(S)_FHT1.aqt
Date: 10/22/12 Time: 15:05:10

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

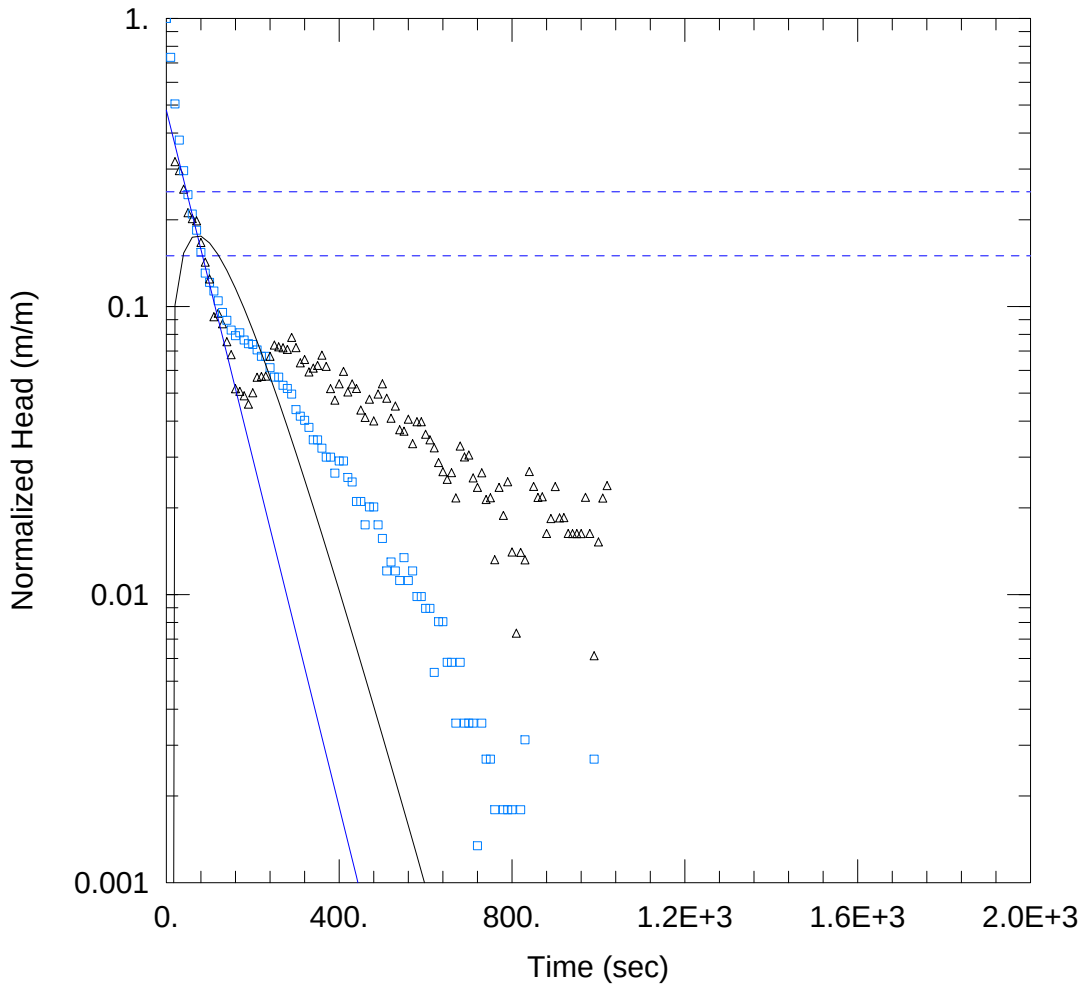
Saturated Thickness: 28.75 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD19(S) FHT 1)

Initial Displacement: 2.555 m
Total Well Penetration Depth: 24.75 m
Casing Radius: 0.025 m
Static Water Column Height: 28.75 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.4468 m/day
y0 = 1.158 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD19(S)_FHT2.aqt
Date: 10/22/12 Time: 15:05:14

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

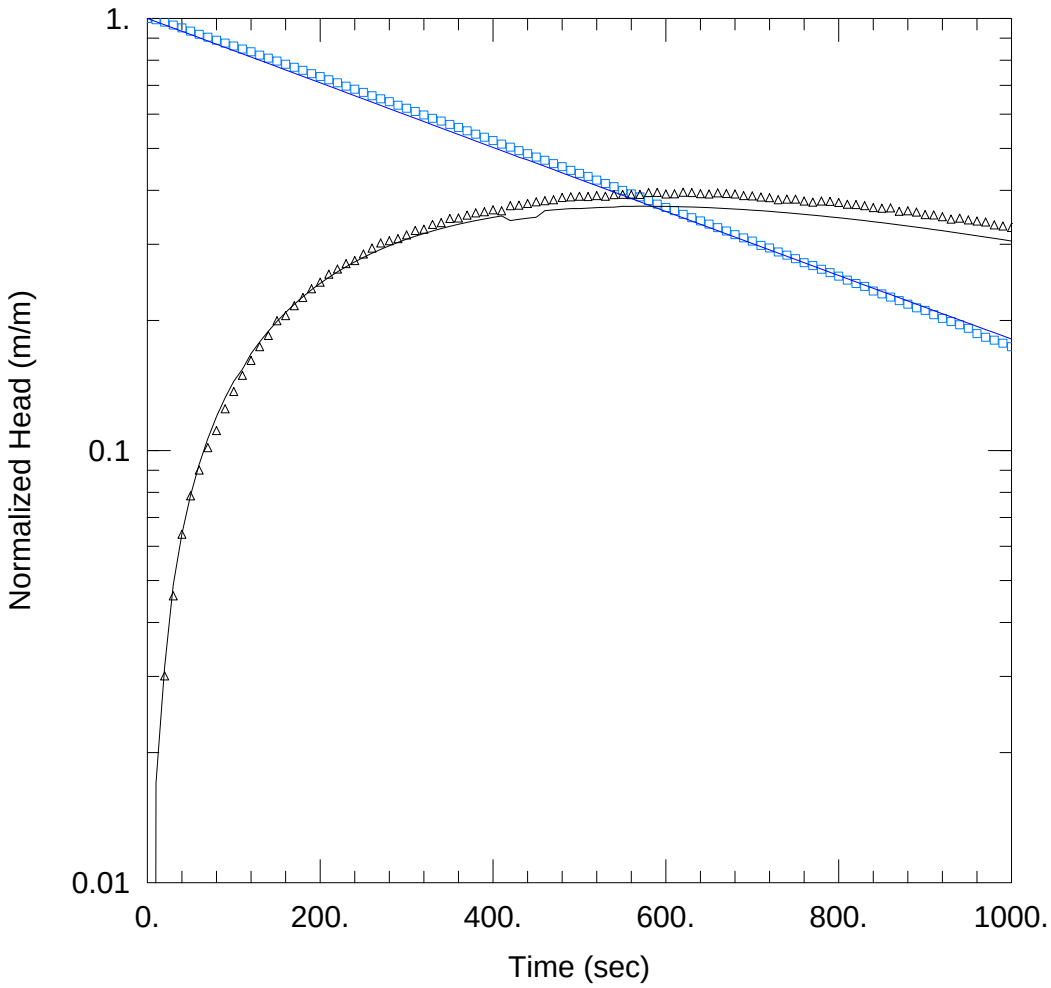
Saturated Thickness: 28.75 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD19(S) FHT 2)

Initial Displacement: 2.235 m
Total Well Penetration Depth: 24.75 m
Casing Radius: 0.025 m
Static Water Column Height: 28.75 m
Screen Length: 3. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.4542 m/day
y0 = 1.073 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD20(D)_FHT.aqt
Date: 10/22/12 Time: 15:05:20

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 41.57 m

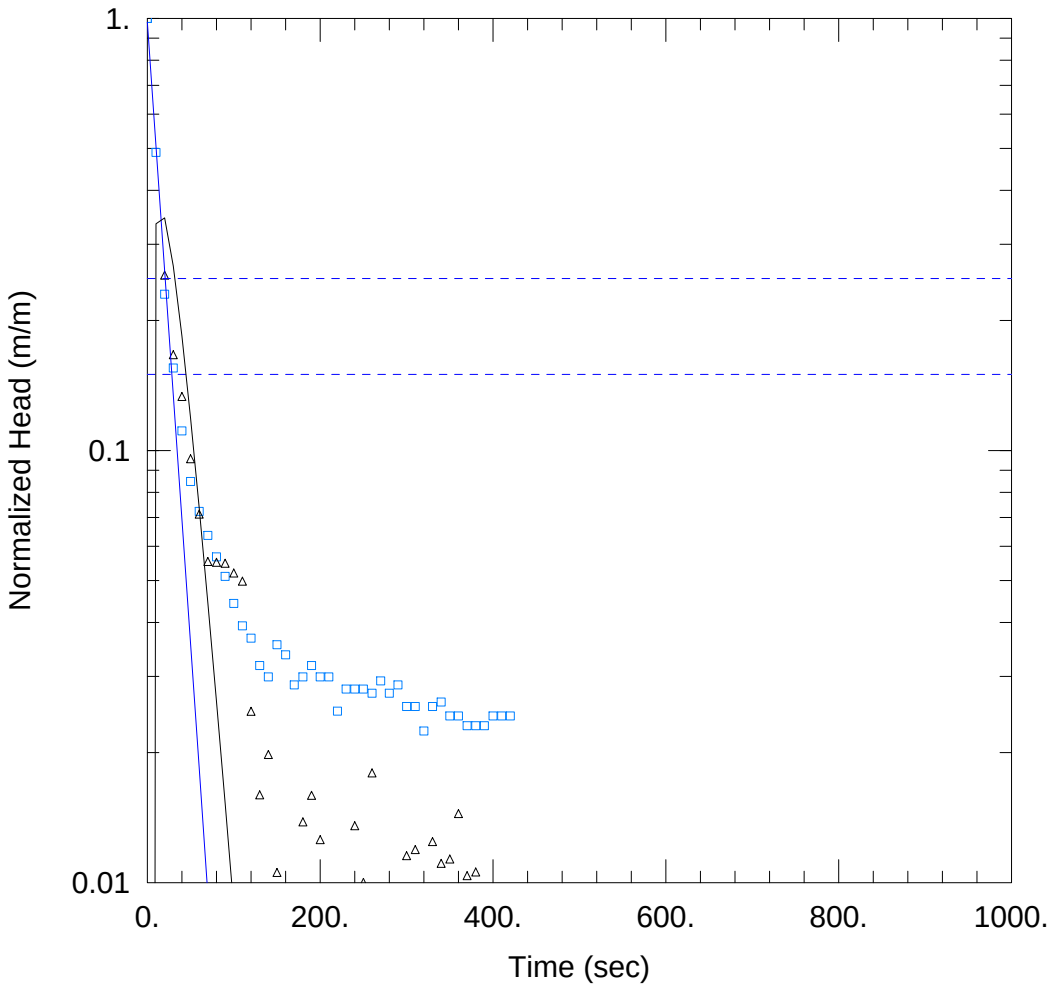
WELL DATA (RAU12HYD20(D) FHT)

Initial Displacement: 6.278 m
Total Well Penetration Depth: 41.07 m
Casing Radius: 0.025 m
Static Water Column Height: 41.57 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.05948 m/day
Kz/Kr = 1.
Ss = 5.184E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD20(S)_FHT1.aqt
Date: 10/22/12 Time: 15:05:24

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

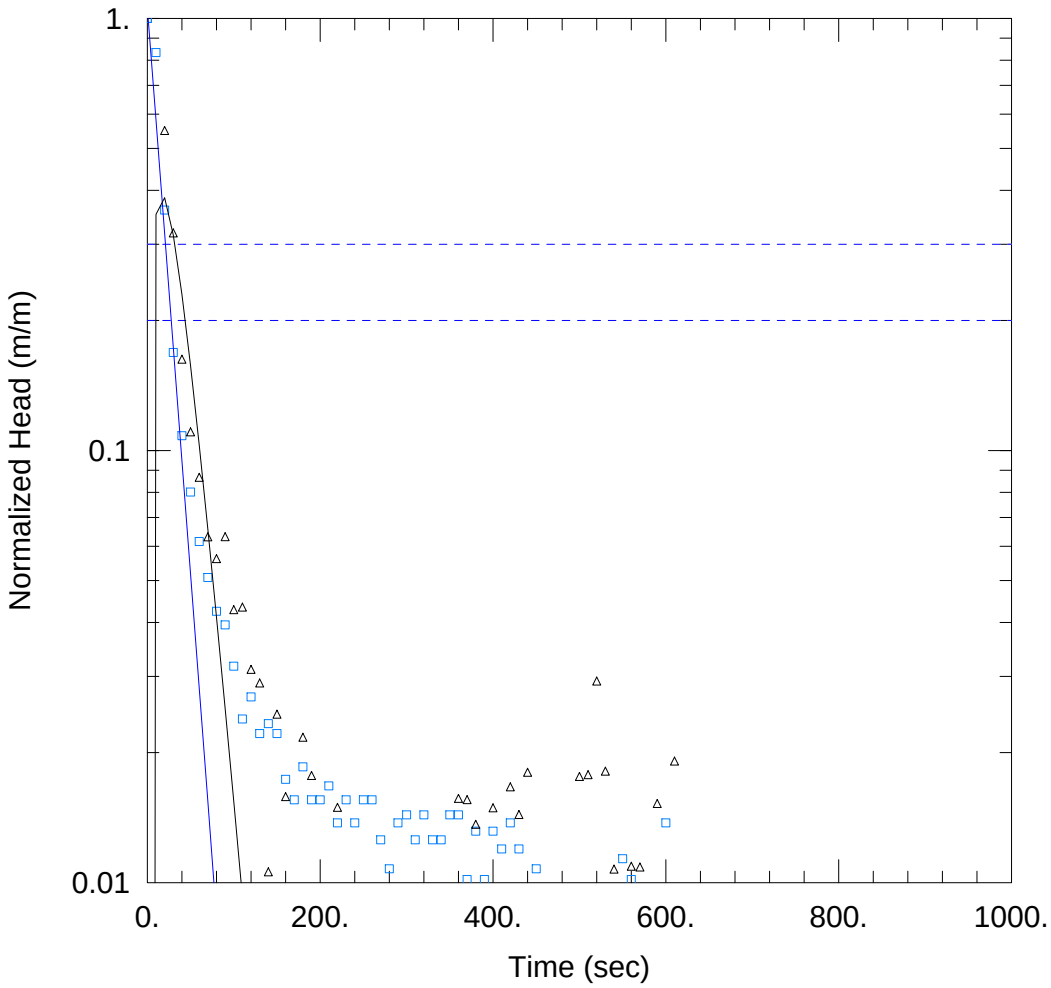
Saturated Thickness: 21.53 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD20(S) FHT 1)

Initial Displacement: 1.604 m
Total Well Penetration Depth: 18.53 m
Casing Radius: 0.025 m
Static Water Column Height: 21.53 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 2.132 m/day
y0 = 1.573 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD20(S)_FHT2.aqt
Date: 10/22/12 Time: 15:05:28

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

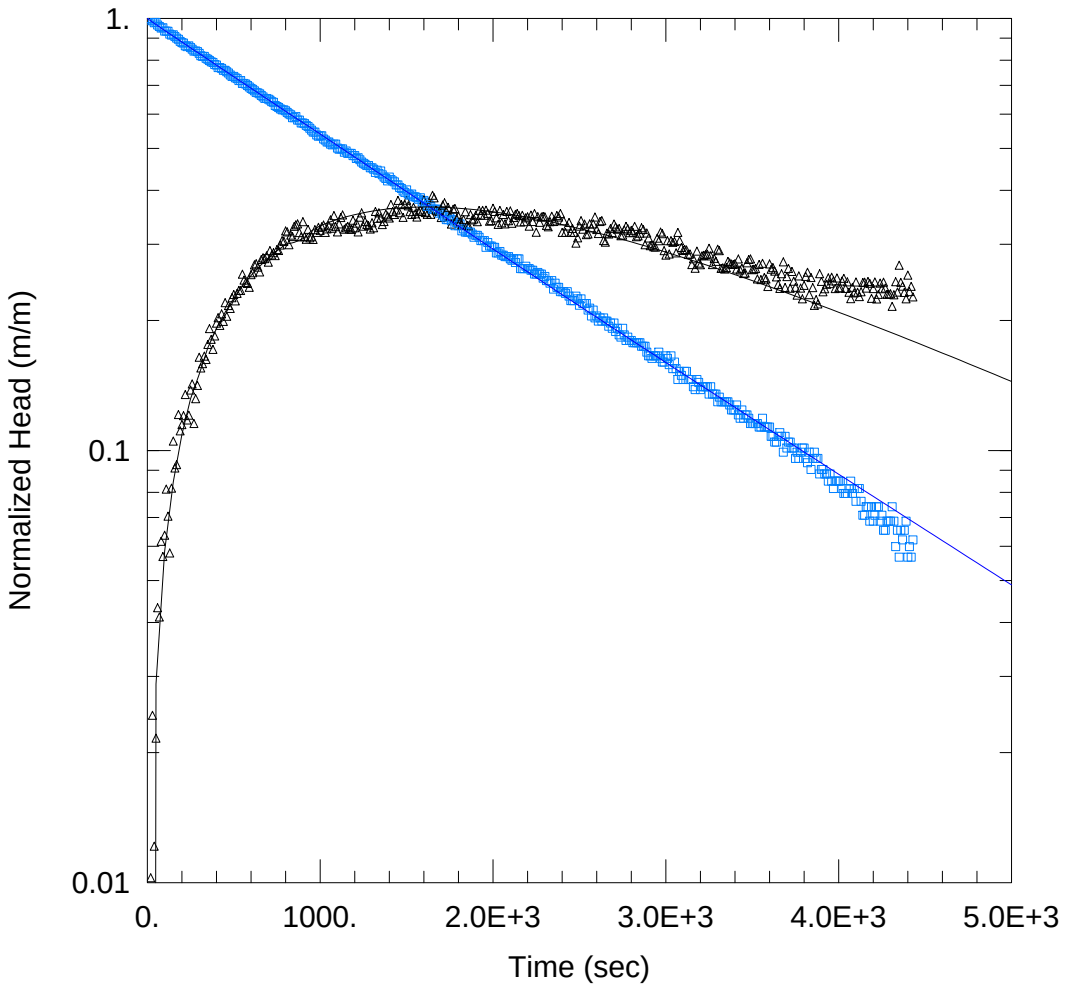
Saturated Thickness: 21.53 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD20(S) FHT 2)

Initial Displacement: 1.672 m
Total Well Penetration Depth: 18.53 m
Casing Radius: 0.025 m
Static Water Column Height: 21.53 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.702 m/day
y0 = 1.783 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD21(D)_SlugIn.aqt
Date: 10/22/12 Time: 15:05:33

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 40.07 m

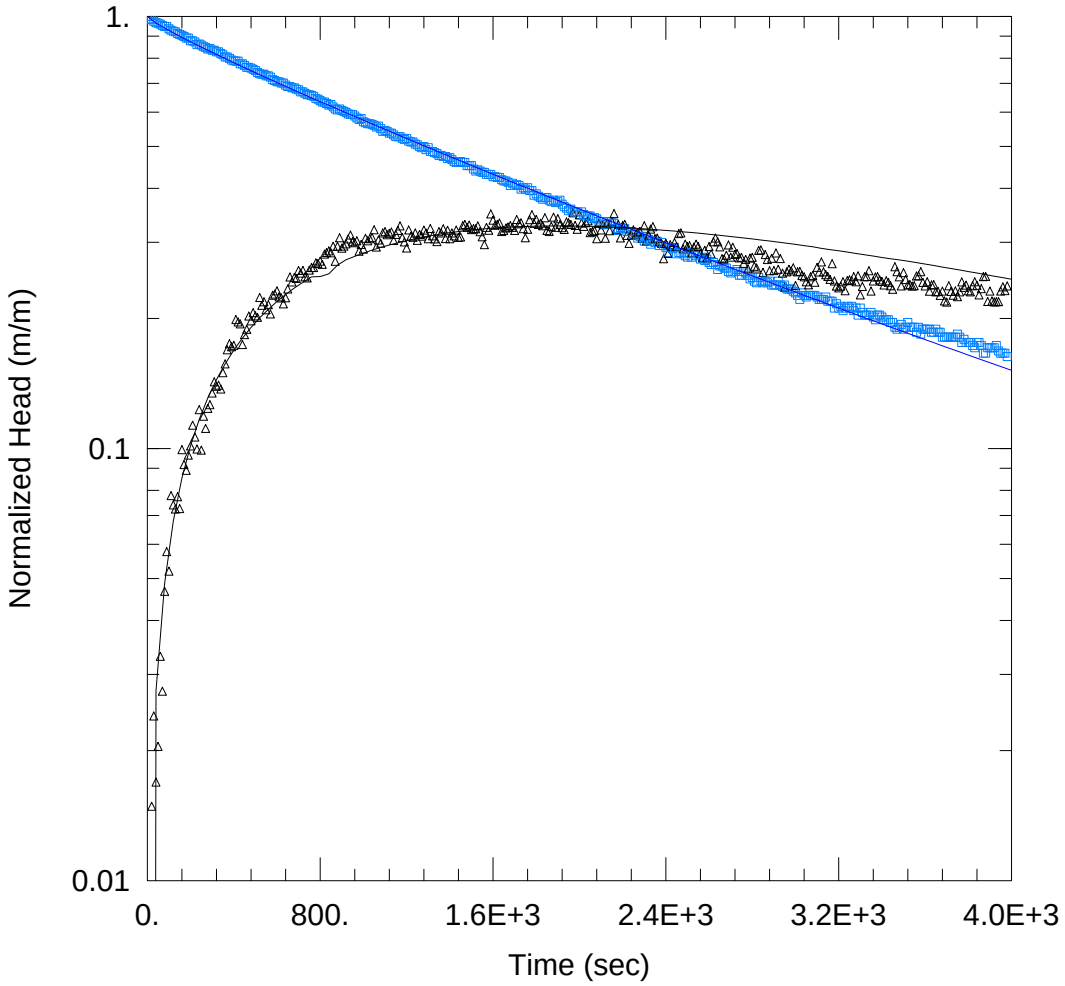
WELL DATA (RAU12HYD21(D) slug in)

Initial Displacement: 0.918 m
Total Well Penetration Depth: 39.57 m
Casing Radius: 0.025 m
Static Water Column Height: 40.07 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.02132 m/day
Kz/Kr = 1.
Ss = 1.001E-7 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD21(D)_SlugOut.aqt
Date: 10/22/12 Time: 15:05:38

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 40.07 m

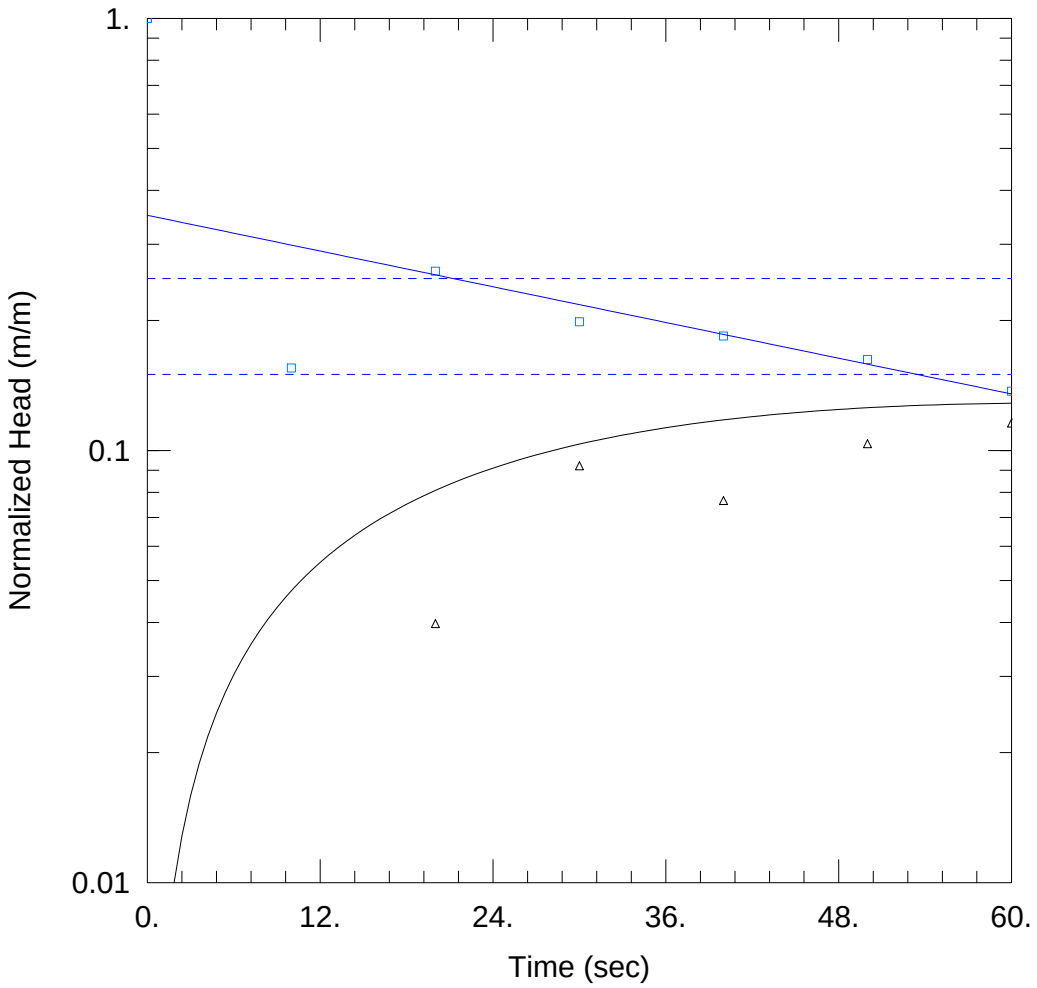
WELL DATA (RAU12HYD21(D) slug out)

Initial Displacement: 1.017 m
Total Well Penetration Depth: 39.57 m
Casing Radius: 0.025 m
Static Water Column Height: 40.07 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.01599 m/day
Kz/Kr = 1.
Ss = 2.174E-5 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD21(S)_FHT1.aqt
Date: 10/22/12 Time: 15:05:42

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

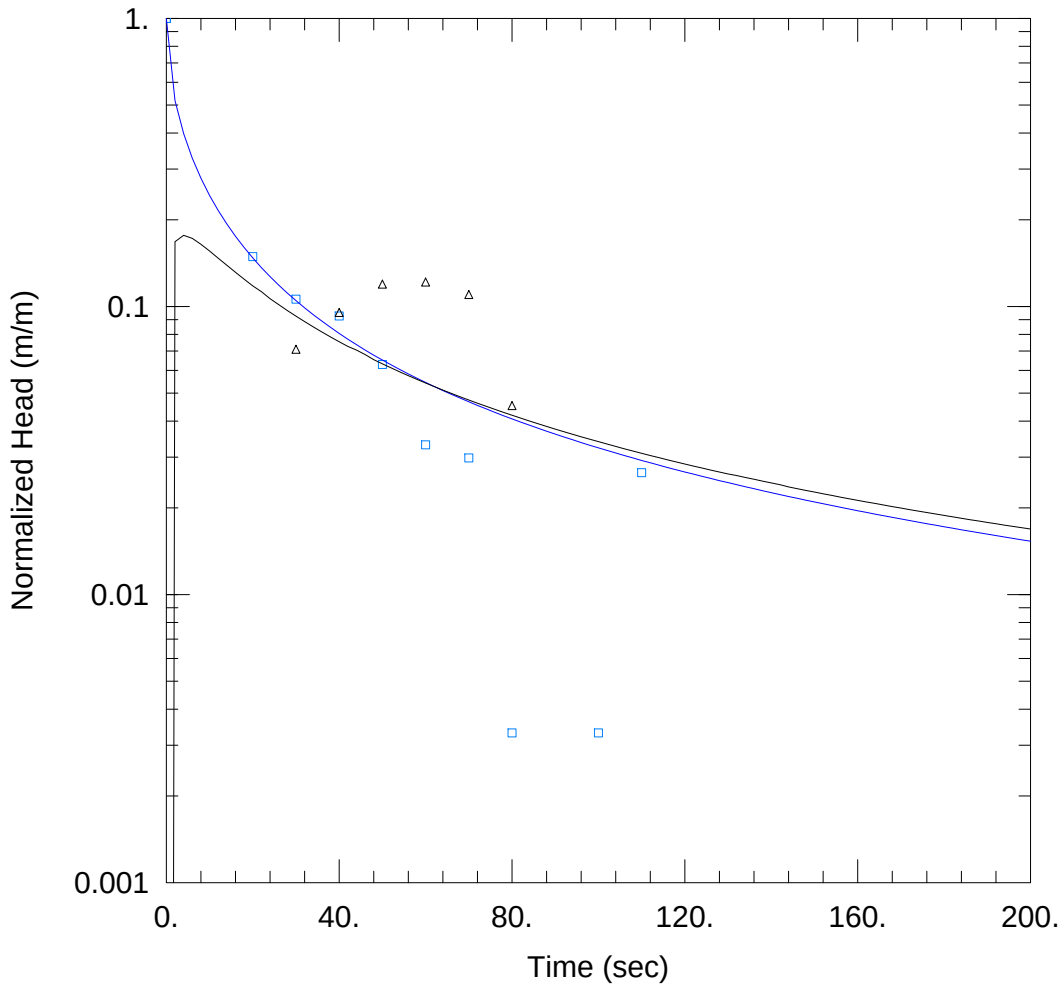
Saturated Thickness: 20.76 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD21(S) FHT 1)

Initial Displacement: 0.277 m
Total Well Penetration Depth: 17.76 m
Casing Radius: 0.025 m
Static Water Column Height: 20.76 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.5107 m/day
y0 = 0.097 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD21(S)_FHT2.aqt
Date: 10/22/12 Time: 15:05:46

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 20.76 m

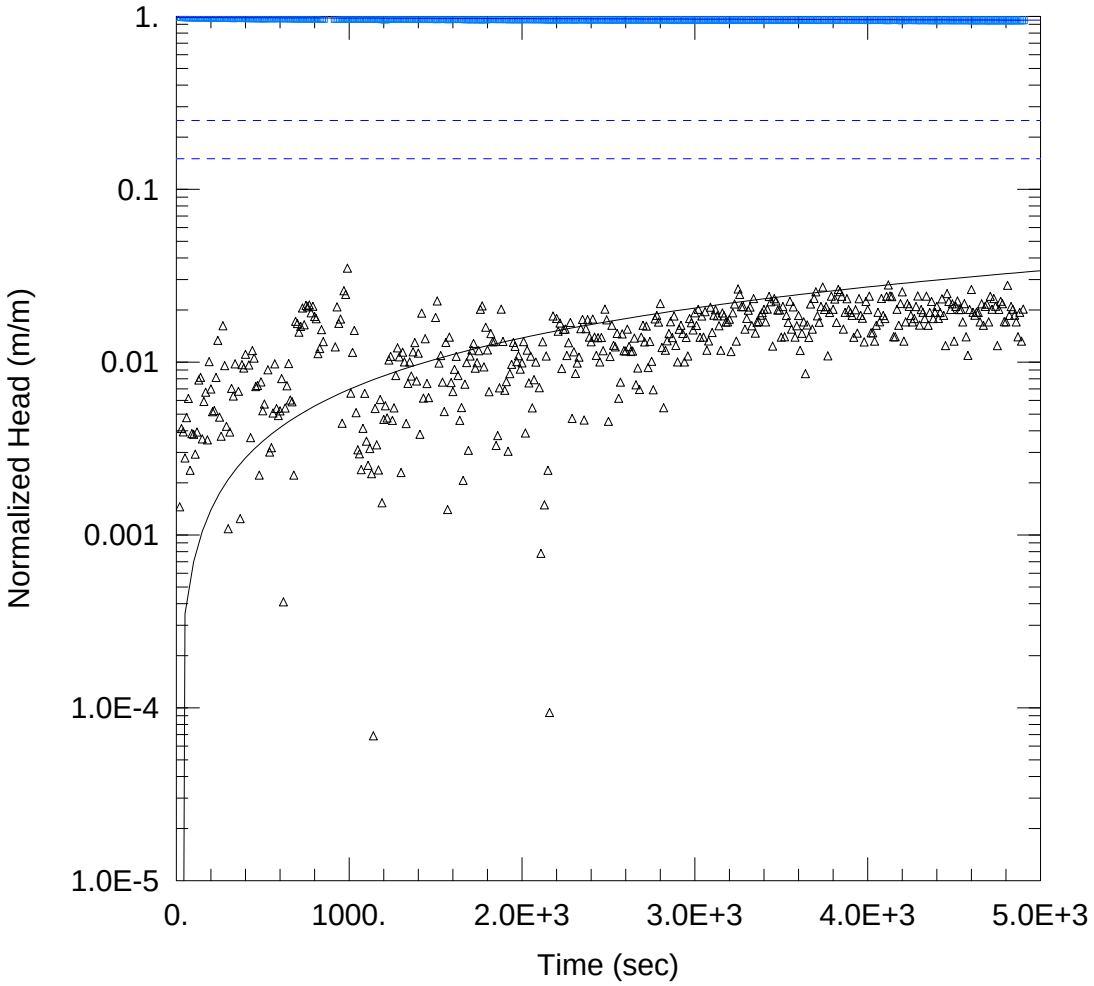
WELL DATA (RAU12HYD21(S) FHT 2)

Initial Displacement: 0.302 m
Total Well Penetration Depth: 17.76 m
Casing Radius: 0.025 m
Static Water Column Height: 20.76 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 1.278 m/day
Kz/Kr = 1.
Ss = 0.01703 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD22(D)_FHT.aqt
Date: 10/22/12 Time: 15:05:50

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

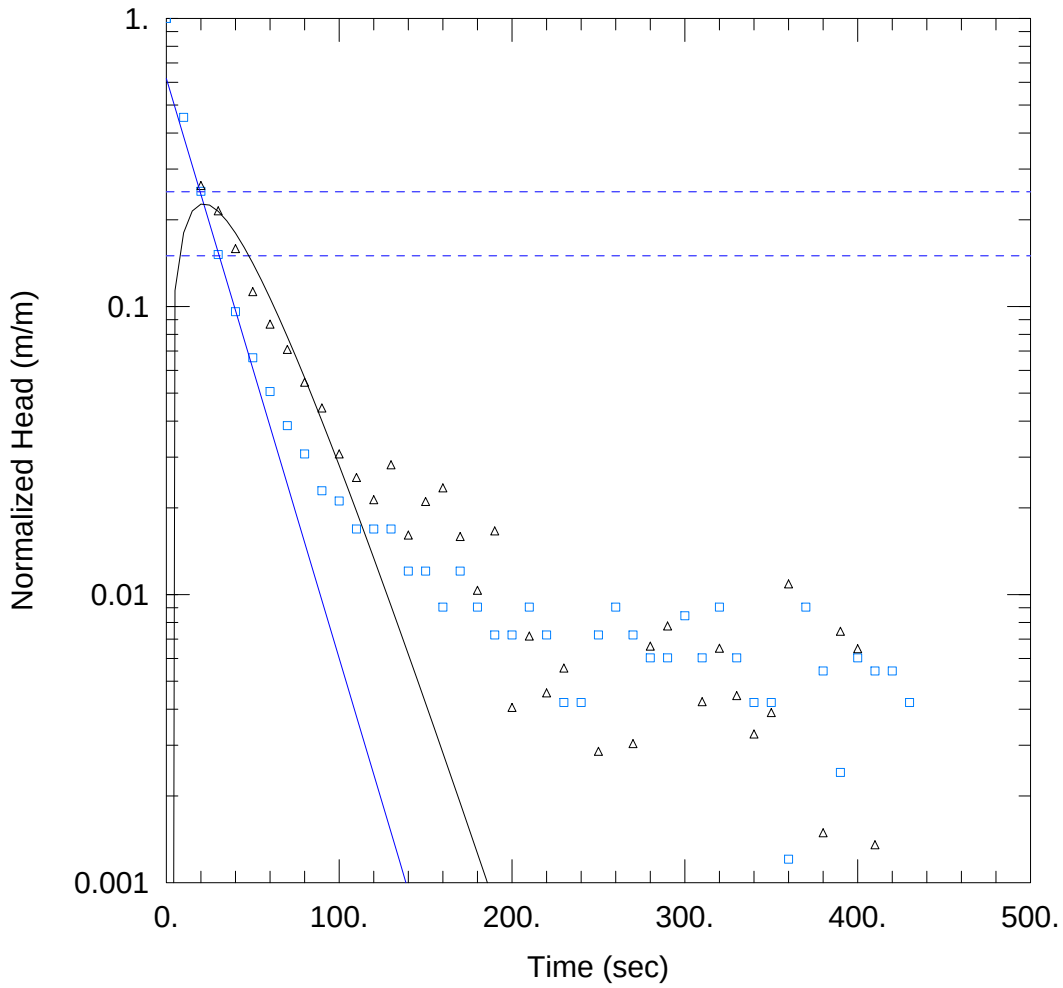
Saturated Thickness: 40.68 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD22(D) FHT)

Initial Displacement: 3.209 m
Total Well Penetration Depth: 40.36 m
Casing Radius: 0.025 m
Static Water Column Height: 40.68 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.0002404 m/day
y0 = 3.161 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD22(S)_FHT.aqt
Date: 10/22/12 Time: 15:05:55

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

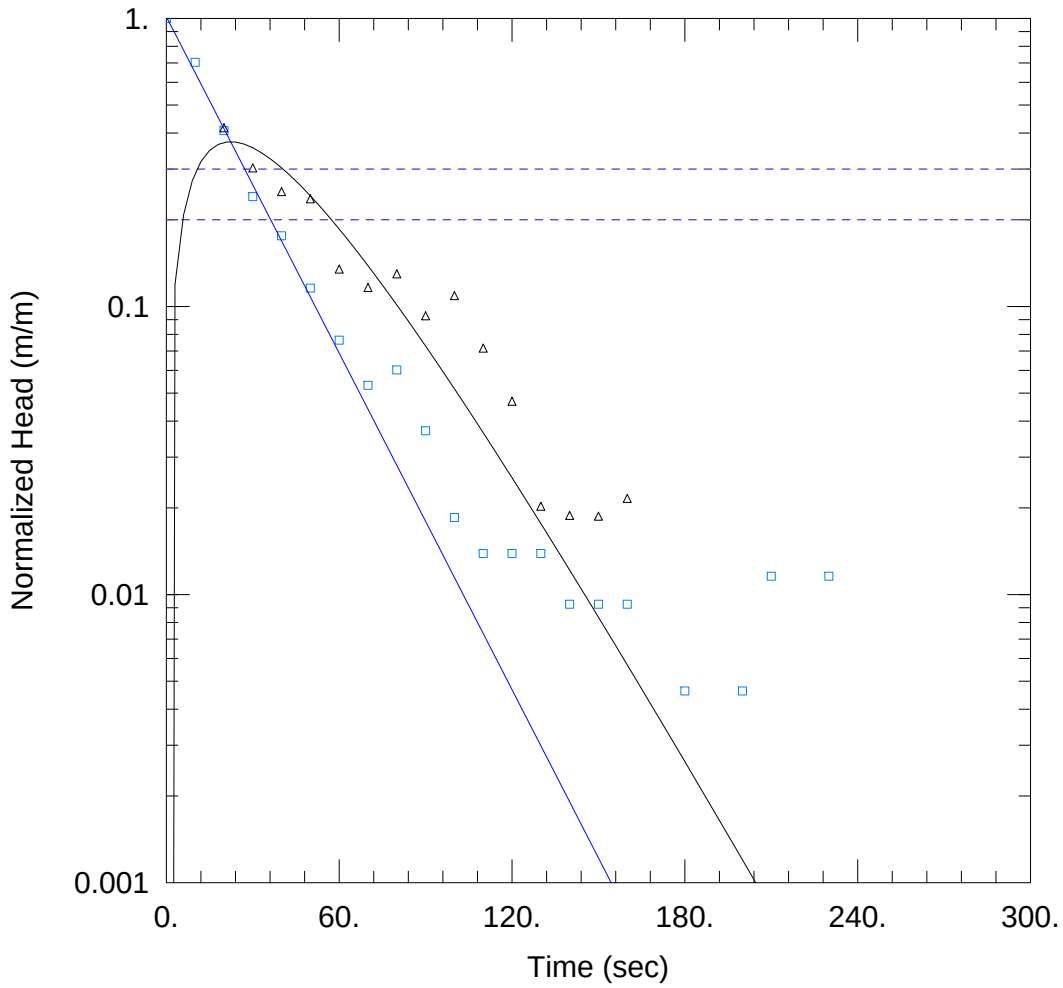
Saturated Thickness: 20.97 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD22(S) FHT)

Initial Displacement: 1.658 m
Total Well Penetration Depth: 18.97 m
Casing Radius: 0.025 m
Static Water Column Height: 20.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.492 m/day
y0 = 1.025 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD22(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:06:00

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 20.97 m Anisotropy Ratio (Kz/Kr): 1.

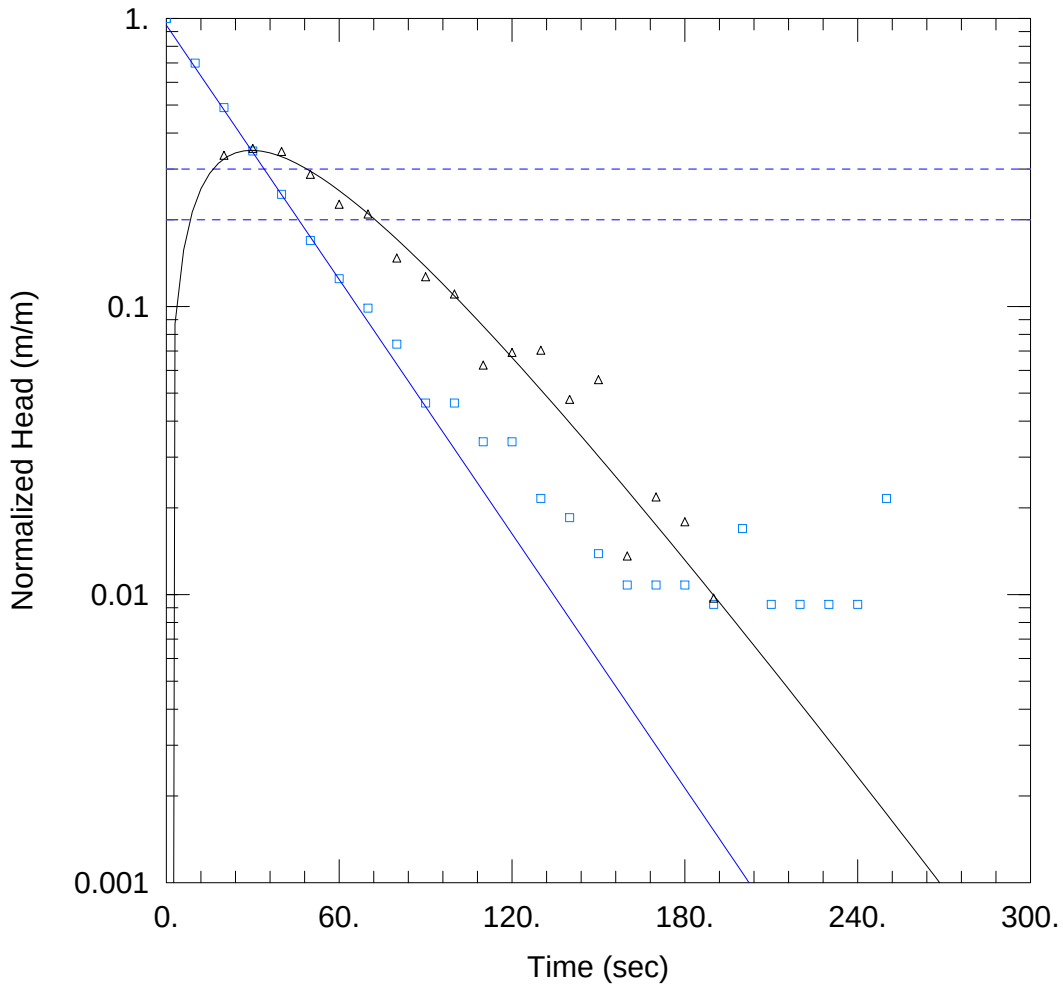
WELL DATA (RAU12HYD22(S) Slug in)

Initial Displacement: 0.432 m
Total Well Penetration Depth: 18.97 m
Casing Radius: 0.025 m
Static Water Column Height: 20.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 1.284 m/day
y0 = 0.4383 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD22(S)_SlugIOutaqt.aqt
Date: 10/22/12 Time: 15:06:05

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

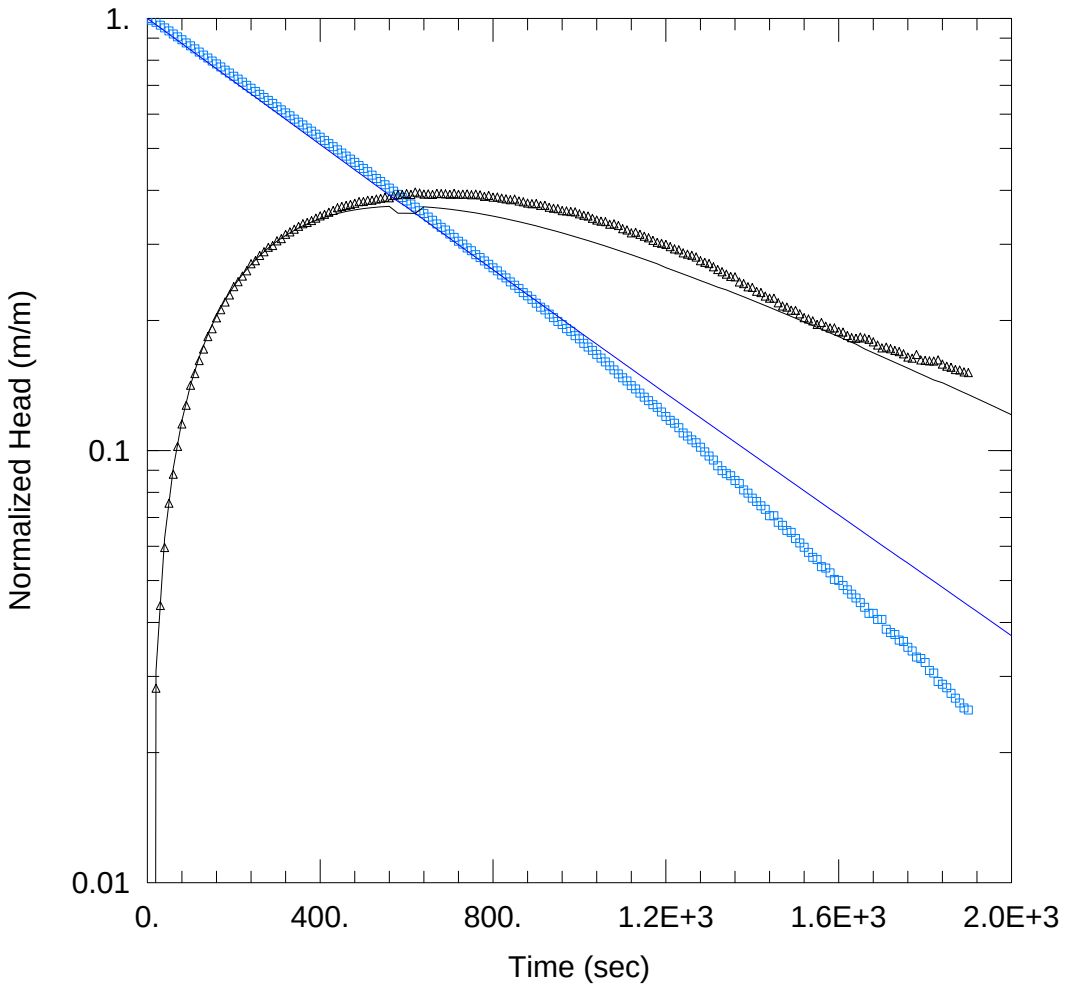
Saturated Thickness: 20.97 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD22(S) Slug out)

Initial Displacement: 0.649 m
Total Well Penetration Depth: 18.97 m
Casing Radius: 0.025 m
Static Water Column Height: 20.97 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.97 m/day
y0 = 0.6149 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD23(D)_FHT1.aqt
Date: 10/22/12 Time: 15:06:09

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 42.64 m

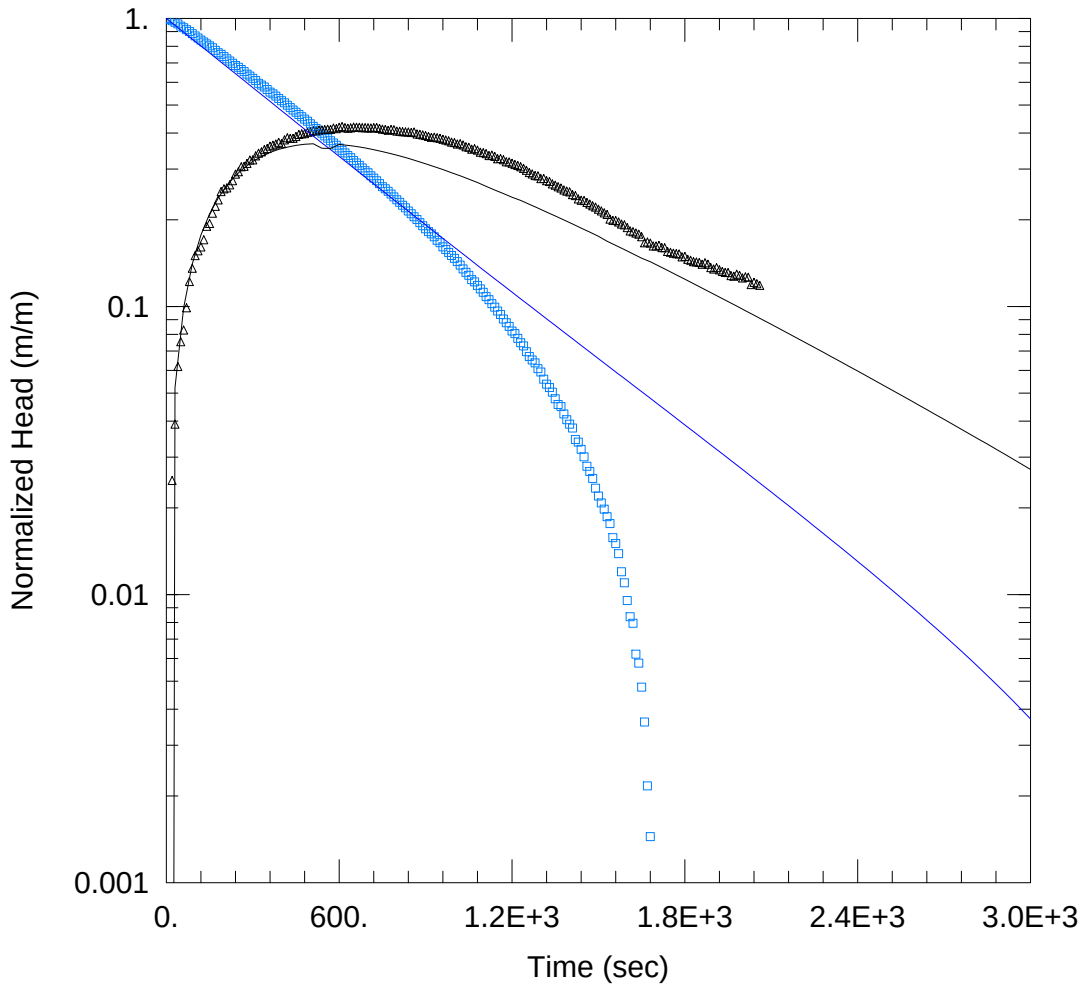
WELL DATA (RAU12HYD23(D) FHT 1)

Initial Displacement: 7.332 m
Total Well Penetration Depth: 42.14 m
Casing Radius: 0.025 m
Static Water Column Height: 42.64 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.05814 m/day
Kz/Kr = 1.
Ss = 5.276E-16 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD23(D)_FHT2.aqt
Date: 10/22/12 Time: 15:06:14

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 42.64 m

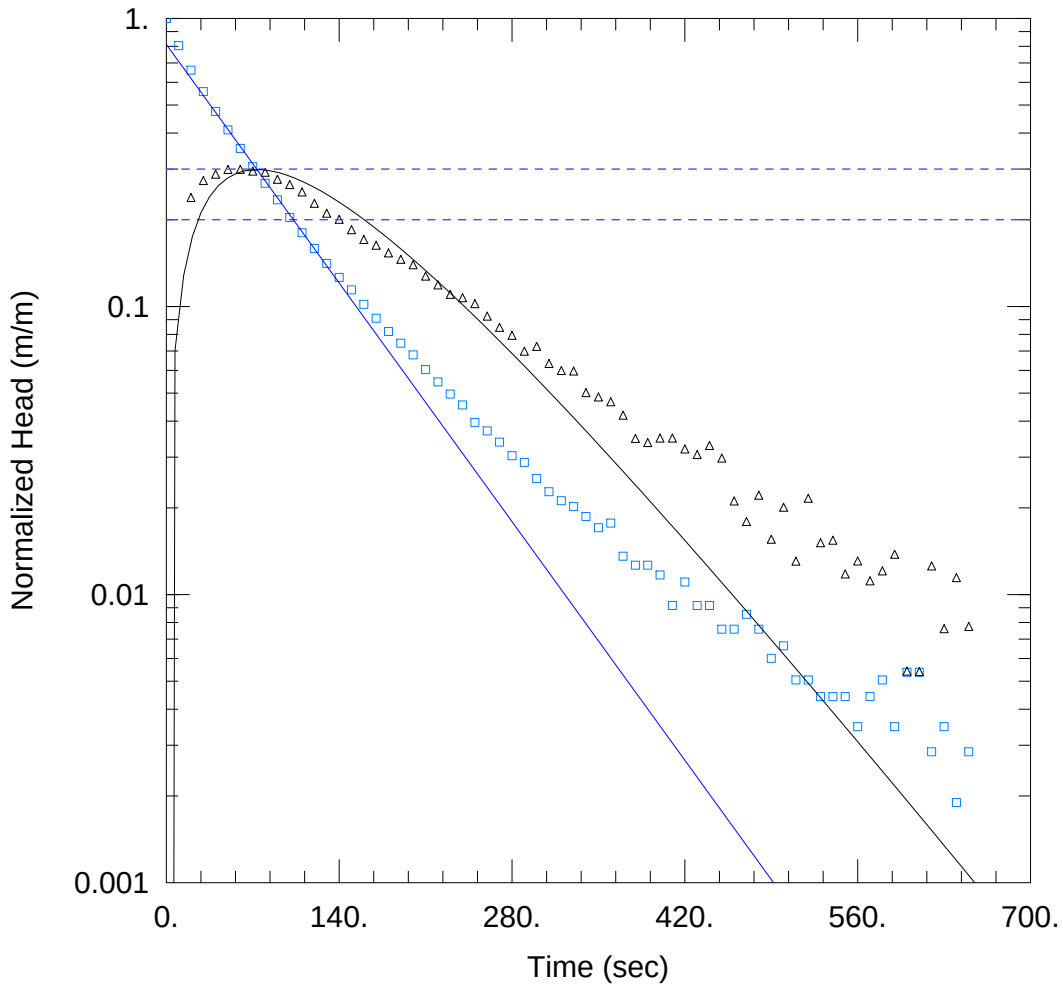
WELL DATA (RAU12HYD23(D) FHT 2)

Initial Displacement: 6.921 m
Total Well Penetration Depth: 42.14 m
Casing Radius: 0.025 m
Static Water Column Height: 42.64 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.0638 m/day
Kz/Kr = 1.
Ss = 9.577E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD23(S)_FHT1.aqt
Date: 10/22/12 Time: 15:06:18

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

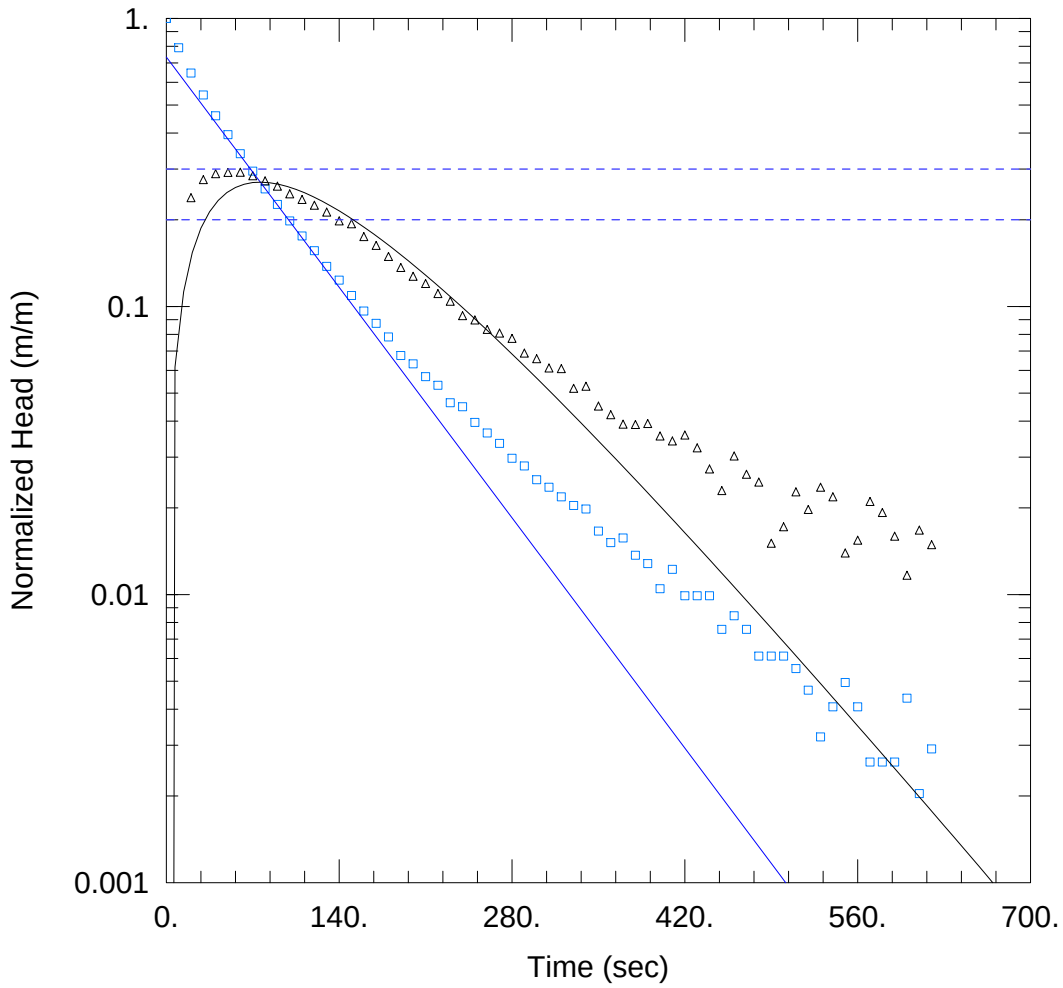
Saturated Thickness: 23.21 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD23(S) FHT 1)

Initial Displacement: 3.164 m
Total Well Penetration Depth: 21.21 m
Casing Radius: 0.025 m
Static Water Column Height: 23.21 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.3952 m/day
y0 = 2.57 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD23(S)_FHT2.aqt
Date: 10/22/12 Time: 15:06:23

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

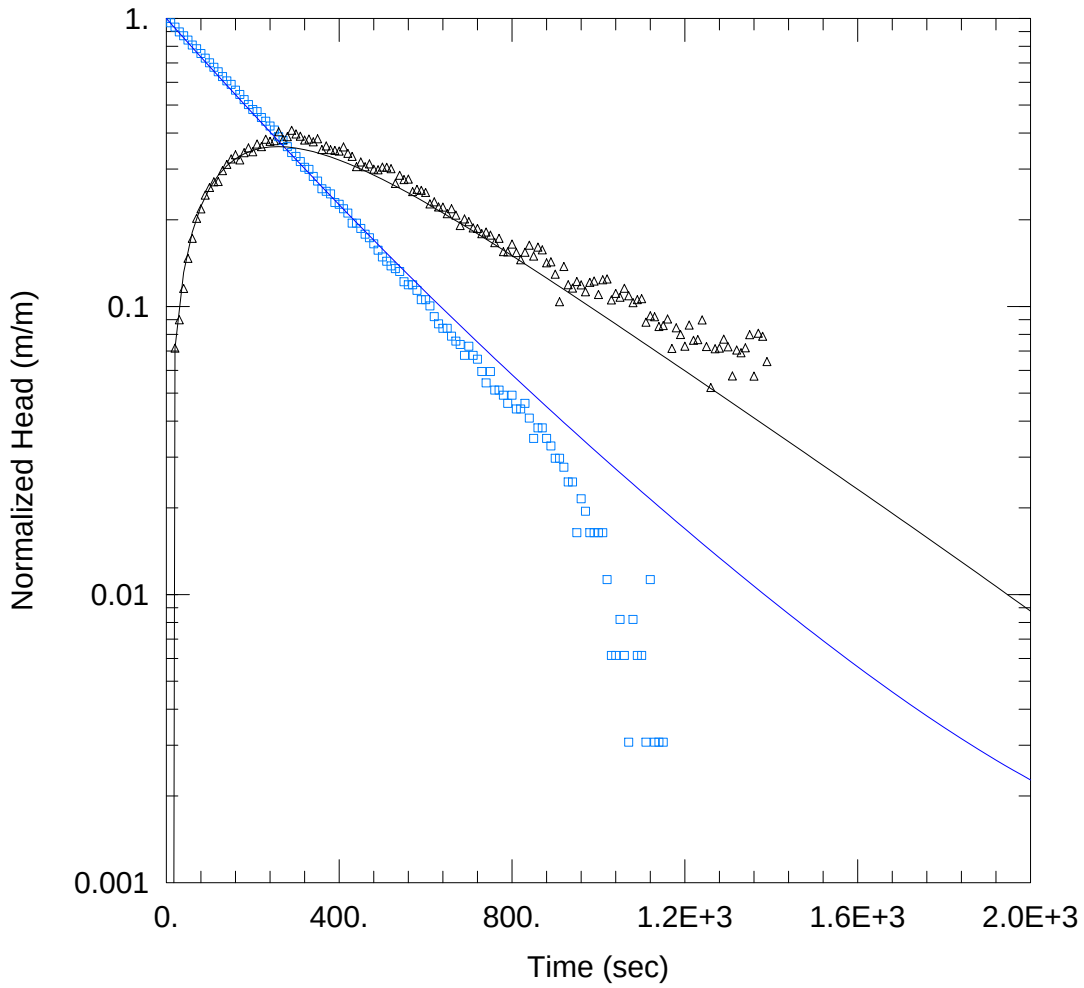
Saturated Thickness: 23.21 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD23(S) FHT 2)

Initial Displacement: 3.434 m
Total Well Penetration Depth: 21.21 m
Casing Radius: 0.025 m
Static Water Column Height: 23.21 m
Screen Length: 3. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.3816 m/day
y0 = 2.522 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD24(D)_SlugOut1.aqt
Date: 10/22/12 Time: 15:06:27

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 20. m

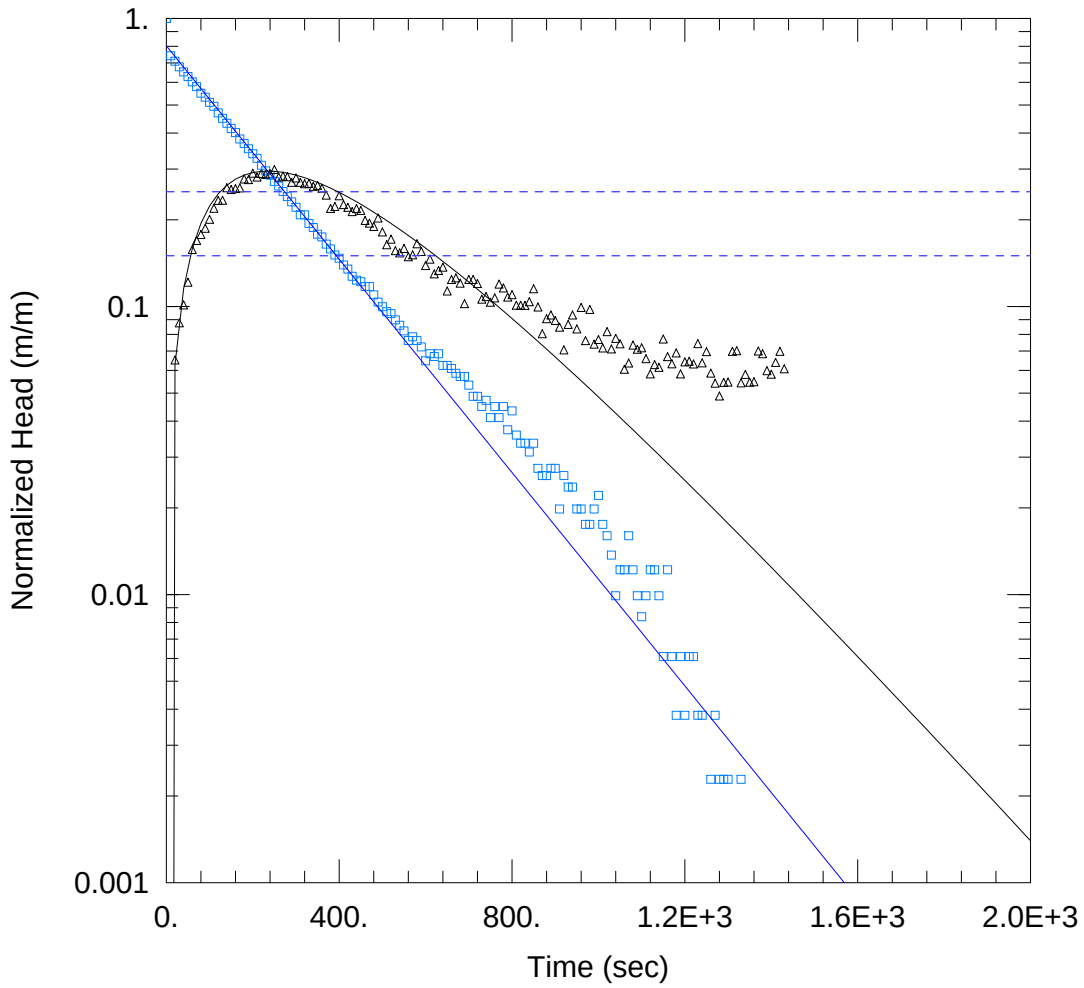
WELL DATA (RAU12HYD24(D) Slug out 1)

Initial Displacement: 0.976 m
Total Well Penetration Depth: 25.04 m
Casing Radius: 0.025 m
Static Water Column Height: 25.54 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.183 m/day
Kz/Kr = 1.
Ss = 7.94E-17 m^{-1}



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD24(D)_SlugOut2.aqt
Date: 10/22/12 Time: 15:06:31

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

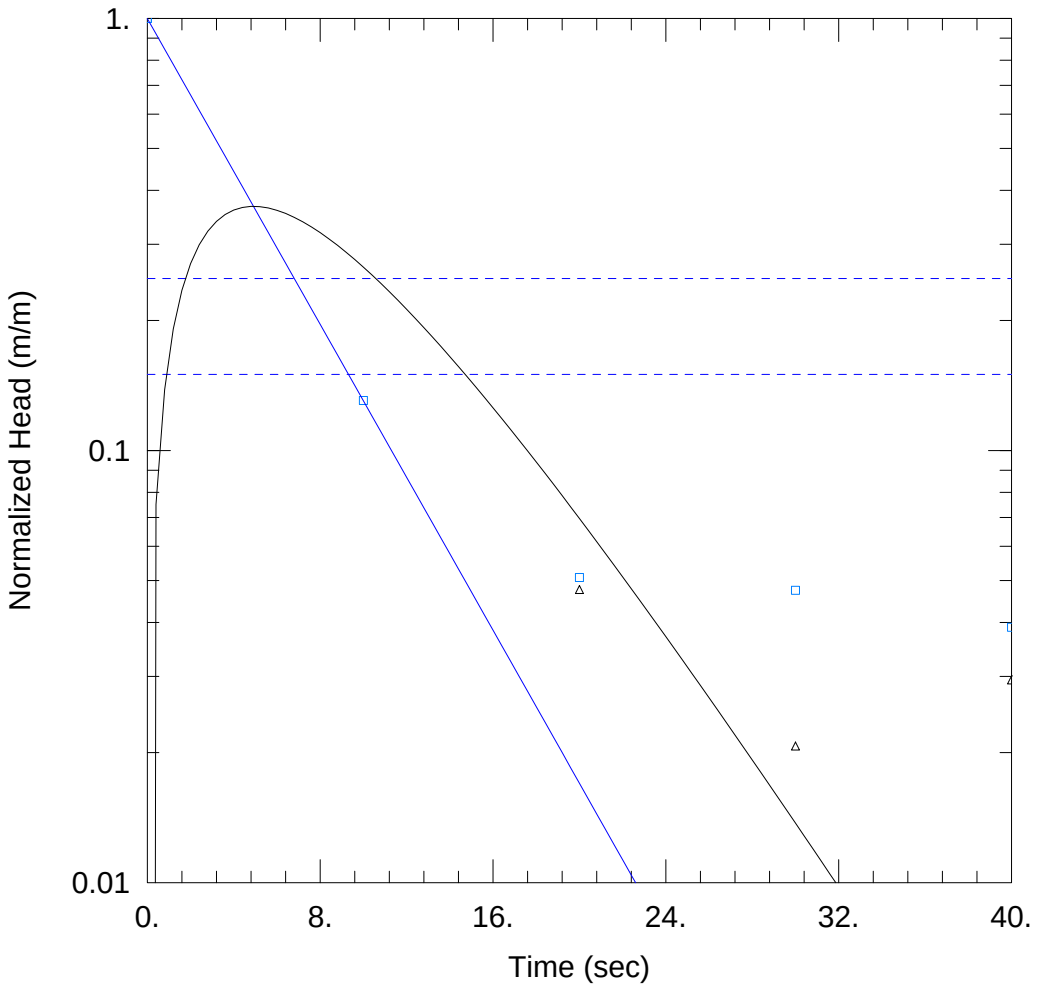
Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD24(D) Slug out 2)

Initial Displacement: 1.313 m
Total Well Penetration Depth: 25.04 m
Casing Radius: 0.025 m
Static Water Column Height: 25.54 m
Screen Length: 3. m
Well Radius: 0.07 m

SOLUTION

Aquifer Model: Confined
Solution Method: Hvorslev
K = 0.1708 m/day
y0 = 1.054 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD24(S)_FHT.aqt
Date: 10/22/12 Time: 15:06:36

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

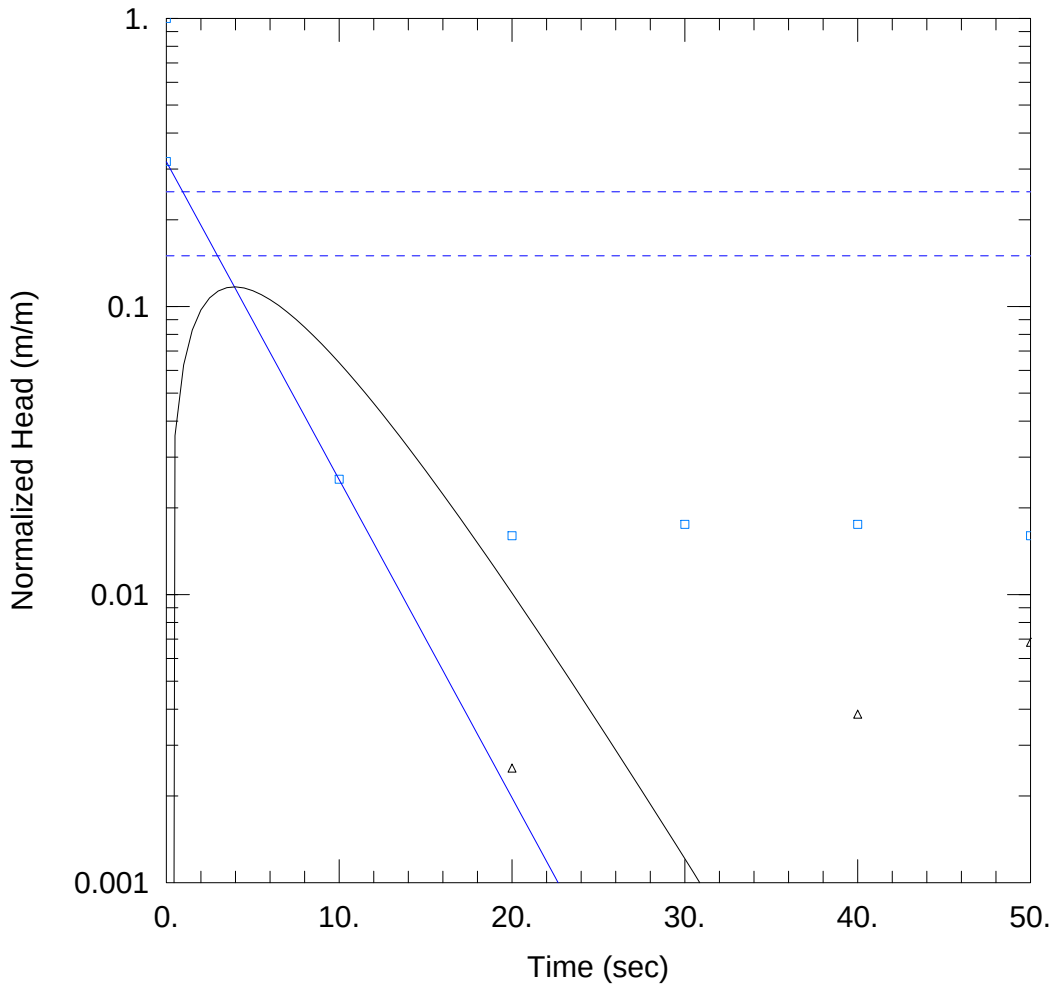
Saturated Thickness: 4.47 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD24(S) FHT)

Initial Displacement: 0.59 m
Total Well Penetration Depth: 2.97 m
Casing Radius: 0.025 m
Static Water Column Height: 4.47 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 13.66 m/day
y0 = 0.5895 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD24(S)_SlugIn.aqt
Date: 10/22/12 Time: 15:06:41

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

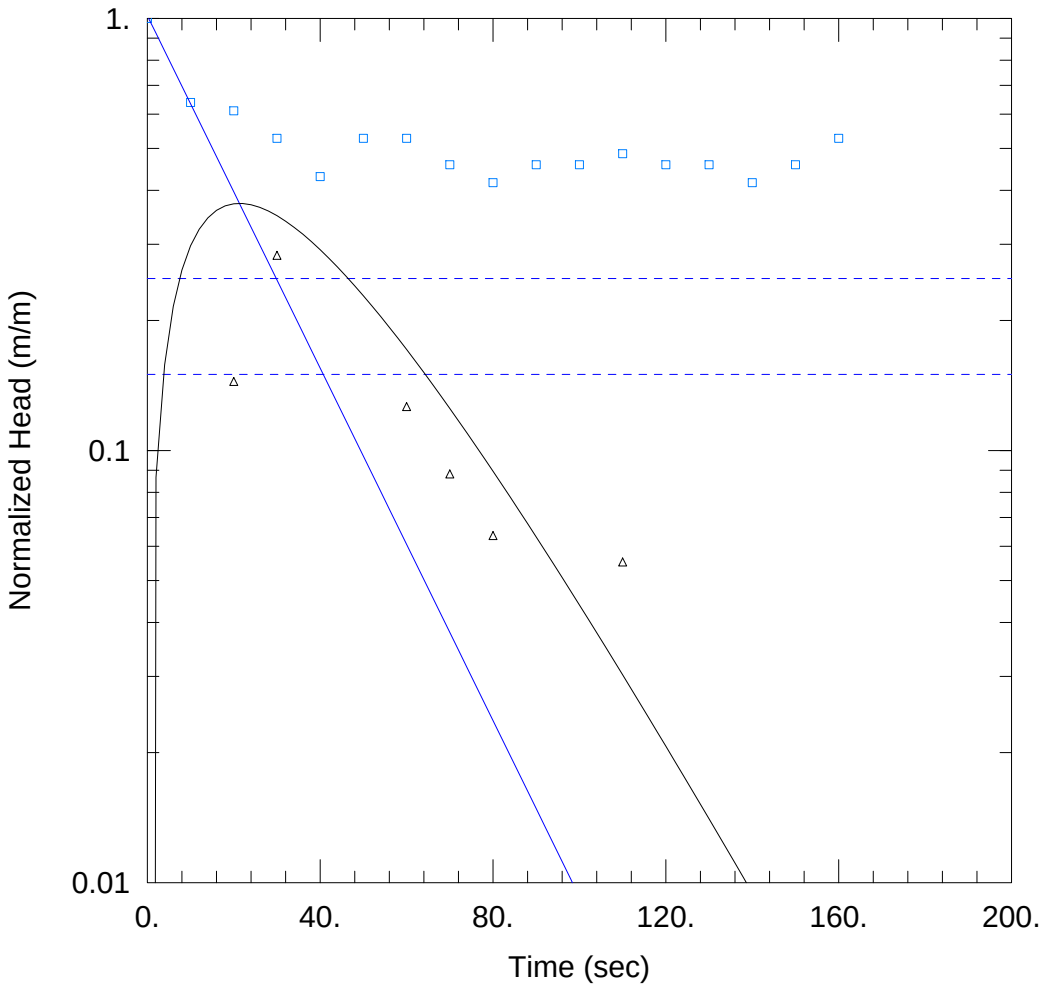
Saturated Thickness: 4.47 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD24(S) Slug in)

Initial Displacement: 1.313 m
Total Well Penetration Depth: 2.97 m
Casing Radius: 0.025 m
Static Water Column Height: 4.47 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 17.05 m/day
y0 = 0.4178 m



WELL TEST ANALYSIS

Data Set: E:\...\RAU12HYD24(S)_SlugOut.aqt
Date: 10/22/12 Time: 15:06:48

PROJECT INFORMATION

Company: SRK
Client: Northland
Project: U4784
Location: Finland
Test Well: RAU12HYD16(S)
Test Date: 9/6/2012

AQUIFER DATA

Saturated Thickness: 4.47 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (RAU12HYD24(S) Slug out)

Initial Displacement: 0.072 m
Total Well Penetration Depth: 2.97 m
Casing Radius: 0.025 m
Static Water Column Height: 4.47 m
Screen Length: 1. m
Well Radius: 0.084 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 3.149 m/day
y0 = 0.07306 m

Annex 3 – Estimated Hydraulic Conductivity

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
Reliable Test														
RAU12HYD01(D)	Slug in	0.55	1.00E-10	0.06	2.18E-12	0.06	0.96			Unconfined Good slug test Good straight line fit	good	0.06	Deep	Unconfined
RAU12HYD01(D)	Slug out	0.64	1.00E-10	0.07	2.18E-12	0.07	0.99				good	0.07	Deep	Unconfined
RAU12HYD01(D)	FHT	0.40	1.00E-10	0.04	2.18E-12	0.04	4.85				good	0.04	Deep	Unconfined
RAU12HYD01(S)	Slug in	2.12	7.38E-05	0.40	3.61E-04	0.41	0.54	0.50	0.62	Unconfined Not a particularly good straight line fit 2 phases to test data Average slug test	good	0.50	Shallow	Unconfined
RAU12HYD01(S)	Slug out	1.32	5.71E-03	0.35	3.25E-03	0.42	0.67	0.55	0.72		good	0.55	Shallow	Unconfined
RAU12HYD01(S)	FHT	2.00	6.49E-04	0.49	1.216r-8	0.39	2.65	0.45	2.17		good	0.45	Shallow	Unconfined
RAU12HYD02(D)	Slug in 1	1.21	1.45E-05	0.21	2.09E-04	0.26	0.90	0.25	0.90	Confined Good slug test Good straight line fit	good	0.25	Deep	Confined
RAU12HYD02(D)	Slug out 1	0.70	1.27E-06	0.10	1.03E-04	0.13	0.99	0.13	0.99		good	0.11	Deep	Confined
RAU12HYD02(D)	Slug in 2	0.75	6.17E-03	0.22	2.75E-03	0.31	0.99	0.30	0.99		good	0.30	Deep	Confined
RAU12HYD02(D)	Slug in 3	2.50	1.48E-03	0.65	9.66E-04	0.89	0.43	0.85	0.43		good	0.85	Deep	Confined
RAU12HYD02(D)	Slug out 3	2.99	1.00E-10	0.49	5.00E-20	0.38	0.98	0.38	0.98		good	0.49	Deep	Confined
RAU12HYD02(S)	FHT 1	20.55	2.77E-05	3.61	3.78E-04	3.59	0.87	4.37	0.87	Unconfined Very fast response. Not much data to estiamte K from.	moderate	4.37	Shallow	Unconfined
RAU12HYD02(S)	FHT 2	7.04	2.37E-01	2.28	3.83E-02	5.93	1.08	6.65	1.08		moderate	6.65	Shallow	Unconfined
RAU12HYD03(D)	Slug in	7.74	8.76E-02	2.28	3.78E-02	4.72	0.18	6.01	0.18	Unconfined Fitted to recommended head range (Butler (1998)) Fast response Poor slug test	moderate	6.01	Deep	Unconfined
RAU12HYD03(D)	FHT 1	31.82	1.00E-15	2.97	5.70E-03	2.64	1.55	3.30	1.55		moderate	2.80	Deep	Unconfined
RAU12HYD03(S)	Slug in	3.72	4.15E-04	0.85	5.68E-04	0.85	0.62	0.83	0.61	Unconfined Average slug test	good	0.83	Shallow	Unconfined
RAU12HYD03(S)	Slug out	4.46	5.31E-05	0.79	6.61E-04	1.14	0.63	1.11	0.63		good	1.11	Shallow	Unconfined
RAU12HYD03(S)	FHT	7.46	1.07E-08	0.85	5.97E-05	0.92	3.12	0.96	3.12		good	0.89	Shallow	Unconfined
RAU12HYD03(Mid)	FHT 1	20.86	1.23E-11	7.51	3.21E-17	5.28	0.86			Unconfined Fast response Not much data for fit	moderate	7.51	Tailings	Unconfined
RAU12HYD03(Mid)	FHT 2	11.02	1.04E-05	5.50	3.09E-02	6.31	0.69	6.76	0.69		moderate	5.91	Tailings	Unconfined
RAU12HYD04(D)	FHT	2.15E-03	4.57E-12	2.05E-04	4.07E-14	1.95E-04	2.05			Unconfined Very slow response. Only 40% recovery but good straight line fit.	good	2.05E-04	Deep	Unconfined
RAU12HYD05(D)	Slug in	1.40	1.01E-04	0.40	3.35E-04	0.35	0.60	0.31	0.48	Confined Average slug test Moderately good straight line fit	good	0.31	Deep	Confined
RAU12HYD05(D)	Slug out	0.75	5.68E-03	0.28	3.25E-03	0.30	0.62	0.31	0.62		good	0.31	Deep	Confined
RAU12HYD05(D)	FHT	1.39	5.27E-05	0.36	2.27E-04	0.29	2.96	0.35	3.25		good	0.32	Deep	Confined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD06(D)	Slug in	1.69	1.27E-04	0.20	1.03E-02	0.21	0.35	0.22	0.36	Unconfined Tests done immediately following snow melt, tailings fully saturated (quick sand-esc conditions surrounding holes), therefore assuming that shallow and deep units acting as a single unconfined aquifer Average slug test	good	0.22	Deep	Unconfined
RAU12HYD06(D)	Slug out	1.77	1.97E-08	0.22	3.49E-06	0.19	0.83	0.25	1.00		good	0.22	Deep	Unconfined
RAU12HYD07(D)	FHT	0.47	1.59E-15	0.03	1.14E-06	0.03	1.31	0.03	1.31	Unconfined Slow response, good straight line fit	good	0.03	Deep	Unconfined
RAU12HYD07(S)	Slug out	0.96	2.59E-01	0.56	2.52E-02	0.98	0.17	0.64	0.12	Unconfined Fast response, average slug test	moderate	0.64	Tailings	Unconfined
RAU12HYD07(S)	FHT	0.58	3.54E-01	0.40	2.52E-02	0.86	0.38	0.64	0.28	Fitted to recommended head range (Butler (1998))	moderate	0.64	Tailings	Unconfined
RAU12HYD08(D)	Slug in	0.58	3.24E-08	0.07	2.06E-16	0.10	0.99	0.11	0.99	Confined Good slug test Slow response	good	0.07	Deep	Confined
RAU12HYD08(D)	Slug out	0.39	2.66E-13	0.03	4.92E-06	0.04	0.95	0.04	0.95		good	0.03	Deep	Confined
RAU12HYD08(S)	Slug in	97.45	1.21E-09	9.70	1.72E-04	8.06	1.04	9.71	1.04	Unconfined Fast response, H0 measured relative to recovery level to avoid negative values in small amount of data Average slug test	good	8.88	Shallow	Unconfined
RAU12HYD08(S)	Slug out	133.20	8.42E-13	10.25	1.03E-04	8.36	0.56	10.08	0.56		moderate	9.31	Shallow	Unconfined
RAU12HYD09(S)	Slug in	11.85	7.67E-09	1.28	5.79E-05	1.12	0.51	1.28	0.51	Unconfined Average slug test	good	1.20	Shallow	Unconfined
RAU12HYD09(S)	Slug out	7.26	7.45E-05	1.34	5.37E-04	1.42	0.49	1.42	0.41		good	1.38	Shallow	Unconfined
RAU12HYD09(S)	FHT	11.40	1.47E-08	1.26	7.41E-05	1.10	2.39	1.25	2.39	Fitted to recommended head range (Butler (1998))	good	1.18	Shallow	Unconfined
RAU12HYD09(D)	FHT	2.34	1.59E-15	0.24	7.94E-17	0.19	5.14	0.19	5.14	Confined condition Slow response, good data set	good	0.24	Deep	Confined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD10(D)	FHT	0.04	1.59E-15	2.77E-03	5.54E-17	2.78E-03	8.30	2.98E-03	8.30	Unconfined Slow response Fitted to recommended head range (Butler (1998))	good	2.77E-03	Deep	Unconfined
RAU12HYD11(D)	FHT 1	85.28	1.59E-15	3.30	9.45E-03	6.10	1.11	6.21	1.11	Unconfined Fast response Fitted to recommended head range (Butler (1998)) Oscillatory response with slug	moderate	4.70	Deep	Unconfined
RAU12HYD11(S)	FHT	1.50	1.14E-03	0.36	1.09E-03	0.28	1.69	0.30	1.69	Unconfined	good	0.30	Shallow	Unconfined
RAU12HYD11(S)	Slug in	1.35	3.76E-02	0.41	1.41E-02	0.40	0.50	0.40	0.48	Fitted to recommended head range (Butler (1998))	good	0.40	Shallow	Unconfined
RAU12HYD11(S)	Slug out	1.67	2.93E-04	0.32	1.49E-03	0.32	0.40	0.32	0.38	Average slug test	good	0.32	Shallow	Unconfined
RAU12HYD12(D)	FHT	19.44	1.59E-15	1.41	1.73E-05	1.46	1.70	1.49	1.70	Unconfined	good	1.43	Deep	Unconfined
RAU12HYD12(D)	Slug in	12.59	1.85E-08	1.46	1.04E-04	1.73	0.79	1.77	0.79	Fitted to recommended head range (Butler (1998))	good	1.60	Deep	Unconfined
RAU12HYD12(D)	Slug out	10.42	6.48E-07	1.39	2.66E-04	1.80	0.68	1.83	0.68		good	1.60	Deep	Unconfined
RAU12HYD12(S)	FHT	6.86	5.60E-04	0.91	1.36E-02	1.20	0.15	1.20	0.14	Bad slug test Fast response	moderate	1.20	Shallow	Unconfined
RAU12HYD12(S)	Slug in	1.69	2.24E-02	0.36	2.52E-02	0.81	0.06	0.92	0.07	Better curve fit	good	0.92	Shallow	Unconfined
RAU12HYD12(S)	Slug out	1.32	1.40E-01	0.41	4.99E-02	0.99	0.10	0.67	0.08	Fast response	moderate	0.67	Shallow	Unconfined
RAU12HYD13(D)	Slug in	0.04	4.93E-07	0.01	3.94E-05	0.01	0.87	0.01	0.87	Unconfined Good slug test Very slow response	good	0.01	Deep	Unconfined
RAU12HYD13(D)	Slug out	0.02	1.85E-15	9.44E-04	2.84E-04	1.17E-03	0.85	1.37E-03	0.92		good	1.06E-03	Deep	Unconfined
RAU12HYD13(S)	Slug in	2.84	4.94E-02	0.83	1.78E-02	2.56	0.25	1.68	0.14		good	1.68	Shallow	Unconfined
RAU12HYD13(S)	Slug out	25.38	1.31E-06	3.15	1.06E-03	3.89	0.73			Unconfined Average slug test	moderate	3.52	Shallow	Unconfined
RAU12HYD13(S)	FHT	17.49	3.41E-06	2.33	8.37E-04	2.98	2.36				moderate	2.66	Shallow	Unconfined
RAU12HYD14(D)	Slug in	0.19	4.34E-09	0.03	4.27E-17	0.03	1.04			Unconfined Slow response Good slug test Not a particularly good straight line fit	good	0.03	Deep	Unconfined
RAU12HYD14(D)	Slug out	1.78	2.32E-13	0.15	1.70E-06	0.14	0.98			Good slug test Slow response	good	0.14	Deep	Unconfined
RAU12HYD14(D)	FHT	0.82	1.00E-15	0.10	5.40E-15	0.13	4.93			Some deviation from straight line at start	good	0.11	Deep	Unconfined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD14(S)	FHT 1	39.18	1.00E-15	4.74	7.14E-16	3.97	0.41			Unconfined Very fast response. Not much data to estiamte K from. Poor slug test	moderate	4.74	Shallow	Unconfined
RAU12HYD14(S)	FHT 2	26.16	1.00E-15	4.01	9.55E-03	3.81	0.58				moderate	3.91	Shallow	Unconfined
RAU12HYD15(D)	Slug in	89.01	1.00E-10	5.02	6.74E-05	8.01	1.69			UnconfinedFast response therefore not a lot of data to secure fit	moderate	6.51	Deep	Unconfined
RAU12HYD15(D)	Slug out	91.30	1.35E-08	11.69	1.99E-04	10.33	0.60	9.91	0.60		moderate	9.91	Deep	Unconfined
RAU12HYD15(D)	FHT 1	26.40	1.00E-10	3.46	1.22E-05	2.83	2.55				moderate	3.14	Deep	Unconfined
RAU12HYD15(D)	FHT 2	40.79	1.00E-15	4.33	2.60E-05	3.32	2.68				moderate	3.82	Deep	Unconfined
RAU12HYD15(S)	Slug in	957.00	1.00E-12	1.96	1.05E-01	5.36	0.12			Unconfined - small upward hydraulic gradient perhaps could be due to location next to lake and in boggy wetland area. Very fast response, little data for curve fit	moderate	3.66	Shallow	Unconfined
RAU12HYD15(S)	Slug out	24.81	5.43E-03	5.68	1.30E-02	5.30	0.59	7.71	0.59	Better curve fit	moderate	7.71	Shallow	Unconfined
RAU12HYD15(S)	FHT 1	27.98	1.00E-12	0.96	1.05E-01	1.90	0.68			Good fit to KGS model, Fit to early time data using B-R	moderate	0.96	Shallow	Unconfined
RAU12HYD15(S)	FHT 2	12.07	1.00E-12	1.29	3.79E-03	1.42	0.62				moderate	1.29	Shallow	Unconfined
RAU12HYD16(D)	Slug in	33.89	1.00E-10	3.50	3.07E-12	3.42	0.44			Unconfined Very fast response therefore not much data to secure fit	moderate	3.50	Deep	Unconfined
RAU12HYD16(D)	FHT 1	53.68	1.00E-10	5.33	3.07E-12	5.43	0.44				moderate	5.33	Deep	Unconfined
RAU12HYD16(D)	FHT 2	40.07	1.00E-10	4.07	3.07E-12	4.97	0.94				moderate	4.07	Deep	Unconfined
RAU12HYD16(S)	Slug out	8.68	1.00E+00	4.86	7.99E-02	8.11	0.33	9.82	0.33	Unconfined Fast response	moderate	6.48	Shallow	Unconfined
RAU12geotech16	FHT	0.02	7.20E-04	0.25	1.55E-01			0.14	0.64	Unconfined Slow response, no screen, just a tube stuck in the ground	moderate	0.14	Shallow	Unconfined
RAU12HYD17(D)	Slug in	3.32	9.89E-06	0.54	1.64E-04	0.73	0.69	0.79	0.69	Semi-confined - upward hydraulic gradient but could be due to location next to lake. Average slug test	good	0.64	Deep	Semi-confined
RAU12HYD17(D)	Slug out	0.50	5.01E-02			0.43	0.64	0.43	0.61	Not a great fit	moderate	0.43	Deep	Semi-confined
RAU12HYD17(D)	FHT	4.05	3.54E-06	0.61	1.44E-04	0.73	0.84			Good straight line	good	0.67	Deep	Semi-confined
RAU12HYD17(S)	Slug in	0.76	1.00E-10	0.07	6.74E-12	0.07	0.96			Unconfined Good slug test Good straight line fit	good	0.07	Shallow	Unconfined
RAU12HYD17(S)	Slug out	0.26	5.89E-04	0.06	7.93E-04	0.07	0.81	0.07	0.73	Average fit	good	0.07	Shallow	Unconfined
RAU12HYD17(S)	FHT	0.90	1.07E-10	0.08	1.16E-05	0.07	1.52			Great fit	good	0.08	Shallow	Unconfined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD18(D)	Slug in	0.32	1.86E-04	0.07	2.79E-04	0.06	1.00	0.06	1.00	Unconfined	good	0.06	Deep	Unconfined
RAU12HYD18(D)	Slug out	0.51	1.67E-09	0.06	4.32E-07	0.06	0.99	0.06	0.99	Good slug test	good	0.06	Deep	Unconfined
RAU12HYD18(D)	FHT	0.69	4.51E-13	0.06	6.90E-06	0.05	2.10	0.06	2.10	Slow response	good	0.05	Deep	Unconfined
RAU12HYD18(S)	Slug in	4.94	2.98E-06	2.68	1.61E-03	1.76	0.58	2.01	0.45	Unconfined	good	2.01	Shallow	Unconfined
RAU12HYD18(S)	Slug out	2.60	1.22E-05	1.60	1.52E-03	1.01	0.78	1.17	0.64	Average slug test Moderately fast response	good	1.17	Shallow	Unconfined
RAU12HYD18(S)	FHT	1.58	4.60E-02	1.94	9.44E-02	2.74	1.38	3.59	1.20	Recovery deviates from straight line	moderate	3.59	Shallow	Unconfined
RAU12HYD19(S)	FHT 1	2.78	4.32E-04	0.59	9.26E-04	0.61	1.67	0.45	1.16	Unconfined	good	0.45	Shallow	Unconfined
RAU12HYD19(S)	FHT 2	2.03	1.79E-03	0.49	1.81E-03	0.45	1.18	0.45	1.07	Fitted to recommended head range (Butler (1998))	good	0.45	Shallow	Unconfined
RAU12HYD19(D)	FHT	0.48	9.65E-03	0.14	4.46E-03	0.14	1.59	0.11	1.39	Unconfined Slow response Fitted to recommended head range (Butler (1998))	good	0.11	Deep	Unconfined
RAU12HYD20(S)	FHT 1	4.87	4.05E-03	1.18	4.41E-03	1.98	1.57	2.13	1.57	Unconfined	good	2.13	Shallow	Unconfined
RAU12HYD20(S)	FHT 2	21.94	1.59E-15	1.55	2.33E-03	1.70	1.78	1.72	1.78	Fast response Fitted to recommended head range (Butler (1998))	good	1.62	Shallow	Unconfined
RAU12HYD20(D)	FHT	0.54	2.48E-10	0.06	5.18E-17	0.06	6.51	0.06	6.51	Unconfined Good straight line fit	good	0.06	Deep	Unconfined
RAU12HYD21(D)	Slug in	0.15	1.17E-08	0.02	1.00E-07	0.02	0.91	0.02	0.91	Unconfined	good	0.02	Deep	Unconfined
RAU12HYD21(D)	Slug out	0.10	5.33E-07	0.02	2.17E-05	0.02	0.97	0.02	0.97	Good slug test Slow response	good	0.02	Deep	Unconfined
RAU12HYD21(S)	FHT 2	5.92	3.54E-01	1.28	1.70E-02	2.84	0.31	3.15	0.31	Unconfined Fast response, oscillations Not much data for fit Fitted to recommended head range (Butler (1998))	moderate	2.21	Shallow	Unconfined
RAU12HYD22(D)	FHT	7.13E-07	1.59E+00	2.78E-06	3.90E-02	2.49E-04	3.16	2.40E-04	3.16	Extrememly slow response, only 5% recovery before transducer had to be removed	moderate	1.64E-04	Deep	Unconfined
RAU12HYD22(S)	Slug in	20.43	1.59E-15	1.37	4.81E-05	1.28	0.44	1.44	0.44	Unconfined	good	1.33	Shallow	Unconfined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD22(S)	Slug out	16.51	1.59E-15	1.05	6.89E-06	0.97	0.61	1.13	0.64	Fitted to recommended head range (Butler (1998))	good	1.01	Shallow	Unconfined
RAU12HYD22(S)	FHT	9.58	3.64E-05	1.72	3.49E-04	1.97	1.63	1.49	1.03		good	1.49	Shallow	Unconfined
RAU12HYD23(D)	FHT 1	0.83	3.54E-16	0.06	5.28E-16	0.06	7.59	0.06	7.59	Unconfined Good straight line fit	good	0.06	Deep	Unconfined
RAU12HYD23(D)	FHT 2	0.92	3.54E-16	0.06	9.58E-17	0.07	7.44	0.07	7.44		good	0.06	Deep	Unconfined
RAU12HYD23(S)	FHT 1	3.18	7.84E-07	0.45	9.29E-05	0.40	2.57	0.42	2.34	Unconfined	good	0.42	Shallow	Unconfined
RAU12HYD23(S)	FHT 2	2.97	3.02E-06	0.45	1.31E-04	0.38	2.52	0.41	2.41	Unconfined	good	0.42	Shallow	Unconfined
RAU12HYD24(D)	Slug out 1	1.78	1.59E-15	0.18	7.94E-17	0.14	0.99	0.15	0.99	Confined, artesian, flowing	good	0.18	Deep	Confined
RAU12HYD24(D)	Slug out 2	0.63	2.24E-04	0.14	4.42E-04	0.16	1.05	0.17	1.05		good	0.17	Deep	Confined
RAU12HYD24(S)	Slug in	15.56	1.59E+00	24.03	3.55E-01	12.82	0.42	17.05	0.42	Unconfined, fast response therefore not a lot of data for fitAverage slug test	moderate	17.05	Shallow	Unconfined
Pukti 1	Slug out	73.53	5.52E-06	30.54	3.63E-02	23.40	0.60	25.15	0.60	Unconfined Very fast response, very little to fit to Average slug test Assumed 1m screen starting 1.5m from base of hole, fully penetrating borehole, piezo radius=0.025m, well radius=0.575m.	moderate	26.97	Shallow	Unconfined
Pukti 2	Slug in	3.86	3.54E-01	5.60	8.24E-02	3.24	0.05	3.77	0.05	Unconfined Assumed 1m screen starting 1.5m from base of hole, fully penetrating borehole, piezo radius=0.025m, well radius=0.575m. Fast response, poor slug test	moderate	3.77	Shallow	Unconfined
Pukti 2	Slug out	2.67	1.20E-01	2.12	8.24E-02	3.85	0.06	3.54	0.06	Fitted to recommended head range (Butler (1998))	good	3.54	Shallow	Unconfined
Pukti 2	FHT	26.87	3.53E-16	4.00	8.24E-02	4.68	0.65	5.62	0.62		moderate	4.34	Shallow	Unconfined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
Pukti 3	FHT	30.37	1.59E-15	1.24	8.04E-05	7.34	1.65	7.60	1.57	Unconfined	moderate	4.29	Shallow	Unconfined
Pukti 3	Slug in	38.63	1.59E-15	6.14	1.75E-13	5.92	0.50	6.13	0.50	**Fast response for FHT and Slug in, much slower for slug out**	good	6.14	Shallow	Unconfined
Pukti 3	Slug out	2.97	7.40E-15	0.48	7.81E-05	0.45	0.74	0.47	0.74	Average slug test Fitted to recommended head range (Butler (1998)) Assumed 1m screen starting 1.5m from base of hole, fully penetrating borehole, piezo radius=0.025m, well radius=0.575m.	good	0.47	Shallow	Unconfined
Unreliable Test														
RAU12HYD02(S)	Slug in 1	135.40	1.00E-10	16.86	1.15E-03	11.26	1.07			Unconfined	low	14.06	Shallow	Unconfined
RAU12HYD02(S)	Slug out 1	7.69	1.00E-01	1.67	1.00E-01	6.25	0.35	6.62	0.35	Very fast response. Not much data to estiamte K from.	low	6.62	Shallow	Unconfined
RAU12HYD03(D)	Slug out	12.16	2.72E-02	3.44	1.38E-02	5.00	0.21	6.50	0.21		low	6.50	Deep	Unconfined
RAU12HYD04(S)	Slug in	0.88	1.00E+00	2.06	2.59E-01	3.95	0.03	5.10	0.03	Unconfined	low	5.10	Shallow	Unconfined
RAU12HYD04(S)	Slug out	7.15	1.00E+00	12.96	2.59E-01	17.46	0.14	23.70	0.14	Bad slug test	low	12.96	Shallow	Unconfined
RAU12HYD04(S)	FHT 1	38.60	9.89E-03	26.51	2.56E-03	8.42	0.24	11.78	0.27	Very fast response - not much to fit curve	low	11.78	Shallow	Unconfined
RAU12HYD04(S)	FHT 2	20.56	1.00E-12	3.47	4.89E-10	13.55	0.77			to	low	13.55	Shallow	Unconfined
RAU12HYD06(S)	Slug in 1	106.40	3.54E-16	6.13	2.45E-17	5.38	0.07	6.83	0.07	Very fast response therefore not much data to secure fit	low	6.13	Tailings	Unconfined
RAU12HYD06(S)	Slug out 1	16.45	1.00E-06	2.27	2.44E-04	2.27	0.62	2.79	0.62	Unconfined aquifer	low	2.27	Tailings	Unconfined
RAU12HYD06(S)	Slug in 2	2.47	1.88E-01	1.19	2.45E-02	1.24	0.06	1.49	0.06	Fitted to recommended head range (Butler (1998))	low	1.49	Tailings	Unconfined
RAU12HYD06(S)	Slug out 2	2.20	3.54E-01	1.40	2.45E-02	4.31	0.29	5.97	0.29	Best fit using KGS model	low	5.97	Tailings	Unconfined
RAU12HYD07(S)	Slug in	8.96	7.43E-04	1.89	2.16E-03	2.04	0.24	2.31	0.22	UnconfinedFast response, average slug testFitted to recommended head range (Butler (1998))	low	2.31	Tailings	Unconfined

Hole ID	Test	Cooper et al (1967)		KGS Model Unc (1994)		Bower-Rice Unc (1976)		Hvorslev (1951)		Assumptions/notes	Reliability	Best K estimate (m/d)	Hole	Aquifer
		T	S	K (m/d)	Ss	K (m/d)	y0 (m)	K (m/d)	y0 (m)					
RAU12HYD10(S)	FHT	19.49	1.25E-01	5.97	0.02	7.89	0.33	9.21	0.33	Unconfined	low	9.21	Shallow	Unconfined
RAU12HYD10(S)	FHT	29.71	1.73E-05	4.89	6.49E-04	4.58	0.91	5.92	0.91	Unconfined	low	5.92	Shallow	Unconfined
RAU12HYD10(S)	Slug in	4.27	2.27E-02	0.35	1.81E-01	2.87	0.09	3.71	0.09	Poor slug test	low	3.71	Shallow	Unconfined
RAU12HYD10(S)	Slug out	3.12	1.55E-01	0.95	5.92E-02	3.38	0.08	4.50	0.08	Fitted to recommended head range (Butler (1998)) Fast response	low	4.50	Shallow	Unconfined
RAU12HYD11(D)	FHT 2	6.08	7.27E-02	1.58	3.41E-02	6.95	0.97	6.72	0.97	Unconfined Fast response Fitted to recommended head range (Butler (1998)) Oscillatory response with slug	low	6.72	Deep	Unconfined
RAU12HYD14(S)	Slug in	23.95	4.89E-10	4.76	1.80E-14	3.95	0.05			Unconfined Very fast response.	low	4.76	Shallow	Unconfined
RAU12HYD14(S)	Slug out	40.14	1.00E-15	7.82	7.53E-15	4.00	0.08			Not much data to estiamte K from. Poor slug test	low	7.82	Shallow	Unconfined
RAU12HYD16(D)	Slug out	41.73	1.00E-10	4.26	3.07E-12	4.35	0.81				low	4.26	Deep	Unconfined
RAU12HYD21(S)	FHT 1	0.92	3.54E-01	0.78	1.70E-02	0.78	0.13	0.51	0.10	Unconfined Fast response, oscillations Not much data for fit Fitted to recommended head range (Butler (1998))	low	0.51	Shallow	Unconfined
RAU12HYD24(S)	Slug out	0.54	7.13E-04	0.03	3.55E-01	2.43	0.07	3.15	0.07	Unconfined, fast response therefore not a lot of data for fit	low	3.15	Shallow	Unconfined
RAU12HYD24(S)	FHT	12.47	2.35E-02	8.30	6.13E-02	10.27	0.59	13.66	0.59	Average slug test	low	13.66	Shallow	Unconfined
Pukti 1	FHT	6.97	3.54E-01	2.28	3.63E-02	21.34	0.86	22.93	0.86	Unconfined Very fast response, very little to fit to Average slug test	low	22.93	Shallow	Unconfined
Pukti 1	Slug in	14.48	1.52E-01	6.38	3.63E-02	21.97	0.12	22.22	0.12	Assumed 1m screen starting 1.5m from base of hole, fully penetrating borehole, piezo radius=0.025m, well radius=0.575m.	low	22.22	Shallow	Unconfined

0.50	Best estimate
0.50	Less likely
0.50	For comparison but not the most suitable method for the data

APPENDIX

F GROUNDWATER WATER QUALITY DATA

Rautuvaara

				Non-TMF Borehole																	
Parameter	Unit	WQO		HYD01		HYD02		HYD04		HYD05	HYD08		HYD10		HYD11		HYD12		HYD14		HYD15		HYD16	
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.8	6.9	6.0	6.1	6.6	6.5	6.8	7.1	7.1	7.0	6.9	7.1	7.0	7.1	9.0	7.2	6.5	7.0	6.6	7.0	6.9
Suspended solids	mg/L	3	25	67	44	9	9	43	15	2	67	85	30	70	27	34	9	12	5	98	5	149	243	146
Ammonium	mg/L	0.101	1	0.003	0.003	0.013	0.025	0.145	0.003	0.003	0.020	0.003	0.022	0.039	0.019	0.010	0.038	0.013	0.021	0.003	0.015	0.007	0.020	0.009
Nitrite as N	mg/L	0.012	0.05218	<2	<2	11.22	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Nitrate as N	mg/L	0.279	20	4.2	309.4	3.5	5.1	5.0	10.5	12.0	29.0	42.8	58.0	70.2	86.4	19.7	3.3	3.3	2.7	22.5	3.8	47.1	18.0	12.9
Chloride	mg/L	3.0	150	2.68	2.12	6.40	4.81	1.27	0.33	0.69	1.22	0.75	1.24	0.90	0.80	0.73	0.71	0.78	0.83	0.45	1.83	0.70	0.53	0.42
Sulphate	mg/L	89	159	120	130	365	276	16	3	5	17	1	14	2	9	10	21	25	22	4	238	6	7	2
Iron	mg/L	0.92	4.07	0.017	0.009	0.001	0.009	0.017	0.023	0.001	0.537	0.012	0.142	0.042	0.021	0.015	0.012	0.078	0.010	0.034	0.025	0.037	0.193	0.060
Aluminium	mg/L	0.050	0.1	0.0055	0.0020	<0.0005	0.0435	0.0467	0.0246	0.0042	1.047	0.0077	0.0675	0.0533	0.0278	0.0386	0.0108	0.1760	0.0250	0.0531	0.0018	0.0216	0.533	0.0731
Arsenic	mg/L	0.0012	0.0050	0.0001	0.0001	<0.00005	0.0001	0.0003	0.0001	0.0001	<0.00005	<0.00005	0.0001	0.0001	<0.00005	<0.00005	0.0007	0.0002	0.0011	<0.00005	0.0001	<0.00005	0.0001	<0.00005
Cadmium	mg/L	0.00001	0.00008	0.000011	0.000005	<0.00001	0.00015	<0.000005	<0.000005	0.000025	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	0.00001	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005
Cobalt	mg/L	0.002	0.004	0.0038	0.0006	0.0214	0.0721	0.0011	0.0004	0.0001	0.0006	<0.00005	0.0004	0.0004	0.0002	0.0003	0.0001	0.0004	0.0002	0.0009	0.0003	0.0008	<0.00005	0.0004
Chromium	mg/L	0.0003	0.001	0.0002	0.0002	<0.0001	<0.0001	0.0024	0.0006	0.0004	0.0015	0.0005	0.0009	0.0010	0.0005	0.0002	0.0005	0.0006	0.0008	0.0002	0.0010	0.0008	0.0006	0.0007
Copper	mg/L	0.0048	0.005	0.0011	0.0010	0.0006	0.103	0.0017	0.0002	0.0006	0.0022	0.0001	0.0010	0.0010	0.0012	0.0006	0.0009	0.0028	0.0006	0.0001	0.0002	0.0002	0.0004	0.0002
Mercury	mg/L	0.000002	0.00005																					
Manganese	mg/L	0.294	0.70	0.444	0.128	0.726	0.728	0.111	0.054	0.0003	0.0591	0.0151	0.1350	0.0654	0.0565	0.116	0.0468	0.0115	0.0178	0.0576	0.4510	0.1889	0.0029	0.0539
Molybdenum	mg/L	0.0002	1	0.0004	0.0002	<0.00005	0.0001	0.0005	0.0002	0.0005	0.0011	0.0003	0.0002	0.0001	0.0002	<0.00005	0.0017	0.0006	0.0043	0.0001	0.0005	<0.00005	0.0016	0.0002
Nickel	mg/L	0.007	0.02	0.0038	0.0028	0.0505	0.171	0.0048	0.0009	0.0004	0.0018	0.0004	0.0015	0.0015	0.0014	0.0027	0.0002	0.0019	0.0006	0.0018	0.0010	0.0013	0.0003	0.0016
Lead	mg/L	0.0001	0.0072	0.0001	0.0000	0.0001	0.0000	0.0003	<0.00002	0.0000	0.0003	<0.00002	0.0001	0.0001	0.00004	0.00003	0.0001	0.0003	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002
Zinc	mg/L	0.002	0.03	0.0065	0.0026	0.0098	0.0485	0.0119	0.0007	0.0007	0.0036	0.0006	0.0073	0.0075	0.0059	0.0042	<0.0005	0.0033	0.0020	0.0005	0.0007	<0.0005	<0.0005	<0.0005
Uranium	mg/L	0.0004	0.015	0.0001	0.0002	<0.00001	0.00004	0.0001	<0.00001	0.0003	0.0002	0.0001	<0.00001	0.00001	0.00004	<0.00001	0.0005	0.0002	0.0014	<0.00001	0.0010	0.00004	0.00005	<0.00001

				Non-TMF Borehole																	
Parameter	Unit	WQO		HYD01		HYD02		HYD04		HYD05	HYD08		HYD10		HYD11		HYD12		HYD14		HYD15		HYD16	
		*TV	*AV	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Conductivity	mS/m	26	41	31.2	34.8	80.3	49.6	10.3	3.4	5.2	12.6	7.5	11.9	5.9	8.2	8.0	11.3	13.5	12.8	3.9	64.7	8.4	6.1	3.6
Calcium	mg/L	25	46	32.7	37.9	114.8	60.1	7.7	3.7	5.3	7.5	8.0	13.9	5.5	8.6	7.3	11.9	16.5	16.2	3.2	98.1	8.6	4.8	3.2
Potassium	mg/L	3.0	4.9	4.9	3.0	4.9	5.0	2.1	0.8	1.3	1.8	0.9	0.4	1.3	1.9	1.7	3.4	3.8	1.9	1.2	5.2	1.2	1.3	0.8
Magnesium	mg/L	10	17	12	14	32	13	1.7	0.6	1.7	2.8	2.9	3.4	2.0	2.3	2.6	3.1	2.8	2.8	1.2	16	2.7	1.4	1.1
Sodium	mg/L	5.3	9.1	7.3	8.6	7.3	5.1	9.5	1.5	2.0	18	3.1	6.4	3.5	4.1	4.0	3.8	5.7	4.0	1.9	8.7	3.8	3.1	1.9
Sulfur	mg/L	29	53	39	43	128	63	5.3	0.8	1.6	6.4	0.5	4.7	0.7	2.9	3.2	6.8	8.9	7.4	1.4	84	1.8	2.0	0.8
Silicon	mg/L	4	11	6.2	7.8	9.9	9.0	4.1	3.7	6.9	11	11	6.7	11	8.1	7.7	7.0	6.2	6.1	5.6	12	11	8.0	6.0
Barium	mg/L	0.010	0.014	0.063	0.050	0.018	0.023	0.029	0.008	0.009	0.016	0.011	0.008	0.008	0.012	0.019	0.015	0.054	0.028	0.016	0.034	0.016	0.016	0.012
Strontium	mg/L	0.070	0.112	0.158	0.188	0.402	0.211	0.032	0.022	0.017	0.042	0.046	0.041	0.023	0.032	0.030	0.064	0.048	0.034	0.011	0.204	0.034	0.014	0.011
Antimony	mg/L	0.00002	0.00006																					

** Trigger Values (TV) and Action Values (AV) for Niesajoki River*
Where number of samples are shown as 2 a mean value has been recorded

= exceeds AV guideline
= exceeds TV guideline

Non-TMF Borehole											
HYD17		HYD19		HYD20		HYD22		HYD23		HYD24	
Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*1*	*1*
7.0	7.1	6.6	7.8	6.7	7.2	7.7	7.3	6.6	6.5	7.0	6.8
95	515	78	1730	30	1323	48	69	28	465	11	237
0.011	0.257	0.172	0.911	0.030	0.039	0.020	0.016	0.003	0.010	0.018	0.011
<2	<2	<2	<2	<2	<2	<2	<2	<2	4.17	<2.0	<2.0
14.4	9.6	6.5	5.0	7.7	14.1	7.5	26.7	15.1	30.9	32.3	31.8
0.69	0.90	0.58	1.06	1.12	0.93	4.08	0.72	1.23	0.87	2.04	0.60
20	18	2	18	2	8	7	1	20	2	9	2
0.724	2.083	0.197	2.583	0.303	0.822	0.105	0.087	1.676	0.017	0.002	0.006
2.11	4.66	0.139	3.86	0.141	0.303	0.0418	0.0309	0.121	0.0030	0.0041	0.0019
0.0002	0.0002	<0.00005	0.0014	<0.00005	0.0003	0.0001	0.0003	0.0005	0.0001	0.0001	0.0002
<0.000005	<0.000005	<0.000005	0.00006	<0.000005	0.00003	0.00001	0.00001	0.00001	0.00001	<0.000005	<0.000005
0.0001	0.0011	0.0010	0.0048	0.0031	0.0018	0.0018	0.0003	0.0019	0.0018	0.0004	<0.00005
0.0017	0.0033	0.0005	0.0055	0.0009	0.0009	0.0005	0.0003	0.0012	0.0006	0.0004	0.0001
0.0009	0.0114	0.0103	0.0132	0.0045	0.0015	0.0006	0.0015	0.0008	0.0002	0.0006	0.0004
0.0142	0.193	0.127	0.167	0.511	0.400	0.269	0.176	0.171	0.219	0.0055	0.0207
0.0009	0.0011	0.0001	0.0016	0.0011	0.0011	0.0006	0.0015	0.0007	0.0001	0.0003	0.0014
0.0011	0.0024	0.0020	0.0102	0.0081	0.0022	0.0019	0.0017	0.0024	0.0022	0.0012	0.0002
0.0002	0.0005	0.0101	0.0031	0.0195	0.0002	0.0001	0.0001	0.00002	0.00002	0.0001	<0.00002
0.0014	0.0024	0.0133	0.0086	0.0051	0.0010	0.0031	0.0058	0.0026	0.0007	0.0019	<0.0005
0.0001	0.0001	0.0001	0.0007	0.0002	0.0004	0.00003	0.0002	0.0007	0.00004	0.0001	0.0004

HYD17		HYD19		HYD20		HYD22		HYD23		HYD24	
Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow
1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*2*	*2*	*1*	*1*
10.8	10.8	3.2	16.5	9.5	19.3	8.3	4.7	20.7	6.7	10.2	4.2
8.2	7.1	2.6	5.8	11.9	12.8	6.8	3.5	15.3	5.7	11.2	3.8
2.2	2.8	0.7	1.9	2.2	2.5	1.3	0.9	2.4	1.1	1.1	0.6
4.0	4.3	0.8	1.9	2.6	3.8	2.3	1.3	3.9	2.2	3.2	1.2
5.8	5.1	2.0	30	3.8	24	6.6	2.9	18.8	3.8	4.5	2.2
6.7	5.2	0.7	5.4	0.6	2.4	2.0	0.5	7.1	0.7	2.8	0.8
11	12	3.1	8.2	5.2	10	8.3	8.6	12	11	6.5	7.7
0.015	0.018	0.010	0.036	0.019	0.029	0.058	0.014	0.132	0.166	0.024	0.015
0.030	0.034	0.014	0.031	0.044	0.061	0.038	0.038	0.072	0.044	0.028	0.036

Rautuvaara

				TMF Boreholes														
Parameter	Unit	WQO		HYD03			HYD06		HYD07		HYD09		HYD13		HYD18		Putki 1 GTK	Putki 2 GTK	Putki 3 GTK
		*TV	*AV	Deep	Shallow	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow			
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1	2	2	3	4	2
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.0	6.1	6.1	7.3	7.3	7.4	6.8	7.2	7.0	6.9	7.3	6.9	6.1	5.0	6.1	6.7
Suspended solids	mg/L	3	25	195	322	249	348	405	224	697	32	29	293	50	37	1381	35.9	374	74.4
Ammonium	mg/L	0.101	1	0.250	0.003	0.105	0.233	0.038	0.113	0.160	0.003	0.020	0.092	0.062	0.022	0.028	0.366	0.038	0.047
Nitrite as N	mg/L	0.012	0.05218	<2.0	<2.0	<2.0	4.11	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.67	0.006	0.003	<0.002
Nitrate as N	mg/L	0.279	20	3.58	4.81	4.46	52.2	95.7	2.19	3.14	2.72	8.35	6.68	4.10	41.17	145.1	0.106	0.003	0.003
Chloride	mg/L	3.0	150	11.6	20.5	28.2	1.56	1.19	4.21	4.19	1.35	1.08	3.30	3.01	2.49	0.97	6.07	14.1	4.08
Sulphate	mg/L	89	159	1306	2493	4881	37	3	92	54	4	9	42	44	64	19	968	2622	210
Iron	mg/L	0.92	4.07	13.6	265	519	0.169	0.049	0.012	0.131	0.041	0.122	0.011	0.144	0.011	0.012	4.38	394	2.20
Aluminium	mg/L	0.050	0.1	0.0011	0.142	0.260	0.284	0.034	0.0096	0.0034	0.0097	0.0011	0.0108	2.01	0.0753	0.0194	2.06	0.114	0.001
Arsenic	mg/L	0.0012	0.0050	0.0004	0.0001	0.0002	0.0003	0.0006	0.0093	0.0006	0.0002	0.0001	0.0003	0.0017	0.0002	0.0001	0.0003	0.0002	0.0001
Cadmium	mg/L	0.00001	0.00008	0.0001	<0.000005	<0.000005	<0.000005	0.00004	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	0.00001	0.00004	0.00004	0.0008	0.00001	0.00001
Cobalt	mg/L	0.002	0.004	0.139	0.0579	0.0454	0.0006	0.0006	0.0007	0.0010	0.0005	0.0010	0.0014	0.0007	0.0014	0.0164	0.734	0.554	0.002
Chromium	mg/L	0.0003	0.001	0.0017	<0.0001	0.0038	<0.0001	0.0004	0.0009	0.0002	<0.0001	<0.0001	<0.0001	0.0036	0.0004	0.0003	0.001	0.0004	0.0001
Copper	mg/L	0.0048	0.005	0.0025	0.0008	0.0007	0.0002	0.0003	0.0007	0.0001	0.0011	0.0017	0.0009	0.0039	0.0013	0.0009	1.243	0.001	0.001
Mercury	mg/L	0.000002	0.00005																
Manganese	mg/L	0.294	0.70	9.66	27.35	57.76	0.0377	0.0353	0.326	0.395	0.162	0.0274	0.2429	0.0885	0.355	0.352	6.09	45.5	0.73
Molybdenum	mg/L	0.0002	1	0.0004	0.0009	0.0027	0.0001	0.0005	0.0043	0.0008	0.0003	0.0001	0.0013	0.0021	0.0012	0.0001	0.0005	0.0015	0.0003
Nickel	mg/L	0.007	0.02	0.0641	0.0250	0.0069	0.0004	0.0026	0.0061	0.0026	0.0008	0.0017	0.0031	0.0036	0.0027	0.0072	0.187	0.133	0.004
Lead	mg/L	0.0001	0.0072	0.0001	0.0006	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0002	0.0010	0.0002	0.0001	0.00019	0.00017	0.00004
Zinc	mg/L	0.002	0.03	0.0265	0.0334	0.0130	<0.0005	<0.0005	0.0012	0.0006	0.0015	0.0073	0.0027	0.0023	0.0030	0.0081	0.1592	0.0395	0.0133
Uranium	mg/L	0.0004	0.015	0.0063	0.0118	0.1253	0.0001	0.0001	0.0203	0.0032	0.0006	0.00003	0.0004	0.0048	0.0001	0.0001	0.0005	0.0129	0.0011

				TMF Boreholes														
Parameter	Unit	WQO		HYD03			HYD06		HYD07		HYD09		HYD13		HYD18		Putki 1 GTK	Putki 2 GTK	Putki 2 GTK
		*TV	*AV	Deep	Shallow	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow			
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1	2	2	3	4	2
Conductivity	mS/m	26	41	184	354	625	23.4	6.14	41.6	35.4	17.3	9.66	25.0	34.3	25.5	7.02	1118	2135	605
Calcium	mg/L	25	46	259	383	513	13.2	5.77	55.9	43.2	21.7	8.29	18.5	11.0	13.5	8.77	253	278	71.8
Potassium	mg/L	3.0	4.9	12	35	67	2.4	1.1	4.7	2.9	3.2	1.6	3.1	2.3	4.3	2.7	16.8	31.6	10.1
Magnesium	mg/L	10	17	90	267	587	4.2	2.6	12	14	4.7	3.3	3.7	3.2	5.8	3.1	55.4	226	23.2
Sodium	mg/L	5.3	9.1	20	31	33	29	3.6	6.3	5.9	4.9	4.6	25	55	25	5.6	11.9	18.5	10.8
Sulfur	mg/L	29	53	369	763	1725	12	1.0	30	18	1.6	2.8	14	13	21	10	324	821	67.9
Silicon	mg/L	4	11	13	14	21	7.4	10	8.4	17	14	13	4.1	4.8	6.6	4.7	11.2	16.3	17.0
Barium	mg/L	0.010	0.014	0.033	0.044	0.016	0.001	0.011	0.038	0.062	0.024	0.019	0.034	0.024	0.038	0.031	0.017	0.012	0.011
Strontium	mg/L	0.070	0.112	0.665	0.032	1.895	0.003	0.021	0.049	0.178	0.056	0.031	0.093	0.064	0.065	0.057	0.407	0.498	0.260
Antimony	mg/L	0.00002	0.00006																

** Trigger Values (TV) and Action Values (AV) for Niesajoki River*
Where number of samples are shown as 2 a mean value has been recorded

= exceeds AV guideline
= exceeds TV guideline

Rautuvaara

Parameter	Unit	WQO		TMF Surface Seepage		WRD Surface Seepage		WRD Trial Pit				TMF Trial Pit		
		*TV	*AV	SWS01	SWS02	SWS04	SWS05	TP2	TP3	TP4	TP5	TP6	TP7	TP8
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	3.6	2.9	6.3	4.0	3.9	5.5	3.6	3.1	5.8	7.7	8.0
Suspended solids	mg/L	3	25											
Ammonium	mg/L	0.101	1											
Nitrite as N	mg/L	0.012	0.05218											
Nitrate as N	mg/L	0.279	20											
Chloride	mg/L	3.0	150	1.37	9.06	1.64	1.92	2.12	2.04	2.43	4.59	24.15	7.68	8.04
Sulphate	mg/L	89	159	148	1641	186	355	401	588	573	1660	10500	5409	464
Iron	mg/L	0.92	4.07	6.13	80.85	0.056	0.295	7.726	38.4	5.494	13.97	365	0.173	0.024
Aluminium	mg/L	0.050	0.1	3.96	11.95	0.0161	7.74	6.44	2.09	15.36	50.85	1.02	0.0346	0.0114
Arsenic	mg/L	0.0012	0.0050	0.0029	0.0027	0.0034	0.0031	0.0046	0.0013	0.0007	0.0029	0.0094	0.0170	0.0250
Cadmium	mg/L	0.00001	0.00008	0.0003	0.0005	<0.000005	0.0003	0.0002	0.0004	0.0003	0.0001	0.0014	0.00002	0.00004
Cobalt	mg/L	0.002	0.004	0.385	1.580	0.0024	0.0965	0.291	0.124	0.265	0.384	1.260	0.0136	0.0020
Chromium	mg/L	0.0003	0.001	0.0011	0.0012	0.0001	0.0007	0.0030	0.0007	0.0083	0.0672	0.0041	0.0003	0.0001
Copper	mg/L	0.0048	0.005	0.558	1.380	0.0101	0.335	1.94	0.0989	1.81	4.14	0.0633	0.0036	0.0044
Mercury	mg/L	0.000002	0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Manganese	mg/L	0.294	0.70	7.72	32.75	0.0332	0.690	1.63	2.35	1.12	1.57	76.91	1.155	0.084
Molybdenum	mg/L	0.0002	1	0.0003	0.0010	0.0001	<0.00005	0.0001	0.0001	0.0001	0.0001	0.0044	0.0201	0.0810
Nickel	mg/L	0.007	0.02	0.154	0.448	0.0066	0.168	0.275	0.239	0.323	0.498	0.904	0.0638	0.0209
Lead	mg/L	0.0001	0.0072	0.0003	0.0002	<0.00002	0.0020	0.0003	0.0006	0.0001	0.0001	0.0031	0.0001	0.00003
Zinc	mg/L	0.002	0.03	0.116	0.236	0.0032	0.186	0.149	0.148	0.134	0.0779	0.2310	0.0093	0.0018
Uranium	mg/L	0.0004	0.015	0.0100	0.0622	0.0002	0.0292	0.0043	0.0169	0.0105	0.0413	0.1150	0.2290	0.0128

Parameter	Unit	WQO		Pit Lakes			
				FS 46 (large pit lake)		FS47 (small pit lake)	
		*TV	*AV	Mean	Max	Mean	Max
		Number of Samples		9	9	7	7
pH	s.u.	<6.7 or >7.0	<6.0 or >9.0	6.6	6.7	6.6	6.8
Suspended solids	mg/L	3	25	1.8	7.0	1.2	3.8
Ammonium	mg/L	0.101	1	0.068	0.126	0.031	0.176
Nitrite as N	mg/L	0.012	0.05218	<0.002	<0.002	<0.002	<0.002
Nitrate as N	mg/L	0.279	20	0.03	0.03	0.02	0.04
Chloride	mg/L	3.0	150	2.8	2.9	3.0	3.1
Sulphate	mg/L	89	159	285	316	322	336
Iron	mg/L	0.92	4.07	0.0990	0.8591	0.380	2.405
Aluminium	mg/L	0.050	0.1	0.006	0.010	0.002	0.002
Arsenic	mg/L	0.0012	0.0050	0.0001	0.0001	0.0001	0.0001
Cadmium	mg/L	0.00001	0.00008	0.00003	0.00004	0.00001	0.00002
Cobalt	mg/L	0.002	0.004	0.012	0.014	0.004	0.015
Chromium	mg/L	0.0003	0.001	0.0004	0.0007	<0.0001	<0.0001
Copper	mg/L	0.0048	0.005	0.007	0.013	0.001	0.002
Mercury	mg/L	0.000002	0.00005				
Manganese	mg/L	0.294	0.70	1.033	1.225	0.339	1.367
Molybdenum	mg/L	0.0002	1	0.0006	0.0007	0.0002	0.0004
Nickel	mg/L	0.007	0.02	0.024	0.029	0.012	0.022
Lead	mg/L	0.0001	0.0072	0.00003	0.00005	0.00002	0.00003
Zinc	mg/L	0.002	0.03	0.038	0.045	0.012	0.024
Uranium	mg/L	0.0004	0.015	0.0049	0.0049	0.0025	0.0025

Parameter	Unit	WQO		TMF Surface Seepage		WRD Surface Seepage		WRD Trial Pit				TMF Trial Pit		
		*TV	*AV	SWS01	SWS02	SWS04	SWS05	TP2	TP3	TP4	TP5	TP6	TP7	TP8
		Number of Samples		1	1	1	1	1	1	1	1	1	1	1
Conductivity	mS/m	26	41											
Calcium	mg/L	25	46	25.2	239	60.6	87.7	104	150	127	183	456	349	62.1
Potassium	mg/L	3.0	4.9	2.70	19.4	2.61	8.03	9.65	12.4	5.99	5.35	109	59.1	31.9
Magnesium	mg/L	10	17	16	129	13	29	22	38	33	62	1104	675	52
Sodium	mg/L	5.3	9.1	2.9	11	4.3	5.2	4.3	5.4	3.3	5.6	30	48	119
Sulfur	mg/L	29	53	59	473	58	114	123	176	166	325	1947	1054	154
Silicon	mg/L	4	11	8.8	11	4.5	11	16	11	17	29	23	8.1	4.7
Barium	mg/L	0.010	0.014	0.003	0.011	0.004	0.005	0.004	0.005	0.003	0.006	0.030	0.048	0.119
Strontium	mg/L	0.070	0.112	0.059	0.473	0.058	0.114	0.123	0.176	0.166	0.325	1.947	1.054	0.154
Antimony	mg/L	0.00002	0.00006	0.009	0.011	0.005	0.011	0.016	0.011	0.017	0.029	0.023	0.008	0.005

Parameter	Unit	WQO		Pit Lakes			
				FS 46 (large pit lake)		FS47 (small pit lake)	
		*TV	*AV	Mean	Max	Mean	Max
		Number of Samples		9	9	7	7
Conductivity	mS/m	26	41	72.2	77.2	76.5	78.8
Calcium	mg/L	25	46	106	115	107	113
Potassium	mg/L	3.0	4.9	13	15	13	13
Magnesium	mg/L	10	17	20	20	22	23
Sodium	mg/L	5.3	9.1	4.2	4.6	5.6	5.7
Sulfur	mg/L	29	53	103.0	111.3	118	120
Silicon	mg/L	4	11	7.9	8.2	6.0	8.0
Barium	mg/L	0.010	0.014	0.013	0.013	0.036	0.040
Strontium	mg/L	0.070	0.112	0.18	0.19	0.22	0.22
Antimony	mg/L	0.00002	0.00006				

** Trigger Values (TV) and Action Values (AV) for Niesajoki River*
Where number of samples are shown as 2 a mean value has been recorded

= exceeds AV guideline
= exceeds TV guideline

** Trigger Values (TV) and Action Values (AV) for Niesajoki River*
Samples shown as mean are an average of all sample depths

= exceeds AV guideline
= exceeds TV guideline

Hannukainen

Group Name	STATIONID	Aquifer	Sampling date	Si_mg/L	pH	HCO3_mg/L	Cl_mg/L	SO4_mg/L	Ca_mg/L	K_mg/L	Mg_mg/L	Na_mg/L	Al_µg/L	As_µg/L	Ba_µg/L	Cd_µg/L	Co_µg/L	Cr_µg/L	Cu_µg/L	Mn_µg/L	Mo_µg/L	Ni_µg/L	Pb_µg/L	Sr_µg/L	Zn_µg/L	U_µg/L	Fe_mg/L
Hannukainen	HAN OW 08D	Deep	20-Jun-11	8.9	7.5	62.82	2.4	237	90	8.4	4.9	18.0	4	0.10	26	0.021	3.69	0.2	3.3	218.0	4.6	7.4	0.03	276	14	17	***0.0005***
Hannukainen	Han OW 08D	Deep	19-Apr-12	9.1	7.2	65.86	2.6	244.1	***0.1***	***0.1***	***0.1***	***0.1***	2.6	0.13	25.3	0.006	2.57	0.2	0.2	179.9	4.88	5.9	0.05	265	11.2	16.64	0.04
Hannukainen	HAN OW 08D	Deep	14-Jun-12	7.5	7.2	98.51	3.7	287.8	85.5	9.2	4.6	54.1	2.9	0.71	32.3	0.008	0.56	0.4	1.0	553.3	7.21	1.1	0.05	272	10.7		0.01
Hannukainen	HAN OW 08D	Deep	14-Jun-12	7.5	7.2	98.51	3.7	288	86	9.2	4.6	54	2.9	0.71	32	0.008	0.56	0.4	1.0	553	7.2	1.1	0.05	272	11		0.010
Hannukainen	HAN OW 08D	Deep	22-Aug-12	7.4	6.8	93.41			95	9.5	5.1	36	2.5	1.22	35	***0.005***	0.15	0.40	0.9	873	8.7	1.0	0.09	311	2.2	27.5	0.091
Hannukainen	HAN OW 08S	Shallow	14-Jun-12	3.6	6.7	16.13	1.0	31.5	10.4	0.8	2.6	2.3	81.5	***0.05***	9.3	***0.005***	1.12	0.3	1.7	128.7	0.13	17.9	0.03	48	2.4		0.06
Hannukainen	HAN OW 08S	Shallow	14-Jun-12	3.6	6.7	16.13	1.0	31	10	0.8	2.6	2.3	82	***0.05***	9.3	***0.005***	1.1	0.3	1.7	129	0.13	18	0.03	48	2.4		0.062
Hannukainen	LVT 6	Shallow	12-Apr-12	12.5	6.0	47.48	2.4	564.2	138.0	0.2	56.6	10.1	8.6	***0.05***	22.0	0.020	0.17	2.0	0.7	10.3	0.09	15.1	***0.02***	785	7.8	0.04	0.01
Hannukainen	LVT 6	Shallow	14-Jun-12	11.8	6.0	39.03	2.8	528.8	178.1	1.8	54.2	11.1	5.9	0.07	22.1	0.018	0.30	0.5	0.4	4.4	***0.05***	14.7	0.05	794	2.5		0.00
Hannukainen	LVT 6	Shallow	14-Jun-12	12	6.0	39.03	2.8	529	178	1.8	54	11	5.9	0.07	22	0.018	0.30	0.5	0.4	4.4	***0.05***	15	0.05	794	2.5		0.002
Hannukainen	LVT 6	Shallow	22-Aug-12	9.6	5.7	16.68			130	2.3	41	6.6	17	***0.05***	47	0.056	25	0.43	10	28	0.10	97	0.07	513	24	0.05	0.001
Hannukainen	SP 305	Shallow	20-Jun-11	6.6	5.7	5.59	2.0	278	72	1.8	25.3	8.0	2	***0.05***	25	0.040	19.32	0.1	4.8	163.5	***0.05***	34	***0.02***	372	14	0.02	0.034
Hannukainen	SP 305	Shallow	12-Apr-12	7.8	6.1	9.31	2.4	41.3	118.9	1.5	39.6	9.4	1.2	***0.05***	27.7	0.018	0.35	0.3	0.6	14.4	0.18	4.4	0.06	541	7.5	0.04	0.00
Hannukainen	SP 305	Shallow	14-Jun-12	7.5	5.9	9.51	2.7	428.2	92.3	1.6	33.5	10.8	1.2	***0.05***	28.3	0.019	0.58	0.1	0.5	30.4	***0.05***	4.3	0.05	433	4.4	0.01	0.00
Hannukainen	SP 305	Shallow	14-Jun-12	7.5	5.9	9.51	2.7	428	92	1.6	34	11	1.2	***0.05***	28	0.019	0.58	0.1	0.5	30	***0.05***	4.3	0.05	433	4.4	0.01	0.002
Hannukainen	SP 305	Shallow	22-Aug-12	7.6	5.9	7.57			97	1.7	33	10	2.3	***0.05***	27	0.016	0.33	0.17	0.9	30	***0.05***	4.1	0.07	492	8.0	0.02	0.003
Hannukainen	**SP 305**	Shallow	**01-Jun-08**		5.07	9.8	1.9	319	78.3	4.95	26.9	10.5															
Hannukainen	SP 310	Shallow	16-Jun-11	7.6	6.7	10.21	3.0	282	72	1.8	26	8.1	25	***0.05***	59	0.022	0.16	0.6	0.8	7.6	0.07	2.5	0.06	382	6.0	0.02	0.014
Hannukainen	SP 310	Shallow	12-Apr-12	7.6	6.3	9.78	2.8	34.5	81.5	1.8	30.5	8.3	0.4	***0.05***	53.1	0.009	0.08	0.7	0.4	2.0	0.11	2.1	0.04	408	6.1	0.01	***0.00***
Hannukainen	SP 310	Shallow	14-Jun-12	7.4	6.4	10.03	3.0	315.4	74.7	1.9	25.5	8.2	1.0	***0.05***	70.8	0.013	0.13	0.5	0.4	9.7	***0.05***	2.8	0.03	353	3.1	0.01	0.00
Hannukainen	SP 310	Shallow	14-Jun-12	7.4	6.4	10.03	3.0	315	75	1.9	25	8.2	1.0	***0.05***	71	0.013	0.13	0.5	0.4	9.7	***0.05***	2.8	0.03	353	3.1	0.01	0.001
Hannukainen	**SP 310**	Shallow	**01-Jun-08**		5.28	9.8	3.6	280	79.3	3.23	25.6	8.44															
Hannukainen	SP 310	Shallow	22-Aug-12	6.9	6.3	12.85			42	1.3	14	5.7	11	***0.05***	29	***0.005***	***0.05***	0.72	0.4	3	0.06	1.1	0.06	212	3.1	0.01	0.005
Hannukainen	Pulkka-törmäntie 7	Deep	01-Dec-07		6.2	42	0.75	69.2	32.1	0.4	3.1	3.5	110	10.00	41.0	2.000	3.00	10.00	10.0	5	5.00	5.0	10.00		12.0		0.015
Hannukainen	Ylläksen-tie 180	Deep	01-Dec-07		6.3	12	2.3	110	40.2	1.1	9.5	4.2	77	10.00	110.0	2.000	3.00	10.00	30.0	5	5.00	5.0	10.00		170.0		0.015
Hannukainen	BH 109	Shallow	20-Jun-11	8.9	6.8	22.90	0.6	0.9	3.8	0.46	1.1	2.7	6	***0.05***	12	***0.005***	0.28	1.1	0.3	19.5	0.48	0.9	***0.02***	22	3.4	0.23	0.007
Hannukainen	BH 109	Shallow	18-Apr-12	9.1	7.0	22.28	0.5	0.7	***0.1***	***0.1***	***0.1***	***0.1***	25.1	***0.05***	9.4	***0.005***	0.07	1.4	0.3	2.5	0.21	0.3	0.02	21	27.2	0.02	0.02
Hannukainen	BH 109	Shallow	14-Jun-12	8.8	6.9	22.62	0.7	0.9	3.5	0.3	1.0	3.0	58.9	***0.05***	10.2	***0.005***	0.10	1.2	0.2	7.9	0.46	0.9	0.04	21	74.3	0.03	0.06
Hannukainen	BH 109	Shallow	22-Aug-12	8.2	6.4	21.16			3.6	0.4	1.0	2.8	21	***0.05***	12	***0.005***	0.05	1.30	0.7	19	0.28	0.5	0.03	21	37	0.07	0.017
Hannukainen	HAN OW 02D	Deep	20-Jun-11	4.5	7.3	44.94	2.9	28.5	18	2.7	1.7	7.0	34	0.26	19	0.014	1.33	0.2	9.1	72.4	3.5	4.3	0.10	46	37	7.1	0.019
Hannukainen	HAN OW 02D	Deep	14-Jun-12	4.6	7.2	47.72	4.0	29.4	17.8	3.1	1.8	8.6	31.7	0.16	17.6	0.014	0.23	0.3	6.9	58.5	3.77	4.1	0.07	46	25.9		0.01
Hannukainen	HAN OW 02D	Deep	14-Jun-12	4.6	7.2	47.72	4.0	29	18	3.1	1.8	8.6	32	0.16	18	0.014	0.23	0.3	6.9	58	3.8	4.1	0.07	46	26		0.015
Hannukainen	HAN OW 02D	Deep	22-Aug-12	4.7	6.9	50.83			18	3.5	2.0	11	35	0.28	22	0.016	0.32	0.37	14	78	4.8	3.9	0.20	46	43	9.5	0.022
Hannukainen	Han OW 02S	Shallow	18-Apr-12	***0.0***	5.8	0.32	0.1	***0.3***	81.9	8.0	4.6	24.7	0.5	***0.05***	1.5	***0.005***	***0.05***	***0.1***	***0.1***	***0.1***	***0.05***	***0.1***	***0.02***	***0***	***0.5***	0.04	***0.00***
Hannukainen	HAN OW 02S	Shallow	14-Jun-12	4.3	6.8	13.37	0.8	2.5	3.2	0.7	0.8	1.4	3.2	***0.05***	2.5	***0.005***	1.18	0.1	2.3	115.9	0.07	1.9	0.05	10	6.0		0.01
Hannukainen	HAN OW 02S	Shallow	14-Jun-12	4.3	6.8	13.37	0.8	2.5	3.2	0.7	0.8	1.4	3.2	***0.05***	2.5	***0.005***	1.2	0.1	2.3	116	0.07	1.9	0.05	10	6.0		0.015
Hannukainen	HAN OW 02S	Shallow	22-Aug-12	3.5	6.7	15.10			3.4	0.4	0.9	1.4	4.0	***0.05***	7.8	***0.005***	1.92	0.11	1.0	381	0.13	2.2	***0.02***	11	6.6	0.07	0.003
Hannukainen	LVT2-OW2s	Shallow	18-Apr-12	3.7	6.8				17.7	2.7	1.8	7.3	3.0	0.05	11.2	0.009	2.91	***0.1***	5.3	321.2	0.16	3.6	***0.02***	15	16.1	0.30	0.00
Hannukainen	LVT3 30.6	Shallow	30-Jun-11	7.4	6.3				60	6.8	15	7.1	6	0.08	35	0.043	0.72	0.4	6.3	11.2	0.07	4.0	0.38	268	36	0.01	0.016
Hannukainen	**SP 303**	Shallow	**01-Jun-08**		6.01	6.7	0.74	0.85	0.61	1.67	0.37	1.38															
Hannukainen	**SP 304**	Shallow	**01-Jun-08**		5.37	4.9	1.1	2.4	0.33	3.66	0.35	1.53															
Hannukainen	SP 306	Shallow	04-Apr-12	5.5	7.2	12.17	0.5	1.2	1.8	0.4	0.6	1.9	13.3	***0.05***	11.9	***0.005***	***0.05***	0.4	0.4	5.1	0.11	0.4	0.03	15	2.6	0.04	0.02
Hannukainen	**SP 306**	Shallow	**01-Jun-08**		5.32	24.4	0.73	1.9	1.05	3.46	0.53	3.51															
Hannukainen	SP 306	Shallow	16-Jun-11	5.4	7.2	13.65	0.6	1.3	1.5	0.35	0.57	1.8	53	***0.05***	11	***0.005***	***0.05***	0.5	0.4	2.4	0.18	0.1	0.09	13	0.5	0.05	0.037
Hannukainen	SP 306	Shallow	12-Jun-12	5.0	6.7	11.65	0.8	1.4	1.5	0.3	0.5	2.0	42.1	***0.05***	10.4	***0.005***	***0.05***	0.4	1.1	5.2	0.17	0.2	0.04	13	8.5	0.04	0.04
Hannukainen	SP 306	Shallow	12-Jun-12	5.0	6.7	11.65	0.8	1.4	1.5	0.3	0.5	2.0	42	***0.05***	10	***0.005***	***0.050***	0.4	1.1	5.2	0.17	0.2	0.04	13	8.5	0.04	0.040
Hannukainen	SP 306	Shallow	23-Aug-12	5.2	6.6	12.00			1.6	0.3	0.6	1.9	61	***0.05***	11	***0.005***	***0.05***	0.64	0.4	3	0.08	0.1	0.03	14	0.8	0.04	0.040
Hannukainen	SP 311	Shallow	20-Jun-11	4.1	5.3	2.81	0.5	1.2	0.7	0.18	0.27	1.2	131	0.11	9.1	***0.005***	0.34	0.5	0.5	7.7	***0.05***	0.4	0.06	10	2.6	0.03	0.66
Hannukainen	**SP 311**	Shallow	**01-Jun-08**		4.98	3.05	0.59	1	0.41	3.29	0.19	1.24															
Hannukainen	**SP 317**	Shallow	**01-Jun-08**		5.54	17.7	316	85.8	4.22	29.9	10.8																
Hannukainen	Ylläksen-tie 168	Deep	01-Dec-07		6.0	28	0.5	2.7	2.7	0.4	0.8	1.6	54	10.00	5.0	2.000	3.00	10.00	35.0	5	5.00	5.0	10.00		45.0		0.015

Kuervitikko

Group Name	STATIONID	Aquifer	Sampling date	Si_mg/L	pH	HCO3_mg/L	Cl_mg/L	SO4_mg/L	Ca_mg/L	K_mg/L	Mg_mg/L	Na_mg/L	Al_µg/L	As_µg/L	Ba_µg/L	Cd_µg/L	Co_µg/L	Cr_µg/L	Cu_µg/L	Mn_µg/L	Mo_µg/L	Ni_µg/L	Pb_µg/L	Sr_µg/L	Zn_µg/L	U_µg/L	Fe_mg/L
Kuervitikko	BH 101	Shallow	20-Jun-11	10	6.0	16.36	2.8	1.0	2.2	0.53	0.9	2.4	20	***0.05***	3.3	0.022	2.11	0.2	0.4	44.0	1.3	4.2	0.21	20	6.6	0.01	0.015
Kuervitikko	BH 101	Shallow	12-Apr-12	8.1	6.6	20.74	0.4	2.9	2.6	1.4	1.6	2.4	19.0	***0.05***	2.9	***0.005***	0.50	0.5	0.1	19.1	1.25	6.9	***0.02***	14	***0.5***	0.02	0.02
Kuervitikko	BH 101	Shallow	12-Jun-12	7.8	6.6	19.30	0.8	3.1	2.5	1.2	1.5	2.7	47.6	***0.05***	3.6	***0.005***	0.12	0.7	0.2	4.9	0.43	1.2	0.04	15	8.5	0.02	0.05
Kuervitikko	BH 101	Shallow	12-Jun-12	7.8	6.6	19.30	0.8	3.1	2.5	1.2	1.5	2.7	48	***0.05***	3.6	***0.005***	0.12	0.7	0.2	4.9	0.43	1.2	0.04	15	8.5	0.02	0.053
Kuervitikko	BH 101	Shallow	23-Aug-12	11	6.2	24.35			3.5	0.7	1.6	3.0	28	***0.05***	4.7	***0.005***	0.67	0.69	1.2	14	0.22	0.6	0.03	28	11	***0.01***	0.016
Kuervitikko	BH 103	Shallow	20-Jun-11	3.6	5.8	8.54	0.5	1.6	1.1	0.27	0.34	1.2	31	***0.05***	8.5	***0.005***	0.40	0.2	0.3	19.3	0.14	0.7	***0.02***	13	213	***0.01***	0.021
Kuervitikko	BH 103	Shallow	12-Jun-12	3.8	6.1	7.05	0.7	1.5	1.2	0.2	0.3	1.3	41.1	***0.05***	7.4	***0.005***	0.06	0.1	0.4	4.6	***0.05***	0.3	0.03	13	83.1	***0.01***	0.01
Kuervitikko	BH 103	Shallow	12-Jun-12	3.8	6.1	7.05	0.7	1.5	1.2	0.2	0.3	1.3	41	***0.05***	7.4	***0.005***	0.06	0.1	0.4	4.6	***0.05***	0.3	0.03	13	83	***0.01***	0.015
Kuervitikko	BH 103	Shallow	23-Aug-12	3.8	5.9	4.68			0.9	0.1	0.3	1.1	53	***0.05***	5.2	***0.005***	***0.05***	0.19	0.2	2	0.03	0.1	0.02	10	23	***0.01***	0.025
Kuervitikko	BH 803	Shallow	20-Jun-11	7.2	6.9	13.93	0.5	1.8	2.3	0.81	1.0	2.4	31	0.07	3.7	***0.005***	0.69	0.5	1.0	60.0	2.0	0.5	0.03	15	6.7	0.03	0.027
Kuervitikko	BH 803	Shallow	04-Apr-12	9.3	6.6	23.84	0.7	1.7	3.7	1.0	1.6	2.5	15.8	0.07	8.2	***0.005***	1.23	0.6	0.8	51.5	0.48	1.5	0.04	24	185.7	0.06	0.02
Kuervitikko	BH 803	Shallow	12-Jun-12	7.7	7.0	16.78	0.6	2.0	2.4	0.7	1.0	2.5	42.2	0.07	3.8	***0.005***	***0.05***	1.4	1.1	5.3	0.25	0.4	0.03	15	26.7	0.02	0.01
Kuervitikko	BH 803	Shallow	12-Jun-12	7.7	7.0	16.78	0.6	2.0	2.4	0.7	1.0	2.5	42	0.07	3.8	***0.005***	***0.050***	1.4	1.1	5.3	0.25	0.4	0.03	15	27	0.02	0.013
Kuervitikko	BH 803	Shallow	23-Aug-12	7.6	7.5	16.00			2.2	0.6	1.1	2.1	73	0.06	3.8	***0.005***	0.06	1.48	0.3	1	0.33	0.3	0.04	14	19	0.03	0.046
Kuervitikko	KUE_OW_01D	Deep	16-Jun-11	12	9.0	53.18	0.9	3.6	5.4	1.3	1.9	11.8	772	3.5	21	***0.005***	1.26	2.1	3.8	4.0	0.83	3.9	0.48	30	5.2	0.25	1.1
Kuervitikko	KUE_OW_01D	Deep	04-Apr-12	8.4	8.5	42.36	0.6	18.4	11.6	1.9	2.8	5.6	93.0	1.17	10.2	***0.005***	0.13	0.3	0.5	2.1	1.55	0.5	0.07	40	0.9	0.92	0.11
Kuervitikko	KUE_OW_01D	Deep	12-Jun-12	2.1	9.1	41.89	1.3	4.8	4.0	1.5	1.6	11.0	53.7	1.49	8.2	***0.005***	0.11	0.2	0.8	1.5	1.00	0.5	0.07	24	1.3	0.24	0.07
Kuervitikko	KUE_OW_01D	Deep	12-Jun-12	2.1	9.1	41.89	1.3	4.8	4.0	1.5	1.6	11	54	1.5	8.2	***0.005***	0.11	0.2	0.8	1.5	1.0	0.5	0.07	24	1.3	0.24	0.066
Kuervitikko	KUE_OW_01D	Deep	23-Aug-12	7.6	7.9	32.59			5.2	0.9	1.9	4.3	118	0.76	7.8	***0.005***	0.09	1.05	1.5	3	0.43	0.6	0.10	26	4.9	0.17	0.085
Kuervitikko	KUE_OW_01S	Shallow	12-Apr-12	6.5	8.7	61.55	3.5	9.6	312.4	0.1	125.4	781.7	170.1	3.53	6.7	0.007	0.17	1.0	2.0	5.2	5.36	0.8	0.09	36	2.9	0.70	0.12
Kuervitikko	KUE_OW_01S	Shallow	12-Jun-12	1.3	9.0	38.42	1.3	3.0	4.4	2.0	1.8	6.6	70.1	0.68	5.5	***0.005***	0.06	0.2	0.7	3.2	0.71	0.3	0.07	25	1.5	0.12	0.06
Kuervitikko	KUE_OW_01S	Shallow	12-Jun-12	1.3	9.0	38.42	1.3	3.0	4.4	2.0	1.8	6.6	70	0.68	5.5	***0.005***	0.06	0.2	0.7	3.2	0.71	0.3	0.07	25	1.5	0.12	0.057
Kuervitikko	KUE_OW_01S	Shallow	23-Aug-12	6.7	7.8	39.83			5.4	0.9	1.7	3.4	203	0.58	6.8	***0.005***	0.08	0.75	1.3	2	0.59	0.6	0.08	28	1.4	0.06	0.173
Kuervitikko	KUE11GT04	Deep	21-Jun-11	4.4	7.1	19.38	0.6	0.7	2.0	0.92	1.1	2.8	12	***0.05***	2.4	***0.005***	0.37	0.1	0.7	238.8	3.7	1.5	0.03	17	8.4	0.01	1.1
Kuervitikko	KUE11GT04	Deep	04-Apr-12	10.4	6.8	17.35	0.5	0.5	2.2	0.5	1.2	2.6	2.2	***0.05***	3.8	***0.005***	***0.05***	0.3	0.6	6.2	0.40	0.2	0.03	18	0.6	0.03	0.02
Kuervitikko	KUE11GT04	Deep	12-Jun-12	2.4	7.4	18.23	0.6	0.9	2.1	0.6	1.0	2.9	2.9	***0.05***	3.8	***0.005***	***0.05***	0.1	0.2	99.9	3.51	0.4	0.02	18	1.1	***0.01***	0.19
Kuervitikko	KUE11GT04	Deep	12-Jun-12	2.4	7.4	18.23	0.6	0.9	2.1	0.6	1.0	2.9	2.9	***0.05***	3.8	***0.005***	***0.050***	0.1	0.2	100	3.5	0.4	0.02	18	1.1	***0.01***	0.19
Kuervitikko	KUE11GT04	Deep	23-Aug-12	0.2	8.0				2.1	0.7	0.9	2.8	11	***0.05***	2.4	***0.005***	0.06	0.12	1.3	36	5.9	0.5	0.02	17	0.8	***0.01***	0.031
Kuervitikko	**SP 307**	Shallow	**01-Jun-08**		5.34	26.8	5	3.2	1.67	4.84	0.69	8															
Kuervitikko	**SP 308**	Shallow	**01-Jun-08**		5.58	14	0.71	1.3	0.4	2.55	0.18	1.93															
Kuervitikko	SP 312	Shallow	20-Jun-11	5.6	6.9	16.40	0.8	1.9	2.0	0.72	0.68	2.5	83	***0.05***	3.7	***0.005***	***0.05***	0.4	0.3	6.8	0.39	0.2	0.03	25	0.6	0.01	0.038
Kuervitikko	SP 312	Shallow	12-Apr-12	5.5	7.5	12.54	0.4	1.6	1.9	0.4	0.6	1.9	30.5	***0.05***	2.1	***0.005***	***0.05***	0.7	0.2	1.1	0.18	0.1	***0.02***	20	0.9	***0.01***	0.03
Kuervitikko	SP 312	Shallow	12-Jun-12	5.4	6.8	12.72	1.1	2.0	1.9	0.6	0.6	2.4	33.5	***0.05***	2.8	***0.005***	***0.05***	0.6	0.7	4.8	0.19	0.3	0.03	21	13.0	***0.01***	0.04
Kuervitikko	SP 312	Shallow	12-Jun-12	5.4	6.8	12.72	1.1	2.0	1.9	0.6	0.6	2.4	34	***0.05***	2.8	***0.005***	***0.050***	0.6	0.7	4.8	0.19	0.3	0.03	21	13	***0.01***	0.039
Kuervitikko	SP 312	Shallow	24-Aug-12	5.5	6.7	12.07			1.7	0.5	0.6	2.1	36	***0.05***	2.7	***0.005***	***0.05***	0.53	0.6	32	0.26	0.2	0.03	20	1.9	***0.01***	0.028
Kuervitikko	**SP 312**	Shallow	**01-Jun-08**		5.47	15.9	2.6	2.8	1.41	1.93	0.48	5.12															
Kuervitikko	SP 314	Shallow	16-Jun-11	12	7.6	26.67	2.2	1.7	3.2	0.43	1.2	3.6	66	***0.05***	3.4	***0.005***	0.10	1.3	0.3	40.3	0.16	0.6	0.03	31	0.5	0.02	0.029
Kuervitikko	SP 314	Shallow	04-Apr-12	11.8	6.3	17.05	0.6	1.1	2.4	0.4	0.7	3.1	33.4	***0.05***	2.2	***0.005***	0.11	1.3	0.5	16.6	0.13	0.5	0.04	24	1.8	0.01	0.03
Kuervitikko	SP 314	Shallow	12-Jun-12	9.8	6.3	14.33	0.8	1.3	1.8	0.3	0.6	3.3	40.5	***0.05***	1.8	***0.005***	0.05	0.9	0.3	12.0	0.09	0.3	0.04	20	2.1	0.01	0.02
Kuervitikko	SP 314	Shallow	12-Jun-12	9.8	6.3	14.33	0.8	1.3	1.8	0.3	0.6	3.3	40	***0.05***	1.8	***0.005***	0.05	0.9	0.3	12	0.09	0.3	0.04	20	2.1	0.01	0.025
Kuervitikko	**SP 314**	Shallow	**01-Jun-08**		5.74	11.6	1.5	0.84	3.02	5.69	1.31	7.65															
Kuervitikko	SP 314	Shallow	23-Aug-12	11	6.1	16.99			2.3	0.3	0.9	3.4	67	***0.05***	1.9	***0.005***	0.13	1.28	0.4	32	0.11	0.5	0.03	23	1.0	0.01	0.029
Kuervitikko	**SP 316**	Shallow	**01-Jun-08**		5.73	164.7	5.9	2.25	19.8	1.46	19.8																

APPENDIX

G GROUNDWATER RECHARGE ESTIMATION

APPENDIX G - WATER BALANCE: RECHARGE ESTIMATE

Groundwater recharge was estimated during the Open Pit Mine Dewatering study (SRK, 2012a). The text below is an extract from that report, and describes the water balance that was used to estimate groundwater recharge:

"In order to obtain estimates of snowmelt, snow storage, actual evapotranspiration, runoff and groundwater recharge, a simple monthly water balance was developed for the area around Äkäsjoki catchment, based on regional monthly climatic data. The water balance was based on a model developed for the NOPEX[1] region by Xu et. al, (1996), and calibrated using available surface water runoff data.

Conceptually, recharge will be confined to periods with a temperature above freezing, which occurs on average from around April to October. Some workers (e.g. Bengtsson, 1982), have shown that snow-melt is a significant source of groundwater recharge as the rate of melting is slow enough to encourage infiltration, whilst others suggest the frozen ground under the snow impedes groundwater recharge. It is likely both mechanisms exist under differing conditions. Snowfall and subsequent melting is described as a function of precipitation and temperature according to the following equations:

$$Snowfall = precipitation \times (1-\{exp[-(temperature - a_1)/(a_1 - a_2)]\}^2)$$

$$Snowmelt = snowpack \times (1-\{exp[-(temperature - a_2)/(a_1 - a_2)]\}^2)$$

Equation G1: Snowfall and snowmelt as a function of precipitation and temperature

where a_1 and a_2 are constants.

Figure G1 illustrates calculated monthly snowfall and snowmelt according to the above equations. It can be seen that snowmelt is predicted to start in April, and peak in May, with residual snowmelt in June. Monthly potential evaporation estimates are based on the FAO local climate model (2008).

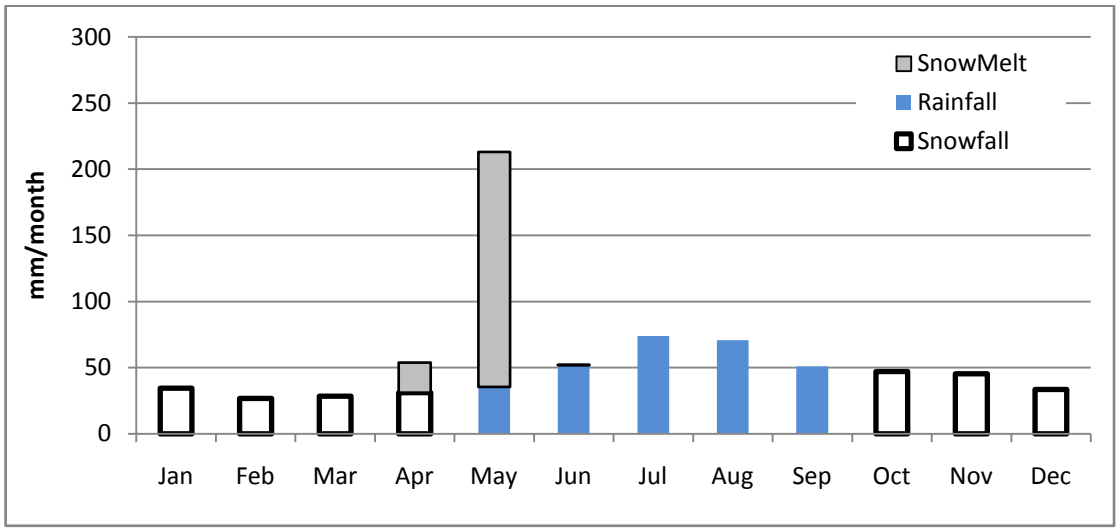


Figure G1: Rainfall, snowmelt and snowfall water balance for the Hannukainen region

[1] *Northern Hemisphere Climate Processes Land Surface Experiment Project*

In order to calibrate the monthly water balance model, estimates of monthly surface water runoff or "quick flow" from over two measurement seasons in the Hannukainen region have been used. Surface water volumes estimated for the Äkäsjoki catchment in early May were closer to the average yields observed at this time of year in the Muonio River than the Torne River. Therefore, variation in total runoff in the Äkäsjoki catchment is assumed to follow the same seasonal variation seen in the average runoff yield of the Muonio River (as shown in Figure G2).

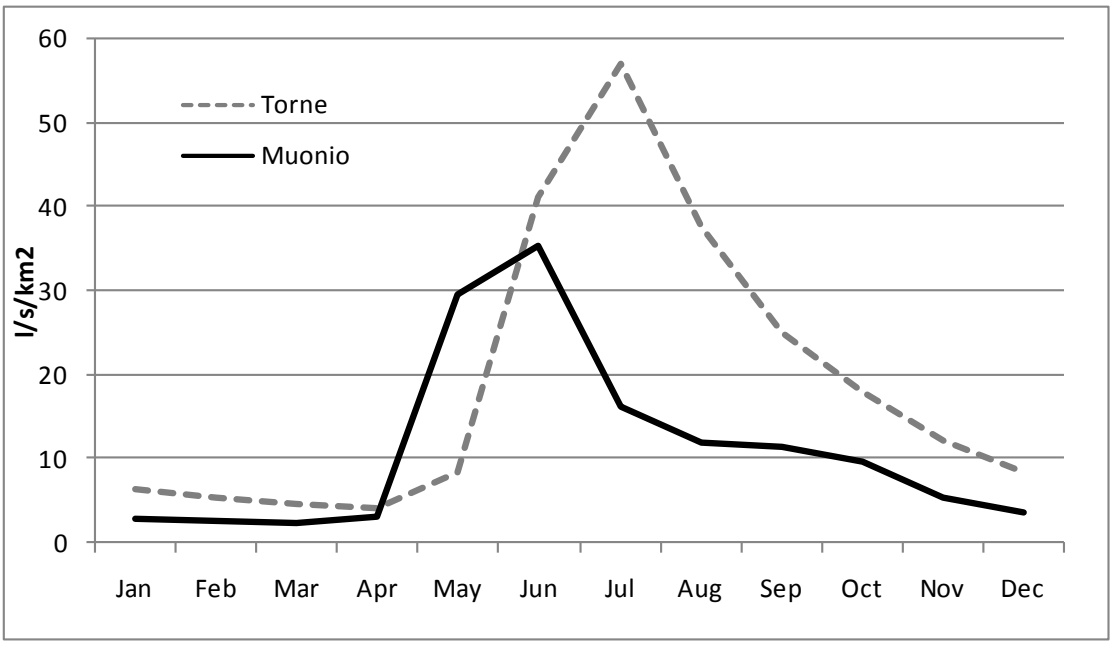


Figure G2: Average monthly yield (L/s/km^2) for the Muonio River at Kallio (1911-1975) and the Torne River (1918-1983)

The May average yield in the Äkäsjoki catchment (25L/s/km^2), is less than the average May yield observed in the Muonio catchment. This is due to the difference in size between the catchment areas, and also to different snowmelt characteristics of the catchments. For this reason a scaling factor is applied to the Muonio catchment yield data to obtain representative average monthly runoff estimates for the Äkäsjoki catchment.

Figure G3 illustrates total modelled runoff (290mm/year) in relation to interpolated catchment yield (291mm/year). Slow flow, representative of rainfall that infiltrates past the capillary zone (i.e. effective precipitation minus runoff) is also shown (74mm/year). It should be noted that the model failed to represent the peak in runoff as suggested by the observed data from the Muonio River, but as explained previously, this is likely due to the different catchment characteristics.

Notwithstanding this inconstancy, the model performs reasonably well with a Nash-Sutcliff efficiency score of 70% (highest possible score 100%) and a model bias of 0.3 (indicating slight underestimation of total runoff). It should be noted that no correction factor has been applied to precipitation data sourced from the SMHI. Monthly variation in all variables is shown in Figure G3.

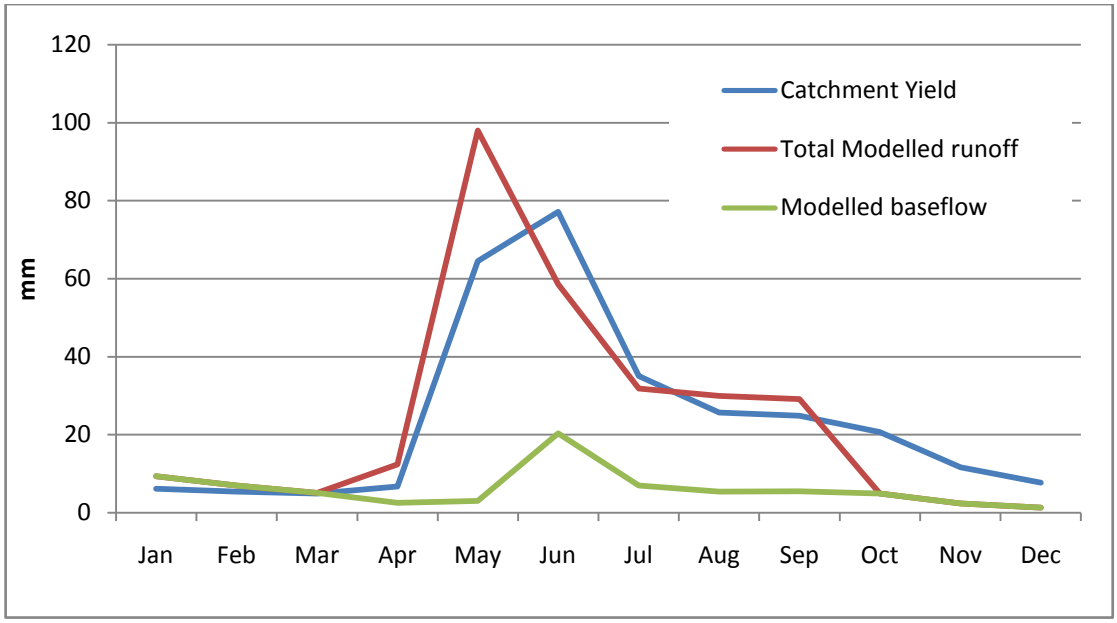


Figure G3: Interpolated local yield compared to modelled effective precipitation and slow flow

Table G1: Water Balance for the area around Hannukainen

Month	Precipitation	Temp	Snowfall	Rainfall	Evaporation	Total Runoff (red[2])	Slow Flow (green[8])	Yield (blue[8])
	mm	deg C	mm	mm	mm	mm	mm	mm
Jan	34.5	-13.3	34.5	0.0	3.00	9	9	6
Feb	26.7	-11.9	26.7	0.0	3.00	7	7	5
Mar	28.5	-7.0	28.5	0.0	8.28	5	5	5
Apr	31.0	-0.7	31.0	0.0	7.77	12	3	7
May	35.4	6.1	0.0	35.4	25.93	98	3	65
Jun	52.0	12.2	0.0	52.0	62.31	59	20	77
Jul	74.0	14.7	0.0	74.0	50.44	32	7	35
Aug	70.8	12.0	0.0	70.8	40.29	30	5	26
Sep	50.9	6.3	0.0	50.9	24.57	29	5	25
Oct	47.1	-0.4	47.1	0.0	8.69	5	5	21
Nov	45.5	-7.7	45.5	0.0	3.52	2	2	12
Dec	33.5	-11.9	33.5	0.0	2.78	1	1	8
Total	**530**		**247**	**283**	**240.6**	**290**	**74**	**291**

In order to further verify the NOPEX model results, a comparison was made to the runoff values predicted by the SYKE Drainage Model for the Äkäsjoki Catchment. Figure G4 illustrates a good correlation between the modelled peak runoff predictions, which corroborates with the suggestion that the peak runoff is indeed occurring in May as opposed to the June peak displayed by the historical data for the Muonio River.

[2] *Colours refer to graph lines in Figure G3.*

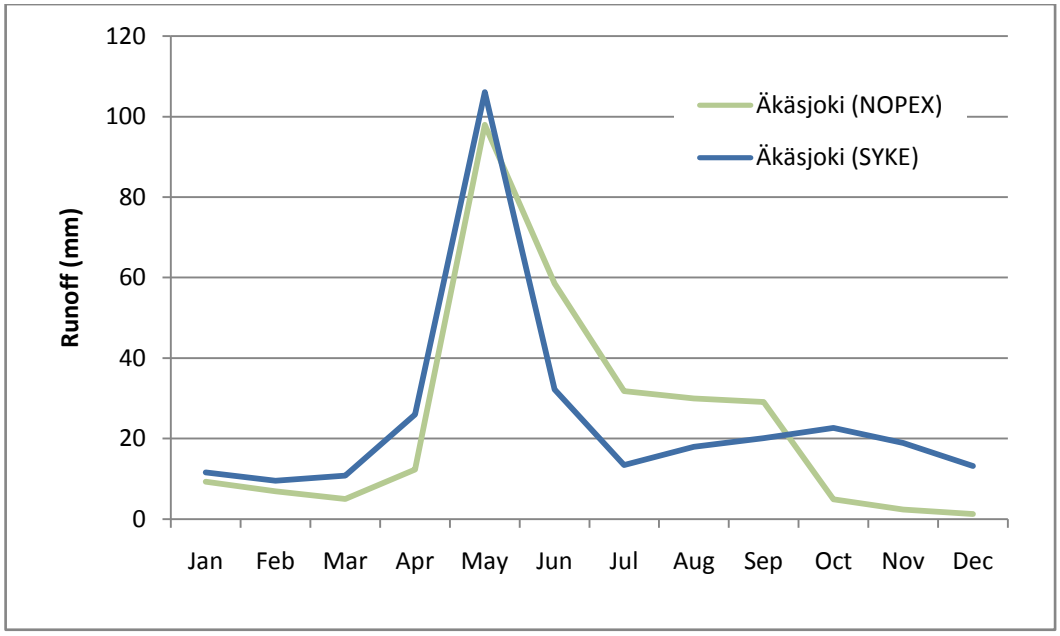


Figure G4: Comparison of Runoff Estimates produced by SYKE and NOPEX Models

It should be noted that there is some variation in the values of runoff between the two models, especially regarding runoff patterns between July and October however, since infrastructure design and flood risk analysis is based on peak runoff, the correlation of peak runoff is of greater significance. Average annual volumes of runoff predicted by the two models are consistent, 9.20L/s/km2 and 9.52L/s/km2 for the NOPEX and SYKE models respectively. Therefore there is a good degree of confidence in these volumes and subsequently pit inflow estimates from surface water."

APPENDIX

H GROUNDWATER LEVEL MONITORING

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
Putki_01	16/03/2012	192.17	2.82	0.96	1.86	190.31		Northland
Putki_02	16/03/2012	196.52	5.72	0.96	4.76	191.76		Northland
Putki_03	16/03/2012	185.00	1.54	0.92	0.62	184.38		Northland
RAU12HYD01(D)	08/06/2012	206.65	8.90	0.79	8.11	198.54		SRK
RAU12HYD01(S)	08/06/2012	206.65	9.34	1.27	8.07	198.58		SRK
RAU12HYD02(D)	08/06/2012	197.60	0.97	0.60	0.37	197.23		SRK
RAU12HYD02(S)	08/06/2012	197.60	2.61	0.75	1.86	195.74		SRK
RAU12HYD04(D)	09/06/2012	189.73	2.90	1.49	1.41	188.32		SRK
RAU12HYD04(S)	09/06/2012	189.73	2.49	1.35	1.14	188.59		SRK
RAU12HYD05(D)	09/06/2012	215.87	5.98	1.06	4.92	210.95		SRK
RAU12HYD05(S)	09/06/2012	215.87	6.47	0.69	5.78		Dry	SRK
RAU12HYD16(D)	09/06/2012	205.09	0.71	1.30	-0.59	205.68	Bad hole? Caving around metal casing in upper 0.5m beneath cement. No visible movement in standing water during test in deep piezo. Standing water visible close by	SRK
RAU12HYD16(S)	09/06/2012	205.09	0.41	0.93	-0.52	205.61		SRK
RAU12HYD17(D)	09/06/2012	196.06	1.19	1.27	-0.08	196.14		SRK
RAU12HYD17(S)	09/06/2012	196.06	1.83	1.65	0.18	195.88		SRK
Putki_02	10/06/2012	196.52	5.66	0.96	4.70	191.82	TOC measurement to top of white inner casing (approx. 3cm below steel casing)	SRK
RAU12HYD03(D)	10/06/2012	196.52	6.09	1.20	4.89	191.63	Caving around top of metal casing; ~2mbgs on S side, ~1mbgs on N side of hole.	SRK
RAU12HYD03(Mid)	10/06/2012	196.52	6.24	1.24	5.00	191.52		SRK
RAU12HYD03(S)	10/06/2012	196.52	5.70	1.02	4.68	191.84		SRK
RAU12HYD14(D)	10/06/2012	190.35	3.65	1.07	2.58	187.77		SRK
RAU12HYD14(S)	10/06/2012	190.35	3.87	1.18	2.69	187.66		SRK
RAU12HYD18(D)	10/06/2012	194.28	2.48	1.00	1.48	192.80	Boggy	SRK
RAU12HYD18(S)	10/06/2012	194.28	2.00	1.16	0.84	193.44		SRK
RAU12HYD08(D)	11/06/2012	197.97	1.06	1.44	-0.38	198.35	Poorly sorted sand/gravel visible around hole. Lots of mosquitoes, difficult access due to bog	SRK
RAU12HYD08(S)	11/06/2012	197.97	1.26	1.16	0.10	197.87		SRK
RAU12HYD13(D)	11/06/2012	194.36	7.97	0.84	7.13	187.23		SRK
RAU12HYD13(S)	11/06/2012	194.36	7.89	0.75	7.14	187.22		SRK
RAU12HYD21(D)	11/06/2012	194.69	1.07	1.14	-0.07	194.76	Very boggy, between two streams. Piezometric WL above ground surface but not flowing	SRK
RAU12HYD21(S)	11/06/2012	194.69	0.48	1.24	-0.76	195.45		SRK

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
Putki_01	12/06/2012	192.17	2.65	0.96	1.69	190.48	TOC measurement to top of white inner casing	SRK
RAU12HYD06(D)	12/06/2012	190.76	0.42	1.00	-0.58	191.34	Ground very soft around hole. Piezometric WL above ground sufrace but not flowing. Measurements taken from reduced casing. Full height of casing (D)=1.0+0.96=1.96m, (S)=1.42+0.48=1.90m	SRK
RAU12HYD06(S)	12/06/2012	190.76	0.96	1.42	-0.46	191.22		SRK
RAU12HYD07(D)	12/06/2012	192.17	0.69	0.88	-0.19	192.36	Ground depressed around hole, radius ~1.5m. Piezometric WL above ground sufrace but not flowing. Measurements taken from reduced casing. Full height of casing (D)=0.88+0.50=1.38m, (S)=0.98+0.94=1.92m. Soft sediment at the base of both (S) and (D) piezos.	SRK
RAU12HYD07(S)	12/06/2012	192.17	0.93	0.98	-0.05	192.22		SRK
RAU12HYD09(D)	12/06/2012	193.99	6.24	1.37	4.87	189.12		SRK
RAU12HYD09(S)	12/06/2012	193.99	6.31	1.31	5.00	188.99		SRK
RAU12HYD23(D)	12/06/2012	215.43	21.21	0.85	20.36	195.07		SRK
RAU12HYD23(S)	12/06/2012	215.43	20.79	1.00	19.79	195.64		SRK
Putki_03	13/06/2012	185.00	1.58	0.92	0.66	184.34	Borehole on slightly raised ground in woods. Bog to the south.	SRK
RAU12HYD10(D)	13/06/2012	201.80	9.64	1.30	8.34	193.46	Bog in lower regions, area of borehole is dry.	SRK
RAU12HYD10(S)	13/06/2012	201.80	9.32	1.10	8.22	193.58		SRK
RAU12HYD19(D)	13/06/2012	213.95	15.41	1.10	14.31	199.64	Standing surface water 10m down slope from borehole	SRK
RAU12HYD19(S)	13/06/2012	213.95	15.35	1.10	14.25	199.70		SRK
RAU12HYD20(D)	13/06/2012	223.45	25.68	1.25	24.43	199.02	On hilltop in bog - perched water table.	SRK
RAU12HYD20(S)	13/06/2012	223.45	25.74	1.27	24.47	198.98		SRK
RAU12HYD22(D)	13/06/2012	204.79	4.14	1.00	3.14	201.65	Reasonably dry area.	SRK
RAU12HYD22(S)	13/06/2012	204.79	4.25	1.22	3.03	201.76		SRK
RAU12HYD11(D)	14/06/2012	196.41	6.93	1.45	5.49	190.93		SRK
RAU12HYD11(S)	14/06/2012	196.41	6.67	1.28	5.39	191.02		SRK
RAU12HYD12(D)	14/06/2012	176.52	1.78	1.80	-0.02	176.54		SRK

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
RAU12HYD12(S)	14/06/2012	176.52	1.00	0.96	0.04	176.49	Measurements taken from reduced casing. Full height of casing (S)=0.96+0.98=1.94m	SRK
RAU12HYD15(D)	14/06/2012	192.99	3.62	1.30	2.32	190.67	Very boggy, spongy ground. Water visible ~10cm below ground surface in old drill hole	SRK
RAU12HYD15(S)	14/06/2012	192.99	3.83	1.40	2.43	190.56		SRK
RAU12HYD24(D)	14/06/2012	199.13	0.00	0.54	-0.54	199.67	Artesian - flow rate measured	SRK
RAU12HYD24(S)	14/06/2012	199.13	1.43	0.90	0.53	198.60		SRK
Putki_01	11/07/2012	193.04			1.95	191.09	GTK/Old Rautaruukki points	Poyry
Putki_02	11/07/2012	196.93			5.10	191.83	GTK/Old Rautaruukki points	Poyry
RAU12HYD01(S)	11/07/2012	206.65			8.09	198.56	SRK/HK-phase2, RAU12HYD01	Poyry
RAU12HYD02(S)	11/07/2012	197.60			1.12	196.48	SRK/HK-phase2, RAU12HYD02	Poyry
RAU12HYD03(S)	11/07/2012	196.52			4.86	191.66	SRK/HK-phase2, RAU12HYD03	Poyry
RAU12HYD04(S)	11/07/2012	189.73			1.28	188.46	SRK/HK-phase2, RAU12HYD04	Poyry
RAU12HYD05(S)	11/07/2012	215.87			5.35	210.52	SRK/HK-phase2, RAU12HYD05	Poyry
RAU12HYD06(S)	11/07/2012	190.76			-0.52	191.28	SRK/HK-phase2, RAU12HYD06	Poyry
RAU12HYD07(S)	11/07/2012	192.17			-0.12	192.29	SRK/HK-phase2, RAU12HYD07	Poyry
RAU12HYD08(S)	11/07/2012	197.97			-0.14	198.11	SRK/HK-phase2, RAU12HYD08	Poyry
RAU12HYD10(S)	11/07/2012	201.80			8.28	193.52	SRK/HK-phase2, RAU12HYD10	Poyry
RAU12HYD11(S)	11/07/2012	196.41			5.44	190.97	SRK/HK-phase2, RAU12HYD11	Poyry
RAU12HYD12(S)	11/07/2012	176.52			0.01	176.51	SRK/HK-phase2, RAU12HYD12	Poyry
RAU12HYD13(S)	11/07/2012	194.36			7.13	187.23	SRK/HK-phase2, RAU12HYD13	Poyry
RAU12HYD14(S)	11/07/2012	190.35			2.63	187.71	SRK/HK-phase2, RAU12HYD14	Poyry
RAU12HYD15(S)	11/07/2012	192.99			2.38	190.62	SRK/HK-phase2, RAU12HYD15	Poyry
RAU12HYD16(S)	11/07/2012	205.09			-0.56	205.64	SRK/HK-phase2, RAU12HYD16	Poyry
RAU12HYD17(S)	11/07/2012	196.06			0.05	196.01	SRK/HK-phase2, RAU12HYD17	Poyry
RAU12HYD18(S)	11/07/2012	194.28			1.16	193.12	SRK/HK-phase2, RAU12HYD18	Poyry
RAU12HYD19(S)	11/07/2012	213.95			14.28	199.67	SRK/HK-phase2, RAU12HYD19	Poyry
RAU12HYD20(S)	11/07/2012	223.45			24.45	199.00	SRK/HK-phase2, RAU12HYD20	Poyry
RAU12HYD21(S)	11/07/2012	194.69			-0.41	195.11	SRK/HK-phase2, RAU12HYD21	Poyry
RAU12HYD22(S)	11/07/2012	204.79			3.09	201.71	SRK/HK-phase2, RAU12HYD22	Poyry
RAU12HYD23(S)	11/07/2012	215.43			20.08	195.36	SRK/HK-phase2, RAU12HYD23	Poyry
RAU12HYD24(S)	11/07/2012	199.13			0.00	199.14	SRK/HK-phase2, RAU12HYD24	Poyry
Putki_03	07/08/2012	185.00	1.54	0.90	0.64	184.36		Uni of Hels
RAU12HYD01(S)	07/08/2012	206.65	9.26	1.30	7.96	198.69		Uni of Hels
RAU12HYD02(S)	07/08/2012	197.60	2.57	0.73	1.84	195.76		Uni of Hels
RAU12HYD03(S)	07/08/2012	196.52	5.82	1.03	4.79	191.73		Uni of Hels
RAU12HYD04(S)	07/08/2012	189.73	2.53	1.35	1.18	188.55		Uni of Hels
RAU12HYD05(S)	07/08/2012	215.87	6.92	0.68	6.24	209.63		Uni of Hels
RAU12HYD08(S)	07/08/2012	197.97	1.18	1.18	0.00	197.97		Uni of Hels
RAU12HYD09(S)	07/08/2012	193.99	6.41	1.38	5.03	188.96		Uni of Hels

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Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
RAU12HYD10(S)	07/08/2012	201.80	9.20	1.14	8.06	193.74		Uni of Hels
RAU12HYD11(S)	07/08/2012	196.41	6.57	1.31	5.26	191.15		Uni of Hels
RAU12HYD12(S)	07/08/2012	176.52	2.07	1.87	0.20	176.32		Uni of Hels
RAU12HYD13(S)	07/08/2012	194.36	7.91	0.80	7.11	187.25		Uni of Hels
RAU12HYD14(S)	07/08/2012	190.35	4.01	1.18	2.83	187.52		Uni of Hels
RAU12HYD15(S)	07/08/2012	192.99	3.86	1.43	2.43	190.56		Uni of Hels
RAU12HYD16(S)	07/08/2012	205.09	1.42	0.93	0.49	204.60		Uni of Hels
RAU12HYD17(S)	07/08/2012	196.06	2.03	1.62	0.41	195.65		Uni of Hels
RAU12HYD18(S)	07/08/2012	194.28	2.17	1.00	1.17	193.11		Uni of Hels
RAU12HYD21(S)	07/08/2012	194.69	0.49	1.17	-0.68	195.37		Uni of Hels
RAU12HYD23(S)	07/08/2012	215.43	20.67	0.97	19.70	195.73		Uni of Hels
RAU12HYD24(S)	07/08/2012	199.13	1.43	0.92	0.51	198.62		Uni of Hels
Putki_01	08/08/2012	192.17	2.94	0.93	2.01	190.16		Uni of Hels
Putki_02	08/08/2012	196.52	5.75	0.90	4.85	191.67		Uni of Hels
RAU12HYD06(S)	08/08/2012	190.76	1.57	1.97	-0.40	191.16		Uni of Hels
RAU12HYD07(S)	08/08/2012	192.17	2.06	1.97	0.09	192.08		Uni of Hels
RAU12HYD19(S)	08/08/2012	213.95	15.12	1.07	14.05	199.90		Uni of Hels
RAU12HYD20(S)	08/08/2012	223.45	25.52	1.28	24.24	199.21		Uni of Hels
RAU12HYD22(S)	08/08/2012	204.79	4.33	1.23	3.10	201.69		Uni of Hels
Putki_01	12/09/2012	192.17	2.76	0.93	1.83	190.34		Uni of Hels
Putki_02	12/09/2012	196.52	5.80	0.90	4.90	191.62		Uni of Hels
Putki_03	12/09/2012	185.00	1.59	0.90	0.69	184.31		Uni of Hels
RAU12HYD01(D)	12/09/2012	206.65	8.84	0.79	8.05	198.60	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD01(S)	12/09/2012	206.65	9.30	1.30	8.00	198.65		Uni of Hels
RAU12HYD02(D)	12/09/2012	197.60	1.17	0.60	0.57	197.03	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD02(S)	12/09/2012	197.60	2.89	0.73	2.16	195.44		Uni of Hels
RAU12HYD03(D)	12/09/2012	196.52	6.22	1.20	5.02	191.50	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD03(S)	12/09/2012	196.52	5.92	1.03	4.89	191.63		Uni of Hels
RAU12HYD04(D)	12/09/2012	189.73	2.99	1.49	1.50	188.23	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD04(S)	12/09/2012	189.73	2.54	1.35	1.19	188.54		Uni of Hels
RAU12HYD05(D)	12/09/2012	215.87	9.70	1.06	8.64	207.23	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD05(S)	12/09/2012	215.87		0.68			dry-6,91 at bottom	Uni of Hels
RAU12HYD06(D)	12/09/2012	190.76	1.50	1.00	0.50	190.26	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD06(S)	12/09/2012	190.76	1.50	1.97	-0.47	191.23		Uni of Hels
RAU12HYD07(D)	12/09/2012	192.17	1.55	0.88	0.67	191.50	Stick up assumed equal to previous monitoring round	Uni of Hels

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Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
RAU12HYD07(S)	12/09/2012	192.17	1.80	1.97	-0.17	192.34		Uni of Hels
RAU12HYD08(D)	12/09/2012	197.97	1.43	1.44	-0.01	197.98	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD08(S)	12/09/2012	197.97	1.21	1.18	0.03	197.94		Uni of Hels
RAU12HYD09(D)	12/09/2012	193.99	6.33	1.37	4.96	189.03	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD09(S)	12/09/2012	193.99	6.43	1.38	5.05	188.94		Uni of Hels
RAU12HYD10(D)	12/09/2012	201.80	9.42	1.30	8.12	193.68	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD10(S)	12/09/2012	201.80	9.07	1.14	7.93	193.87		Uni of Hels
RAU12HYD11(D)	12/09/2012	196.41	6.91	1.45	5.47	190.95	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD11(S)	12/09/2012	196.41	6.59	1.31	5.28	191.13		Uni of Hels
RAU12HYD12(D)	12/09/2012	176.52	1.81	1.80	0.01	176.51	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD12(S)	12/09/2012	176.52	1.99	1.87	0.12	176.40		Uni of Hels
RAU12HYD13(D)	12/09/2012	194.36	8.03	0.84	7.19	187.17	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD13(S)	12/09/2012	194.36	7.99	0.80	7.19	187.17		Uni of Hels
RAU12HYD14(D)	12/09/2012	190.35	3.83	1.07	2.76	187.59	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD14(S)	12/09/2012	190.35	4.14	1.18	2.96	187.39		Uni of Hels
RAU12HYD15(D)	12/09/2012	192.99	3.69	1.30	2.39	190.60	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD15(S)	12/09/2012	192.99	3.89	1.43	2.46	190.53		Uni of Hels
RAU12HYD16(D)	12/09/2012	205.09	2.30	1.30	1.00	204.09	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD16(S)	12/09/2012	205.09	1.94	0.93	1.01	204.08		Uni of Hels
RAU12HYD17(D)	12/09/2012	196.06	1.43	1.27	0.16	195.90	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD17(S)	12/09/2012	196.06	2.09	1.62	0.47	195.59		Uni of Hels
RAU12HYD18(D)	12/09/2012	194.28	2.58	1.00	1.58	192.70	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD18(S)	12/09/2012	194.28	2.12	1.00	1.12	193.16		Uni of Hels
RAU12HYD19(D)	12/09/2012	213.95	15.14	1.10	14.04	199.91	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD19(S)	12/09/2012	213.95	15.01	1.07	13.94	200.01		Uni of Hels
RAU12HYD20(D)	12/09/2012	223.45	25.38	1.25	24.13	199.32	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD20(S)	12/09/2012	223.45	25.43	1.28	24.15	199.30		Uni of Hels
RAU12HYD21(D)	12/09/2012	194.69	1.15	1.14	0.01	194.68	Stick up assumed equal to previous monitoring round	Uni of Hels

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Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
RAU12HYD21(S)	12/09/2012	194.69	0.51	1.17	-0.66	195.35		Uni of Hels
RAU12HYD22(D)	12/09/2012	204.79	4.21	1.00	3.21	201.58	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD22(S)	12/09/2012	204.79	4.38	1.23	3.15	201.64		Uni of Hels
RAU12HYD23(D)	12/09/2012	215.43	21.26	0.85	20.41	195.02	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD23(S)	12/09/2012	215.43	20.64	0.97	19.67	195.76		Uni of Hels
RAU12HYD24(D)	12/09/2012	199.13	0.46	0.54	-0.08	199.21	Stick up assumed equal to previous monitoring round	Uni of Hels
RAU12HYD24(S)	12/09/2012	199.13	1.48	0.92	0.56	198.57		Uni of Hels
BH-109	13/06/2012	229	1.21		0.3	228.7	Measurment is NOT from the cover tubes end. Brown water.	Northland
BH-109	02/11/2012	229	1.19		0.28	228.72		Northland
SP112	19/11/2007	#N/A			0.77	162.76	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP113	19/11/2007	#N/A			0.95	163.21	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP114	19/11/2007	#N/A			3.51	168.26	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP108	19/11/2007	#N/A			0.15	169.31	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP102	19/11/2007	#N/A			0.4	171.37	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP120	19/11/2007	#N/A			1.68	171.58	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-310	13/05/2011	178.85	7.92			172.43	GW level corrected to account for borehole dip	SRK
SP-310	19/11/2007	178.85			6.05	172.8	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-310	10/10/2011	178.85	7.52		5.98	172.87		Northland
SP-310	02/11/2012	178.85	7.45		5.91	172.94		Northland
SP-310	22/10/2011	178.85	7.3		5.87	172.98		SRK
SP-310	09/12/2011	178.85	7.41		5.87	172.98		
SP-310	02/12/2011	178.85	7.31		5.77	173.08		

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
SP107	19/11/2007	#N/A			1.29	173.3	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-310	13/06/2012	178.85	7.05		5.51	173.34	Water is cloudy.	Northland
SP119	19/11/2007	#N/A			1.83	173.36	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP110	19/11/2007	#N/A			3.4	173.96	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP118	19/11/2007	#N/A			0.37	174.64	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP115	19/11/2007	#N/A			1.96	175.14	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP116	19/11/2007	#N/A			0.74	175.6	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP117	19/11/2007	#N/A			1.2	177.55	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-317	13/05/2011	#N/A	5.93			177.88	GW level corrected to account for borehole dip	SRK
SP-317	19/11/2007	#N/A			3.31	179	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP106	19/11/2007	#N/A			2.3	179.57	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-317	22/10/2011	#N/A	4.28		2.68	179.63		SRK
LVT1	13/05/2011	#N/A	2.42			181.92	GW level corrected to account for borehole dip	SRK
LVT1	22/10/2011	#N/A	2.32		0.98	182.02	Name on borehole LVT2	SRK
HAN11HYDR01 (S)	05/12/2011	190.569	8.72		8.18	182.389		
HAN11HYDR01 (S)	02/12/2011	190.569	8.7		8.16	182.409		
HAN11HYDR01 (S)	10/10/2011	190.569	8.58		8.04	182.529		Northland
HAN11HYDR01 (D)	02/11/2012	190.569	8.71		8.02	182.549	HAN_OW_08S, Total hole depth 9.2m, means no water in it or only some residual water on the bottom cap	Northland
HAN11HYDR01 (S)	17/04/2012	190.569	8.42		7.88	182.689	HAN_OW_08D	Northland

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
HAN11HYDR01 (S)	11/11/2011	190.569	8.31		7.77	182.799		
HAN11HYDR01 (S)	02/11/2012	190.569	8.01		7.47	183.099	HAN_OW_08D	Northland
HAN11HYDR01 (S)	13/05/2011	190.569	8.05			183.19	GW level corrected to account for borehole dip	SRK
HAN11HYDR01 (D)	05/12/2011	190.569	7.83		7.14	183.429		
HAN11HYDR01 (D)	02/12/2011	190.569	7.82		7.13	183.439		
HAN11HYDR01 (S)	13/06/2012	190.569	7.54		7	183.569	HAN_OW_08S	Northland
HAN11HYDR01 (D)	10/10/2011	190.569	7.65		6.96	183.609		Northland
HAN11HYDR01 (D)	11/11/2011	190.569	7.42		6.73	183.839		
HAN11HYDR01 (D)	22/10/2011	190.569	7.35		6.69	183.879	Name on borehole HAN_OW_09	SRK
HAN11HYDR01 (D)	13/06/2012	190.569	6.99		6.3	184.269	HAN_OW_08D	Northland
HAN11HYDR02	13/05/2011	#N/A	4.26			186.15	GW level corrected to account for borehole dip	SRK
SP-305	10/10/2011	189.29	3.24		2.47	186.82		Northland
SP-305	09/12/2011	189.29	3.14		2.37	186.92		
SP-305	13/05/2011	189.29	3.19			186.93	GW level corrected to account for borehole dip	SRK
SP-305	02/12/2011	189.29	3.11		2.34	186.95		
SP-305	13/06/2012	189.29	3.11		2.34	186.95		Northland
SP-305	02/11/2012	189.29	3.05		2.28	187.01		Northland
SP-305	22/10/2011	189.29	3.12		2	187.29		SRK
SP-305	19/11/2007	189.29			1.96	187.33	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
HAN08025	22/10/2011	#N/A	4.49		4.49	189.32	Name on borehole HAN08026	SRK
HAN08025	13/05/2011	#N/A	4.59			189.57	GW level corrected to account for borehole dip	SRK
SP105	19/11/2007	#N/A			7.09	190.2	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
HAN11GT03	13/05/2011	#N/A	2.29			190.9	GW level corrected to account for borehole dip	SRK
LAUR11_PDH008	13/05/2011	#N/A	2.77			192.46	GW level corrected to account for borehole dip	SRK
HAN11GT03	22/10/2011	#N/A	0.47		0.33	192.56	Recorded as HAN_SRK_08	SRK
LAUR11_PDH008	22/10/2011	#N/A	2.3		1.94	192.96	Name on borehole LAUR11MET05	SRK
LAUR11PDH024	22/10/2011	#N/A	11.23		10.85	194.67	Name on borhole LAUR11PHD025	SRK
HAN08MET31	13/05/2011	#N/A	10.96			194.78	GW level corrected to account for borehole dip	SRK
HAN11HYDR03 D	17/04/2012	214.043	19.715		19.145	194.898	HAN_OW_02D	Northland
LAUR11PDH024	13/05/2011	#N/A	11.67			195.05	GW level corrected to account for borehole dip	SRK

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Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
HAN07084	13/05/2011	#N/A	5.02			195.22	GW level corrected to account for borehole dip	SRK
LVT6	10/10/2011	203	8.16		7.1	195.9		Northland
LVT6	13/05/2011	203	8.12			195.96	GW level corrected to account for borehole dip	SRK
HAN08MET32	13/05/2011	#N/A	8.72			196.29	GW level corrected to account for borehole dip	SRK
LVT6	11/11/2011	203	7.68		6.62	196.38		
LVT6	02/12/2011	203	7.62		6.56	196.44		
HAN07084	22/10/2011	#N/A	4.76		3.62	196.5	Name on borehole HAN07085	SRK
LVT6	13/06/2012	203	7.51		6.45	196.55		Northland
HAN11GT05	22/10/2011	#N/A	27.2		27.02	196.66	Recorded as HAN_SRK_01	SRK
LVT6	02/11/2012	203	7.28		6.22	196.78		Northland
HAN11GT06	22/10/2011	#N/A	5.69		5.59	197.17	Recorded as HAN_SRK_03, name on borehole HAN_SRK_03	SRK
HAN11GT06	13/05/2011	#N/A	5.75			197.65	GW level corrected to account for borehole dip	SRK
LVT6	22/10/2011	203	5.72		4.62	198.38		SRK
LVT4	13/05/2011	#N/A	7.09			198.41	GW level corrected to account for borehole dip	SRK
LVT4	22/10/2011	#N/A	6.85		5.39	198.61		SRK
BH-402	13/06/2012	206	8.21		7.38	198.62		Northland
HAN11HYDR03 D	05/12/2011	214.043	15.46		14.89	199.153		
HAN11HYDR03 D	02/11/2012	214.043	15.1		14.53	199.513	HAN-OW_02D	Northland
HAN11HYDR03 D	13/06/2012	214.043	13.86		13.29	200.753	HAN_OW_02D	Northland
HAN11HYDR03 D	13/05/2011	214.043	13.85			200.78	GW level corrected to account for borehole dip	SRK
HAN11HYDR03 D	11/11/2011	214.043	13.6		13.03	201.013		
HAN11HYDR03 D	22/10/2011	214.043	13.43		12.83	201.213	Recorded as (and name on borehole) HAN_OW_02D	SRK
HAN11HYDR03 D	10/10/2011	214.043	13.19		12.62	201.423		Northland
HAN11GT05	13/05/2011	#N/A	27.2			201.45	GW level corrected to account for borehole dip	SRK
HAN11GT04	13/05/2011	#N/A	10			202.51	GW level corrected to account for borehole dip	SRK
HAN11GT04	22/10/2011	#N/A	9.4		9.19	203.04	Recorded as HAN_SRK_02	SRK
LVT2	13/05/2011	#N/A	0			203.3	GW level corrected to account for borehole dip	SRK
LVT5	13/05/2011	#N/A	6.4			203.85	GW level corrected to account for borehole dip	SRK
LVT5	22/10/2011	#N/A	6.15		4.95	204.05	Name on borehole LVT6	SRK
HAN11HYDR03 S	10/10/2011	214.043	9.83		9.44	204.603		Northland

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
HAN11HYDR04	13/05/2011	#N/A	9.26			204.83	GW level corrected to account for borehole dip	SRK
HAN11HYDR03 S	17/04/2012	214.043	9.32		8.93	205.113	HAN_OW_02S	Northland
HAN11HYDR04	22/10/2011	#N/A	8.88		8.68	205.125	Name on borehole HANHYD04, recorded as HAN_PW_02	SRK
HAN11HYDR03 S	13/05/2011	214.043	8.58			205.87	GW level corrected to account for borehole dip	SRK
HAN11HYDR03 S	05/12/2011	214.043	8.44		8.05	205.993		
HAN11HYDR03 S	11/11/2011	214.043	8.2		7.81	206.233		
HAN11HYDR03 S	13/06/2012	214.043	8.16		7.77	206.273	HAN_OW_02S	Northland
HAN11HYDR03 S	22/10/2011	214.043	8.13		7.71	206.333	Recorded as (and name on borehole) HAN_OW_02S	SRK
HAN11HYDR03 S	02/11/2012	214.043	7.58		7.19	206.853	HAN-OW_02S	Northland
SP304	19/11/2007	#N/A			2.08	207.31	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP304	22/10/2011	#N/A	2.16		0.54	208.85		SRK
SP304	13/05/2011	#N/A	0			211.39	GW level corrected to account for borehole dip	SRK
SP311	19/11/2007	216.26			0.19	216.07	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP311	13/05/2011	216.26	0.97			216.26	GW level corrected to account for borehole dip	SRK
SP311	10/10/2011	216.26	0.03		0	216.26	Dirty, I didn't want to put the equipment there at all	Northland
SP311	11/11/2011	216.26	0.01		-0.02	216.28	Frozen	
BH-101	10/10/2011	228	9.94		8.92	219.08	-	Northland
BH-101	05/12/2011	228	9.72		8.7	219.3	suojaputki on on	
SP303	22/10/2011	#N/A	2.15		0.95	219.34		SRK
BH-101	03/04/2012	228	9.47		8.45	219.55		Northland
SP303	19/11/2007	#N/A			0.54	219.75	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP303	13/05/2011	#N/A	0			221.39	GW level corrected to account for borehole dip	SRK
SP308	19/11/2007	#N/A			1.41	222.36	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-312	13/05/2011	233.89	11.4			223.82	GW level corrected to account for borehole dip	SRK

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
SP316	19/11/2007	#N/A			2.18	224.34	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP312	03/04/2012	#N/A	8.93		7.52	226.37		Northland
SP-312	10/10/2011	233.89	8.68		7.27	226.62		Northland
SP-312	19/11/2007	233.89			6.39	227.5	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
SP-312	05/12/2011	233.89	7.04		5.63	228.26	ei suojaputkea	
KUE08063	13/05/2011	#N/A	8.31			228.67	GW level corrected to account for borehole dip	SRK
BH-103	10/10/2011	231	3.34		2.31	228.69		Northland
BH-103	05/12/2011	231	3.29		2.26	228.74	suojaputki on	
KUE08063	22/10/2011	#N/A	7.11		6.97	229.33		SRK
KUE07013	13/05/2011	#N/A	7.83			229.94	GW level corrected to account for borehole dip	SRK
KUE08071	13/05/2011	#N/A	10.87			230	GW level corrected to account for borehole dip	SRK
KUE08071	22/10/2011	#N/A	9.66		9.44	230.46		SRK
KUE07013	22/10/2011	#N/A	6.48		6.39	231.38		SRK
SP306	19/11/2007	234.13			2.29	231.84	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
KUE08047	13/05/2011	#N/A	10.08			232.86	GW level corrected to account for borehole dip	SRK
KUE08073	13/05/2011	#N/A	9.62			232.91	GW level corrected to account for borehole dip	SRK
SRK_RES_01	13/05/2011	#N/A	6.05			232.95	GW level corrected to account for borehole dip	SRK
SP-306	03/04/2012	#N/A	2.32		0.98	233.15		Northland
SP306	13/05/2011	234.13	1.88			233.46	GW level corrected to account for borehole dip	SRK
SP306	05/12/2011	234.13	1.89		0.55	233.58	ei suojaputkea	
KUE08073	22/10/2011	#N/A	8.15		7.9	233.94		SRK
KUE08047	22/10/2011	#N/A	8.58		8.44	234.03		SRK
SP306	10/10/2011	234.13	1.42		0.08	234.05		Northland
HAN11HYDR05 (D)	03/04/2012	240.652	7.21		6.58	234.072		Northland
KUE11GT02	13/05/2011	#N/A	7.61			234.45	GW level corrected to account for borehole dip	SRK
HAN11HYDR05 (D)	10/10/2011	240.652	6.74		6.11	234.542		Northland
KUE11GT03	13/05/2011	#N/A	10.68			234.81	GW level corrected to account for borehole dip	SRK

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
HAN11HYDR05 (D)	05/12/2011	240.652	6.2		5.57	235.082		
SRK_RES_01	22/10/2011	#N/A	3.89		3.89	235.11	Name on borehole SRK_RES_02	SRK
KUE11GT04	13/05/2011	247.81	12.76			235.38	GW level corrected to account for borehole dip	SRK
CON08023	13/05/2011	#N/A	6.79			235.44	GW level corrected to account for borehole dip	SRK
KUE11GT01	22/10/2011	#N/A	4.45		4.17	235.7	Cannot measure past 11m getting stuck - at accute angle	SRK
KUE11GT02	22/10/2011	#N/A	5.12		4.91	235.7	Recorded as KUE_SRK_02, name on borehole KUEGT02	SRK
HAN11HYDR05 (D)	22/10/2011	240.652	5.06		4.86	235.792	Lost buoyancy here, name on borehole KUE_OW_01D	SRK
KUE11GT05	22/10/2011	#N/A	10.19		10.03	235.83	Recorded as KUE_SRK_05	SRK
KUE11GT03	22/10/2011	#N/A	8.48		8.48	236	Recorded as KUE_SRK_03	SRK
BH-803	03/04/2012	237	1.49		0.51	236.49		Northland
KUE11GT04	03/04/2012	247.81	11.24		11.09	236.72		Northland
HAN11HYDR05 (S)	03/04/2012	240.652	4.51		3.93	236.722		Northland
KUE11GT04	10/10/2011	247.81	10.96		10.81	237	Angle??50?	Northland
BH-803	10/10/2011	237	0.97		-0.01	237.01		Northland
BH-803	05/12/2011	237	0.97		-0.01	237.01	suojaputki on	
KUE11GT04	22/10/2011	247.81	10.8		10.61	237.2	Recorded as KUE_SRK_04	SRK
KUE11GT05	13/05/2011	#N/A	10.63			237.81	GW level corrected to account for borehole dip	SRK
HAN11HYDR05 (S)	10/10/2011	240.652	3.42		2.84	237.812		Northland
HAN11HYDR05 (S)	05/12/2011	240.652	3.33		2.75	237.902		
KUE08027	13/05/2011	#N/A	5.46			238.47	GW level corrected to account for borehole dip	SRK
KUE08027	22/10/2011	#N/A	4.12		3.88	240.05	Name on borehole KUE08028	SRK
HAN11HYDR05 (D)	13/05/2011	240.652	0			240.65	GW level corrected to account for borehole dip	SRK
SP314	13/05/2011	246.49	5.78			241.72	GW level corrected to account for borehole dip	SRK
SP314	03/04/2012	246.49	5.05		3.96	242.53		Northland
SP314	10/10/2011	246.49	4.67		3.58	242.91	also not exact 90 degrees, but closely. Still an ordinary groundwater hole	Northland
SP314	22/10/2011	246.49	4.51		3.44	243.05	Name on borehole SP315	SRK
SP314	05/12/2011	246.49	4.34		3.25	243.24		
SP314	19/11/2007	246.49			3.04	243.45	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry

Manually recorded Groundwater Level Data

Station	Date	Z (masl)	GW depth (m bTOC)	Stick up (mags)	GW_depth (mbgs)	GW level (masl)	Comment	CollectedBy
SP307	13/05/2011	#N/A	7.1			248.59	GW level corrected to account for borehole dip	SRK
SP307	19/11/2007	#N/A			3.68	250.91	Exact date unkown, actually collected sometime between week 47 and week 52 2007.	Poyry
BH-109	10/10/2011	229	1.17		0.26	228.74		Northland
BH-109	11/11/2011	229	1.22		0.31	228.69		
BH-109	09/12/2011	229	1.23		0.32	228.68		
BH-109	17/04/2012	229	1.43		0.52	228.48	plenty of water, not possible to empty	Northland
BH-402	17/04/2012	206	8.48		7.65	198.35		Northland
HAN11HYDR01 (D)	10/04/2012	190.569					HAN08_OW-08D. Hole DRY	Northland
HAN11HYDR01 (D)	17/04/2012	190.569					HAN_OW_08S. Hole DRY	Northland
HAN11HYDR01 (S)	10/04/2012	190.569	8.72		8.18	182.389	HAN08_OW-08S	Northland
KUE 08045	22/10/2011	241	8		7.85	233.15		SRK
KUE 08046	22/10/2011	238	8.6		8.38	229.62		SRK
KUE 08069	22/10/2011	242	7.63		7.53	234.47		SRK
KUE08081	22/10/2011	247	7.78		7.65	239.35		SRK
LVT6	10/04/2012	203	7.78		0.1	202.9	1,5"" tube	Northland
SP-305	10/04/2012	189.29	3.26		2.49	186.8	Very dark, iron? + particles in the water	Northland
SP-310	10/04/2012	178.85	7.92		6.38	172.47	Plenty of water nearby, immediately filled with new water	Northland

Modified manually

Estimated using GIS

APPENDIX

I GROUNDWATER MODELLING

1 NUMERICAL GROUNDWATER MODEL

1.1 Introduction

The Rautuvaara TMF is located in the Niesa Basin, which is located in the headwaters of the Niesajoki River. The principal objectives of the numerical groundwater models constructed for Rautuvaara were to:

- Develop the conceptual understanding of the Niesa Basin;
- Provide a water balance for tailings ponds under current and LOM conditions; and
- Predict seepage from the ponds to the local river network.

The output of the groundwater models provided input parameters for geochemical models and surface water models that have been used to assess potential impacts to the local groundwater and surface water systems.

During the Hannukainen Phase 1 DFS and HIA studies 3D groundwater models were constructed for the Hannukainen site using the GMS[1] modelling environment. The model area included the Niesajoki catchment. There is very limited hydrogeological information available beyond the immediate vicinity of the existing TMF in the Niesa Basin and so little information with which to define boundary conditions of a model. It was therefore decided that the regional Hannukainen model should be used for the first phase of numerical modelling work at Rautuvaara. Once more information becomes available, e.g. from the GPR survey, then it may be more appropriate to construct a local scale model of the site.

The following text describes the Hannukainen GW model, giving details of amendments that have been made in order to incorporate the conceptual model that has been developed for the Rautuvaara site. Broadly, the numerical groundwater model has been used simulate the following scenarios:

- Steady state 'current conditions' model for winter, summer and average climate conditions; and
- Steady state 'LOM' model for winter, summer and average climate conditions.

Transient modelling was not undertaken at Rautuvaara due to uncertainty of the storage properties at the site. In addition, a model has not been developed specifically for post-closure because it is envisaged that the proposed closure plan would not result in significant changes to the hydrogeological regime in the basin and therefore the LOM models can be considered representative of long term impacts[2].

It is important to bear in mind that a numerical model is a mathematical representation of a real life situation and therefore can only be, at best, an approximation of the groundwater flow processes. The results from the numerical model should be regarded with caution and with due consideration for the assumptions that underpin them.

[1] *Groundwater Modelling System (GMS), developed by AquaVeo*
[2] *Upon closure the High-S cell will be covered with a top structure and it is considered likely that the rate of seepage from the facility (3 mm/yr) will remain the same. The LIMS tailings will be covered with material that is likely to be more permeable than the tailings themselves and so seepage from the tailings will also be similar post-closure to LOM. Therefore the LOM model can be considered valid for both the LOM and post-closure scenarios.*

1.2 Model Set-up

1.2.1 Model Code

The Hannukainen model was constructed in MODFLOW-2005, a block-centred, finite-difference, groundwater flow and transport model. MODFLOW was chosen over other groundwater modelling codes at Hannukainen for its simplicity and extensive validation on numerous mining projects. In addition MODFLOW is capable of representing hydrogeological units independently of the grid, which is beneficial in an environment such as Hannukainen where geological contacts and structural features are shallowly dipping and recent sediments have accumulated over an angular unconformity.

MODFLOW is an equivalent porous media model, meaning that it assumes the groundwater flows through the rock matrix. This was not the case at Hannukainen where flow in the bedrock is structurally controlled, and the same limitation applies at Rautuvaara. Pumping tests at Hannukainen provided an estimate of the bulk rock hydraulic properties as opposed to the hydraulic conductivity of a single fracture. Slug tests, such as those performed at Rautuvaara, test a smaller portion of the aquifer but still provide information on the bulk rock rather than individual structures. Therefore, using these hydraulic properties and defining a sufficiently large model volume, so as to overcome the effect of 'scale dependence', MODFLOW can be used to represent aquifer-scale groundwater flow. MODFLOW model assumptions are discussed in Harbaugh and McDonald (1996).

1.2.2 Model Area

A suitable model area was selected based on the anticipated radius of influence of the mine operation and the regional hydrological regime. The model area extends well beyond the anticipated radius of influence of the proposed mine infrastructure and incorporates all potential groundwater and surface water receptors. The model area is shown in Figure 1-1.

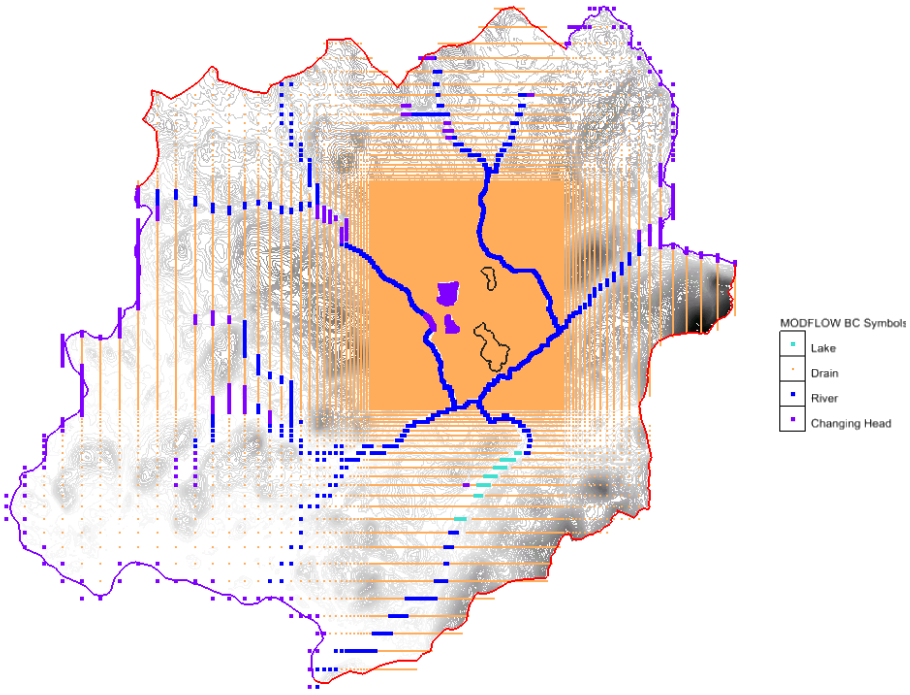


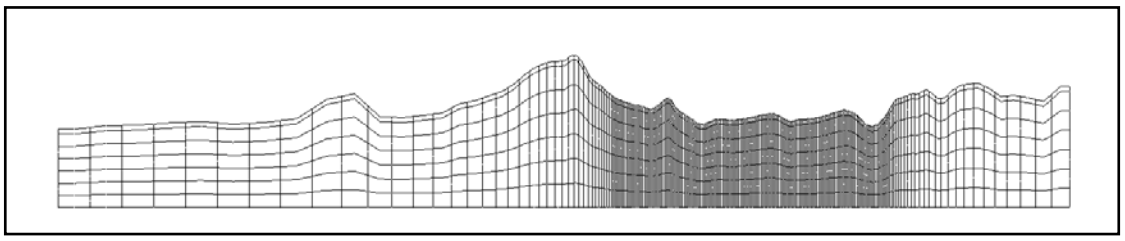
Figure 1-1: Model Area and Boundary Conditions

1.2.3 Grid

A seven layer, finite difference grid was constructed with 269 rows and 241 columns for the current conditions. An additional row was added for the Rautuvaara LOM scenarios to enable improved representation of the High-S cell. The model extends approximately 37 km north to south, 34 km east to west and covers an area of about 790 km^2. Column width and row height in the region of the proposed pits and associated facilities at Hannukainen is 50 m. Between this region and the model boundary, column width and row height increase with a multiplier of 1.1 to about 950 m. The grid construction is such that column width in the Rautuvaara region is 50 m however row height increases from approximately 300 m north of the North Pond to approximately 800 m south of the South Pond. Since the objective of the model was to simulate catchment scale groundwater flow it was not considered necessary to refine the grid significantly in the region of the TMF.

The mesh extends from -60 to 715 m above sea level (asl). This depth was selected in order to ensure that groundwater flow beneath the proposed Hannukainen pit, which extends to around -10 masl, could be accurately modelled. Layer geometry was based on the conceptual model in which more permeable overburden typically overlies less permeable fresh rock units. The top elevation of Layer 1, which generally represents the overburden, was derived from topography and the layer was assumed to be 15 m thick throughout the model. Layers 2 – 7 represent the fresh rock. The base of Layer 7 was assigned a constant value of -60 masl and layers 2 – 7 were then distributed evenly between the base of Layer 1 and base of Layer 7. This resulted in a layer thickness of about 50 m in the region of the proposed TMF and mine site. The top of Layer 1 was modified for the LOM scenarios in order to incorporate the proposed LIMS tailings pile at Rautuvaara.

A cross section through the grid is given in Figure 1-2.



Row 188, Vertical magnification = 10

Figure 1-2: Model Grid Cross-Section

1.2.4 Boundary Conditions

No-flow boundary conditions (red line in Figure 1-1) have been used to represent groundwater catchment divides in the northern and south-eastern extents of the model area. It was assumed that the position of the groundwater divides could be derived from topography, i.e. the groundwater divide is equates to the topographic divide. Topography is shown in Figure 1-1; increasing elevation is represented with darker contours.

The north-eastern and western boundaries are defined as constant head boundaries (purple line in Figure 1-1), corresponding to the Kesankijoki and Muonionjoki rivers respectively. It was assumed that these rivers are sufficiently well connected to the groundwater system to be constant head sources, but also sufficiently large and distant from the proposed pits that they will not be affected by mining operations.

Constant head boundaries should be used only at locations where it can be assumed that they will not add or remove unrealistic volumes of water to or from the model. The flow from all constant head boundary cells was monitored during steady state and transient modelling.

Local rivers and other surface water bodies are potential receptors to mining operations and have therefore been included in the groundwater model. Rivers and lakes were generally represented as river boundaries and constant head boundaries respectively. Lake cells were used to represent the existing North Pond and South Pond in the Niesa Basin for the Rautuvaara model update. The user must define a conductance for the lake bed sediments, lake bathymetry, known inflows (surface water runoff, precipitation) and known outflows (surface water discharge, evaporation) in order that the model can simulate the interaction between the groundwater system and the lake and subsequently calculate a water balance and water level for the lake. The assumptions made when estimating these parameters are described below in Section 1.2.5.

Peat-bogs and swamps cover much of the low-lying areas. This standing water has been accommodated in the model using drain cells in the uppermost layer with an elevation equal to topography in that cell.

The Hannukainen and Kuervitikko pits were represented in the Hannukainen DFS and HIA models as drain cells. Infrastructure at the Hannukainen site is beyond the scope of the Rautuvaara HIA and so the pit drain cells have been removed from the model and replaced with drain cells representing peat-bog / swamp as described above.

1.2.5 Recharge

There is significant seasonal climatic variation at Rautuvaara. In order to investigate the influence of seasonal changes on the hydrological regime the current conditions and LOM configurations were run under three climatic conditions; summer, winter and average.

Climate data and recharge estimates were extracted from the water balance modelling work that was undertaken during the Hannukainen DFS (SRK, 2011a). In order to obtain estimates of snowmelt, snow storage, actual evapotranspiration, runoff and recharge, a simple monthly water balance was developed for the area around Äkäsjoki catchment, based on regional monthly climatic data. The water balance, summarised in Table 1-1, was based on a model developed for the NOPEX[3] region by Xu et. al, (1996), and calibrated using available surface water runoff data (SRK, 2011a).

[3] *Northern Hemisphere Climate Processes Land Surface Experiment Project*

Table 1-1: Summary of Monthly Water Balance Developed for the Äkäsjoki catchment (from SRK, 2011a)

	Precipitation (Ppt)	Temperature	Potential Evapotranspiration (PotET)	Snowfall	Rainfall	SnowPack	SnowMelt	Active rainfall	Available water	Actual ET	Soil Store	Modelled quickflow (surface water run-off)	Modelled baseflow (groundwater recharge)	Ppt : PotET	Rainfall : PotET
	mm	deg C	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	-	-
Jan	34.5	-13.3	3.0	34.5	0.0	114.5	0.0	0.0	50.0	3.0	37.7	0.0	9.3	0.1	-
Feb	26.7	-11.9	3.0	26.7	0.0	141.3	0.0	0.0	37.7	3.0	27.7	0.0	7.0	0.1	-
Mar	28.5	-7.0	10.0	28.5	0.0	169.8	0.0	0.0	27.7	8.3	14.3	0.0	5.1	0.4	-
Apr	31.0	-0.7	28.0	31.0	0.0	178.0	22.8	0.0	14.3	7.8	17.0	9.8	2.6	0.9	-
May	35.4	6.1	64.0	0.0	35.4	0.2	177.9	8.2	52.4	25.9	106.3	94.9	3.1	1.8	1.81
Jun	52.0	12.2	96.0	0.0	52.0	0.0	0.2	11.8	158.3	62.3	37.6	38.3	20.3	1.8	1.85
Jul	74.0	14.7	98.0	0.0	74.0	0.0	0.0	22.1	111.6	50.4	29.3	24.9	7.0	1.3	1.32
Aug	70.8	12.0	64.0	0.0	70.8	0.0	0.0	28.0	100.1	40.3	29.8	24.6	5.4	0.9	0.90
Sep	50.9	6.3	30.0	0.0	50.9	0.0	0.0	26.4	80.8	24.6	27.1	23.6	5.5	0.6	0.59
Oct	47.1	-0.4	11.0	47.1	0.0	47.1	0.0	0.0	27.1	8.7	13.4	0.0	5.0	0.2	-
Nov	45.5	-7.7	4.0	45.5	0.0	92.6	0.0	0.0	13.4	3.5	7.5	0.0	2.4	0.1	-
Dec	33.5	-11.9	4.0	33.5	0.0	126.1	0.0	0.0	7.5	2.8	3.4	0.0	1.3	0.1	-

The following assumptions were made for each scenario:

- Average conditions;
  - No snow cover and all surface water free of ice. Surface water run-off to tailings lakes small due to diversion ditches around the ponds, values adjusted during model calibration;
  - Groundwater recharge equal to the geometric mean of monthly 'modelled baseflow' (see Table 1-1);
  - Lake cell precipitation equal to average annual precipitation. Evaporation calculated based on a ratio of rainfall:evaporation of 1:1.29 which is the average ratio of the summer months (i.e. months in which precipitation falls as rain rather than snow); and
  - Lake bed sediment conductance unknown, adjusted during model calibration.
- Summer conditions:
  - Equivalent to conditions observed during the field visit in June 2012 therefore groundwater levels recorded during the visit can be used for model calibration;
  - No snow cover and all surface water free of ice. Surface water run-off to tailings lakes small due to diversion ditches around the ponds, values adjusted during model calibration;
  - Groundwater recharge initially assumed to be equal to the average annual recharge value predicted by NOPEX model and used in the Hannukainen DFS model (74 mm/yr). Subsequently adjusted to 72.8 mm/yr during model calibration using PEST;
  - Lake cell precipitation and evaporation equivalent to long term average data for the month of May measured at the nearby Kaunisvaara weather station (18381). May data was used rather than June as the spring thaw was relatively late in 2012 and so historical May values were considered to be more representative for the climatic conditions in June 2012 than the average June values; and
  - Increased lake bed sediment conductance.
- Winter conditions:
  - Ground covered with snow and surface waters frozen. Zero surface water runoff to the tailings lakes;
  - Groundwater recharge equal to the average of values predicted by the water balance model for winter months (October – April);
  - Zero precipitation during winter months as precipitation falls as snow. Evaporation equal to average potential evapotranspiration during the winter months; and
  - Reduced lake bed sediment conductance.

The recharge, lake bed leakance (calculated as conductance divided by thickness) and climate values used in the model are summarised in below.

Table 1-2: Summary of Climate Parameters Used in the Rautuvaara Models

Parameter	Unit	Average	Summer	Winter
Groundwater recharge	m/d	1.62E-04	1.99E-04	1.55E-04
Lake cell properties:				
Precipitation	m/d	1.47E-03	1.18E-03	0.00E+00
Evaporation	m/d	1.89E-03	2.13E-03	3.00E-04
Surface water runoff	m^3/d	25(NP*); 40 (SP*)	235 (NP); 165 (LP)	0.00
Lake bed leakance	1/d	1.00E-04	1.50E-04	7.00E-05

* NP = North Pond, SP = South Pond

The High-S tailings will be located in a discrete cell, lined with a bentonite and HTPE liner. It has been estimated in the TMF study that leakage beneath a high quality HDPE liner installation will be in the order of 1,437 m^3/yr or 3 mm/yr, assuming a 10 m head (Nils Eriksson, 2011). It has been assumed that this flux applies throughout the operational period and will continue post-closure.

1.2.6 Material Properties

At Hannukainen the location of the mineralisation and hydrogeological units is strongly structurally controlled. The reverse thrust at Hannukainen dips 20-30° to the west and marks the boundary between the footwall and hanging wall deposits (SRK, 2011d). At Kuervitikko the Hannukainen Thrust Zone (HTZ) is offset by approximately 750 m and appears to be more heavily fractured than other portions of the fault. The offset length of the HTZ is bound to the north and south by branch faults, forming a parallelogram (Figure 1-3).

These geometries would be difficult to incorporate in a traditional layered grid and for that reason the Hydrogeological-Unit Flow (HUF) Package was used as the internal flow package in MODFLOW-2005.

The HUF Package allows the geometry of the hydrogeological units to be defined independently of the grid layers and consequently shallowly dipping contacts are relatively simple to represent. The hydraulic properties of each hydrogeological unit, or HUF zone, are defined by the user. The effective hydraulic property of each model cell is calculated by the HUF Package in the Ground-Water Flow Process according to the relative proportions of HUF zones within the saturated portion of the cell.

Four HUF zones used to represent the hydrogeological system at Hannukainen; Overburden, Hanging wall, Footwall, HTZ. Three additional HUF zones were incorporated in to the model to represent the conceptual model at Rautuvaara; Niesa bedrock, Niesa overburden and Tailings:

- The northwest boundary between the Niesa and Hannukainen bedrock / overburden HUF zones was defined by the Rautuvaara Shear Zone, a fault located midway up the hills to the northwest of the Niesa Valley striking approximately northeast and dipping steeply to the southeast. The contact was assumed to be vertical due to the steep nature of the fault, described not only in the literature but also evident from the interaction between the fault and the topography[4];

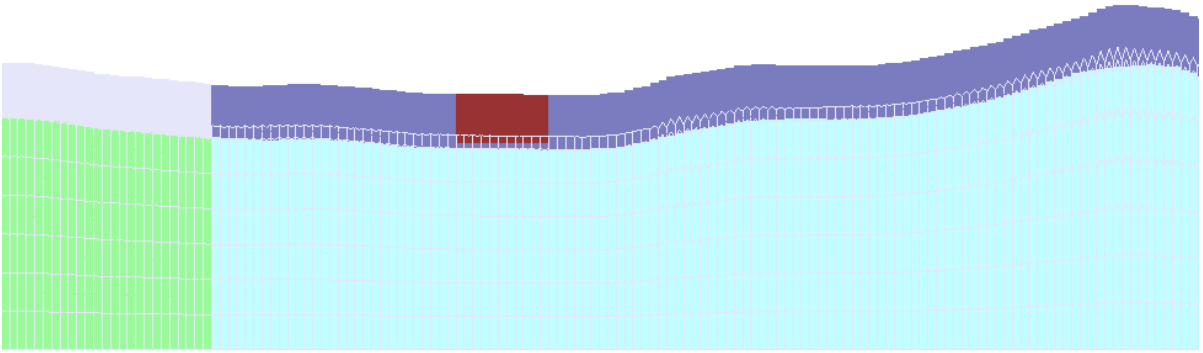
[4] There is very little deviation in the strike of the surface expression of the fault despite significant changes in the topography which indicates a near vertical structure.

- Maps of bedrock geology suggest that bedrock geology in the Niesa Valley is equable to the hanging wall at the Hannukainen site;
- Slug tests in the bedrock estimated a wide range of hydraulic conductivity spanning nearly four orders of magnitude. It appears that in some locations there is a zone of more permeable material at the top of the bedrock unit due to, it is assumed, increased weathering, while at others bedrock is significantly less permeable and presumably less weathered;
- The Hannukainen overburden was assumed to be 15 m thick throughout the site. Drill logs at Rautuvaara indicate that the overburden thickness is more variable at Rautuvaara (1 – 46 m observed during drilling at the site) and is generally thicker (average thickness 18 m). Overburden thickness appears to increase on the hillsides at Rautuvaara;
- The zone of more permeable weathered bedrock material has been combined with the overburden material in the numerical model to simplify the system in to a two layer system; more permeable overburden/weathered bedrock and fresh bedrock. The more permeable overburden and weathered bedrock is collectively described as the Niesa overburden. The thickness of the Niesa overburden was defined as 30 m throughout the model however, beneath the existing TMF the thickness of the Niesa overburden was reduced to approximately 15 m in order to accommodate the tailings; and
- The current tailings were assumed to be approximately 15 m thick. The LOM LIMS tailings thickness was calculated using the proposed topography of the TMF facility. It was assumed that the LOM tailings will have the same hydraulic properties as the current tailings. The High-S LOM tailings will be deposited on top of a low permeability liner and so were incorporated in to the groundwater model as a zone of low recharge. Therefore hydraulic properties and thickness were not required for these tailings.

Figure 1-3 shows the orientations of the seven HUF zones.



(a)



Columns 67 – 258, Row 258, Vertical magnification = 5

(b)

Figure 1-3: HUF zones (a) areal extent of the bedrock geology and (b) relationship of Niesa Basin HUF zones to one another and the MODFLOW grid

Hydraulic properties determined by the hydrogeological test work were used as the initial values for each unit (see the main report). These properties were modified during calibration within pre-defined ranges (generally the 25th – 75th percentile range of the property). Table 1-3 shows the calibrated hydraulic properties associated with each HUF zone present in the model.

Table 1-3: Summary of modelled materials and their assigned properties

HUF zone	K[5] (m/d)	K_x:K_y	Data source and comments
Tailings	5.0	1	K properties estimated from slug tests and falling head tests. No K_x:K_y data available; isotropy assumed
Niesa overburden	1.2	1	
Niesa bedrock	0.07	1	Similar geology to the hanging wall therefore hanging wall properties assumed initially and modified within the range observed fro slug tests and falling head tests at Rautuvaara
Hannukainen overburden	0.1	1	K and storage properties estimated by PSD analysis. No K_x:K_y data available; isotropy assumed
Hanging wall	0.03	1	Pumping test and spinner test analysis
Footwall	0.03	0.01	
HTZ	0.1	0.05	Pumping test analysis

1.3 Calibration and Current Conditions Models

Three, steady state, "current conditions" models were constructed to calibrate the model inputs and provide starting heads for subsequent predictive models; summer, winter and average. The HUF zone hydraulic properties, model recharge term and lake cell parameters were calibrated to groundwater levels measured by SRK in June 2012 and lake stage recorded in the North Pond and South Pond.

The groundwater monitoring locations used as calibration targets in the steady state models are all located within / close to the proposed TMF as no data was available elsewhere in the catchment. Groundwater levels were taken over a seven day period in early to mid June. Wells are located in both the bedrock and the overburden aquifers. The calibration target for the shallow and deep piezometers was 1.6 m and 3.7 m respectively based on the maximum variation observed at any one monitoring location during the monitoring period (June to September 2012).

Model calibration consisted of two phases:

1. Initially the HUF zone hydraulic properties were calibrated using the current conditions summer model, using the groundwater monitoring data described above as the calibration target. The groundwater recharge term in the current conditions summer model uses a monthly average based on estimates for May from historical precipitation data (3.1 mm/month, see Section 1.2.5).
2. Following this initial calibration, the winter, summer and average models were calibrated in parallel in order to determine the lake cell parameters (bed conductance and surface water run-off). The precipitation and evaporation terms were determined from historical data, as described above in Section 1.2.5.

[5] *K = Hydraulic conductivity, Kx:Ky = vertical anisotropy*

Figure 1-4 shows the groundwater levels recorded in the overburden and bedrock piezometers ('observed') plotted against the heads calculated by the numerical model ('computed') in the calibrated current conditions summer model. The green and blue dotted lines demonstrate the calibration targets for the bedrock and overburden piezometers respectively.

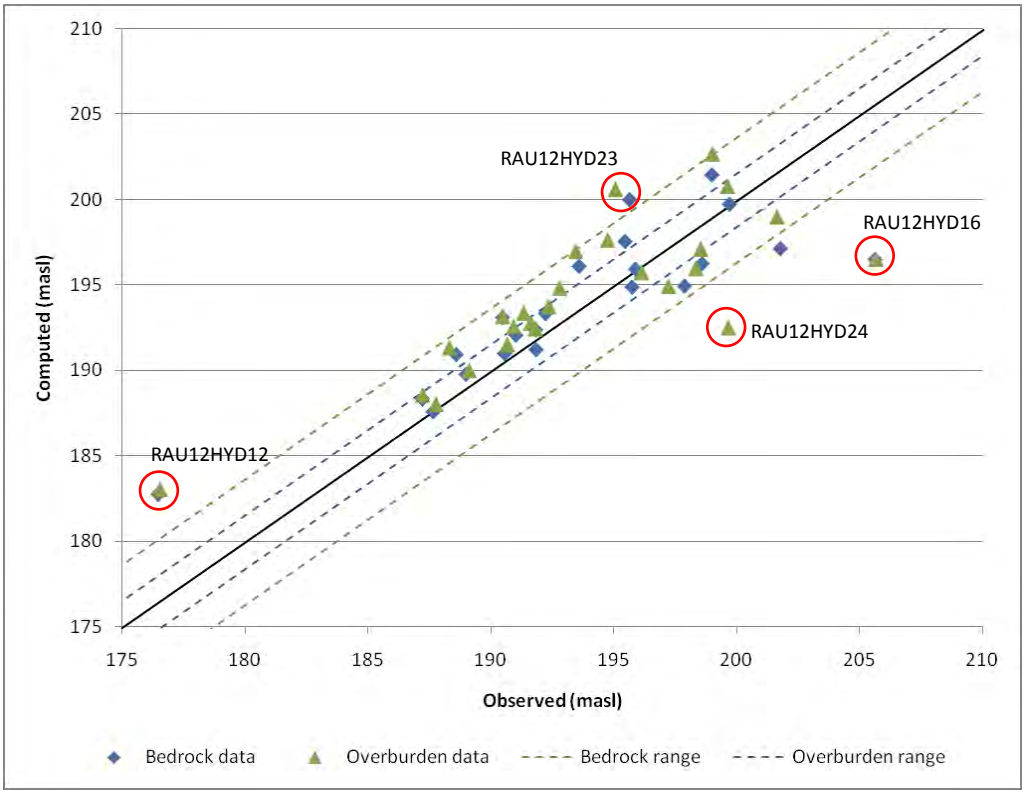


Figure 1-4: Observed vs. computed total head for the "current conditions summer" model, with dashed lines indicating the calibration target for overburden and bedrock wells

In the calibrated current conditions summer model:

- It can be seen that computed groundwater levels are generally within the 3.7 m range observed in the bedrock aquifer, however since the observed range in the overburden aquifer is more constrained (1.6 m) fewer wells are within this calibration target (approximately 64 % and 36 % respectively). Approximately 70% of the computed values were greater than the observed values, and 30% lower, as demonstrated in Figure 1-4. The most significant outliers are located at:
  - RAU12HYD12 (+6.5 m) – Located close to the Niesa River. The model cell contains a river boundary condition in addition to the well which may affect the predicted groundwater level;
  - RAU12HYD16 (-9.2 m) – Particularly low hydraulic conductivity noted in the deep aquifer at this location which may cause a local elevation in GW levels that cannot be replicated by a single hydrogeological unit;
  - RAU12HYD23 (+5.5 m) – The well is located less than 5 m from a wetland area, yet the recorded water level is approximately 20 mbgs indicating that the hydrogeological regime is more complex at this location than replicated in the numerical modelling environment; and

  - o RAU12HYD24 (-7.2 m) – Artesian conditions at this well indicating confined conditions in the deep aquifer which is not simulated in the numerical model.

- The residual error (observed minus computed), appears to be correlated to location; calculated water levels are generally greater than observed values to the east of the TMF and lower than observed to the west. This suggests that the current conceptual model of the site, which assumes a single bedrock unit throughout the Niesajoki catchment, may not be sufficient to represent the system and more investigation of the bedrock aquifer may be required to fully characterise the deep rock environment;
- The steady state model has a root mean square (RMS) error of 3.4 m; and
- Observed lake stage in the North and South Ponds is 190.5 masl and 190.0 masl respectively and modelled levels were 190.48 masl and 189.93 masl respectively.

Despite the residual errors in the calculated water levels the model is considered a reasonable representation of the current groundwater regime. The calibrated hydraulic properties and lake cell parameters were used in the LOM models.

Figure 1-5 shows the flow vectors in the vicinity of the TMF under current, steady state summer conditions. They demonstrate the movement of groundwater down-gradient from elevated areas of topography towards the local rivers from either side of the river channels. The model predicts a groundwater divide located through the middle of the existing tailings pile which is consistent with field observations and previous studies.

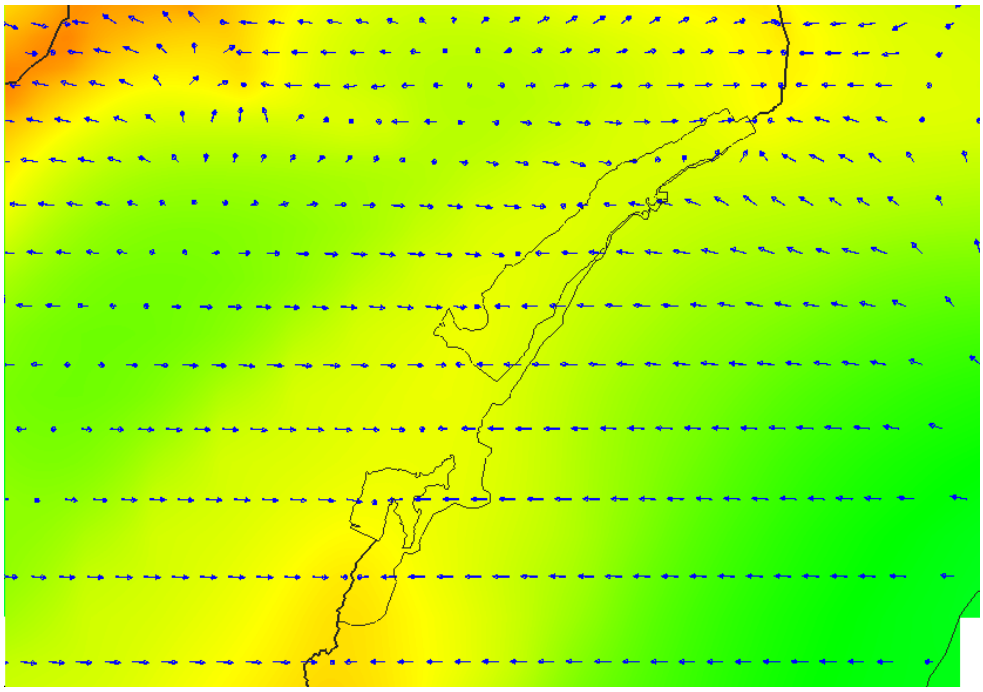


Figure 1-5: Steady state "current conditions summer" flow vectors at Rautuvaara showing rivers and existing tailings ponds

The current conditions summer model indicates that rivers are generally gaining rivers, i.e. receive water from the groundwater system via baseflow. This is consistent with the conceptual model and the preliminary results of the University of Helsinki study. The predicted rate of baseflow in the Niesajoki is about 0.7 m^3/d/m of river, and in the Kylmäoja Ditch is approximately 0.5 m^3/d/m of river. This rate of baseflow is consistent with the bedrock conditions and observed flow rates in the rivers.

1.4 Predictive Models

Three predictive scenarios were developed to simulate LOM tailings; summer, winter, average. The models are based on their current conditions equivalents with three modifications:

- The top of layer one (equal to surface topography) was modified to include the expanded LIMS pile. The TMF design was provided by Pöyry;
- The High-S tailings were represented in the model as a region of low recharge, equal to 3 mm/yr. The High-S tailings will be located in a discrete cell, lined with a bentonite and HTPE liner. It has been estimated in the TMF study that leakage beneath a high quality HDPE liner installation will be in the order of 3 mm/yr, assuming a 10 m head (Nils Eriksson, 2011), and this value has been assumed in the numerical modelling; and
- Run-off in to the tailings ponds has been adjusted to achieve the correct stage in the North Pond and South Pond, 190.5 masl and 190.0 masl respectively.

Since completing the modelling the design of the TMF has been modified to a small degree:

- The High-S tailings cell has been moved approximately 50 m northeast; and
- The North Pond elevation will be maintained at 191.0 masl.

It is the opinion of SRK that these changes will not have a significant effect on the impacts predicted by the numerical model.

1.5 Limitations

The model presented here is a numerical simplification of a large, complex system and is therefore subject to inherent limitations. The most significant of these is given below and should be borne in mind when considering the results of the model.

- Section 1.2.5 presents the variation in effective precipitation (precipitation & snowmelt – evaporation – runoff), which ranges from 1 – 20 mm/month. An attempt has been made to simulate the impact of this variation by developing three climatic scenarios for the current conditions and LOM models, however the models do not simulate the impact of climatic events such as snow melt during the spring thaw;
- As with any hydrogeological investigation, there remains some uncertainty around the hydraulic properties of the hydrogeological units modelled. There is uncertainty of the bulk hydraulic properties of the Rautuvaara units because they have been estimated using slug tests and falling head tests which only test the aquifer immediately surrounding the borehole. The potential impact of uncertainties in the hydraulic properties on the model predictions was investigated as part of a sensitivity analysis, discussed in Section 1.6;
- Compressive effects of the tailings facility on the hydraulic properties of the underlying formations have not been modelled, although this is considered to be negligible in terms of the larger scale groundwater regime;
- Generally a uniform overburden thickness of 30 m was assumed within the Niesa Valley, with smaller thickness defined beneath the existing tailings and associated ponds. This is contrary to the conceptual model which describes a highly variable overburden thickness. Given the uncertainties relating to the distribution of overburden

thickness and hydraulic properties it was considered likely that this simplification was appropriate for the first phase of numerical modelling at Rautuvaara; and

- The topography was generated from a DEM with a 25 m resolution. Since the smallest model cell size is 50 m^2 the DEM resolution was considered adequate to generate a sufficiently accurate model topography.

1.6 Sensitivity Analysis

Sensitivity was assessed through the calculation of a sensitivity rating (SR), using the equation given in EPA guidelines (USEPA, 2001):

$$SR = \frac{\frac{Y_2 - Y_1}{Y_2}}{\frac{X_2 - X_1}{X_2}}$$

Equation 1: Sensitivity rating (USEPA, 2001)

where Y_1 = output generated using original input value, Y_2=output generated using new input value, X_1=original input value, and X_2=new input value.

The significance of uncertainty in the hydraulic properties assigned to the bedrock and overburden HUF zones and the lake cell parameters (evaporation, precipitation, bed leakance and surface water run-off) was investigated through a sensitivity analysis of lake stage to these parameters. The results of the sensitivity analysis of lake stage to regional scale (>10%) changes (up and down) in hydraulic properties are summarised in Table 1-4.

Table 1-4: Sensitivity Rating (%) of lake stage to model input parameters at Rautuvaara

Parameter	Sensitivity Rating (%)
Bedrock K	1
Overburden K	1
Lake cell properties	
Precipitation	3
Evaporation	2
Bed leakance	2
Surface water runoff	2

It can be seen in Table 1-4 that lake stage is relatively insensitive to all changes in hydraulic conductivity and lake cell properties. Given the uncertainty of these parameters this means that there are numerous combinations of these parameters that will achieve an equally good calibration to the observation data, i.e. the solution in non-unique.

1.7 Model Output Parameters

The results of the current conditions and LOM models were used to estimate steady state input parameters for the geochemical modelling, specifically:

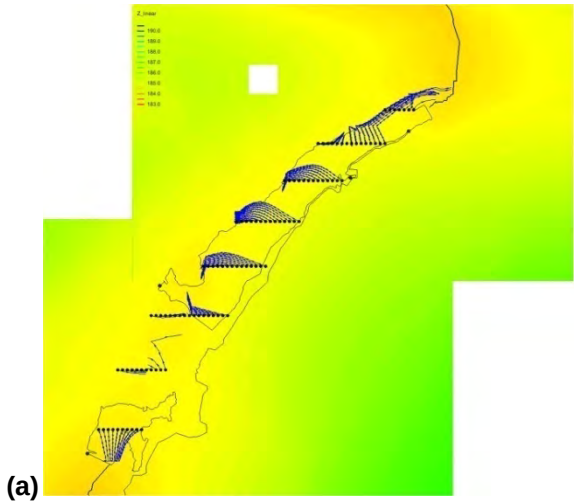
- Piezometric surface to predict the likely migration of potential contaminants;
- Lake water balance for the existing and proposed tailings ponds to generate source terms for each pond; and

- Seepage through the dams at either end of the tailings ponds to calculate loading to the groundwater and surface water systems down gradient of the TMF infrastructure.

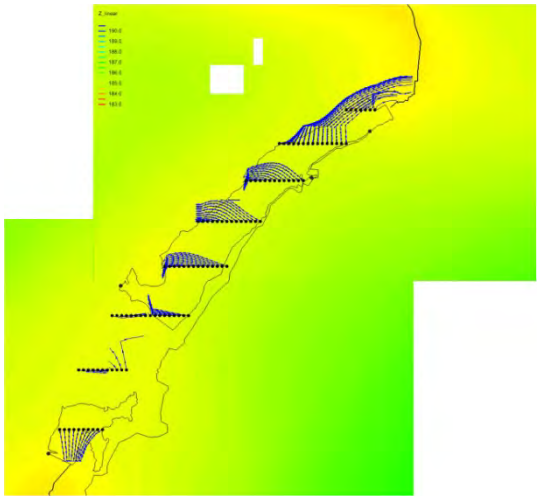
The results of the numerical modelling are given below and the predicted impacts are described in Section 9 of the main report.

1.7.1 Steady State Piezometric Surface

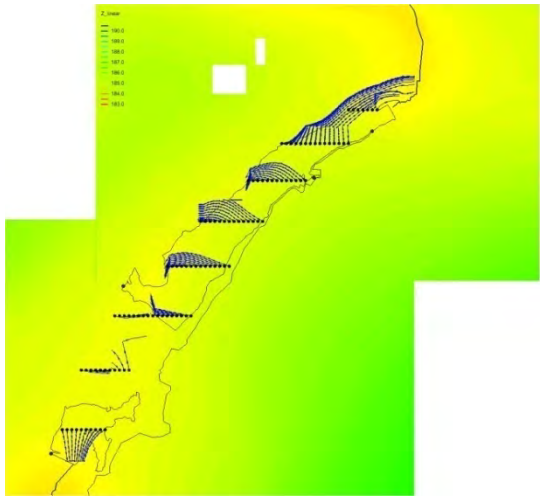
The predicted piezometric surfaces in different climate conditions are shown below in Figure 1-6 and Figure 1-7 for current conditions and LOM respectively. Particle tracking was undertaken at the facility to predict the likely pathway of potential tailings seepage. These tracks are shown on in Figure 1-6 and Figure 1-7 below.



(a)



(b)



(c)

Figure 1-6: Predicted Piezometric Surface and particle tracks for Current Conditions in (a) summer, (b) winter and (c) average climate conditions

It can be seen in Figure 1-6 that under current conditions:

- Generally, groundwater within the TMF flows south towards the Niesajoki River. The general, or regional, groundwater divide is located within the North Pond, and defines the divide between groundwater that ultimately flows north to the Kylmäoja Stream or south to the Niesajoki River providing baseflow to these rivers;
- There are some more complex 'local' groundwater movements within the TMF facility:
    - There is a local groundwater divide located within the existing tailings. Consequently tailings seepage from the northern third (approximately) of the dam flows toward the North Pond while the remaining two thirds reports to the South Pond and subsequently to the Niesajoki River;
    - Particle tracking within the North Pond shows that particles in the southern half of the dam tend to migrate south meeting northward migrating particles from the tailings pile approximately at the position where there currently exists a counter pressure dam. This dam has been constructed to maintain separation between the poor quality tailings seepage and better quality water in the North Pond.
    - Ultimately all of the water within the TMF will flow south to the Niesajoki River due to the regional groundwater divide;
- Groundwater in the North Pond tends to flow along the northwestern side of the valley, which corresponds to the position of the original river bed.

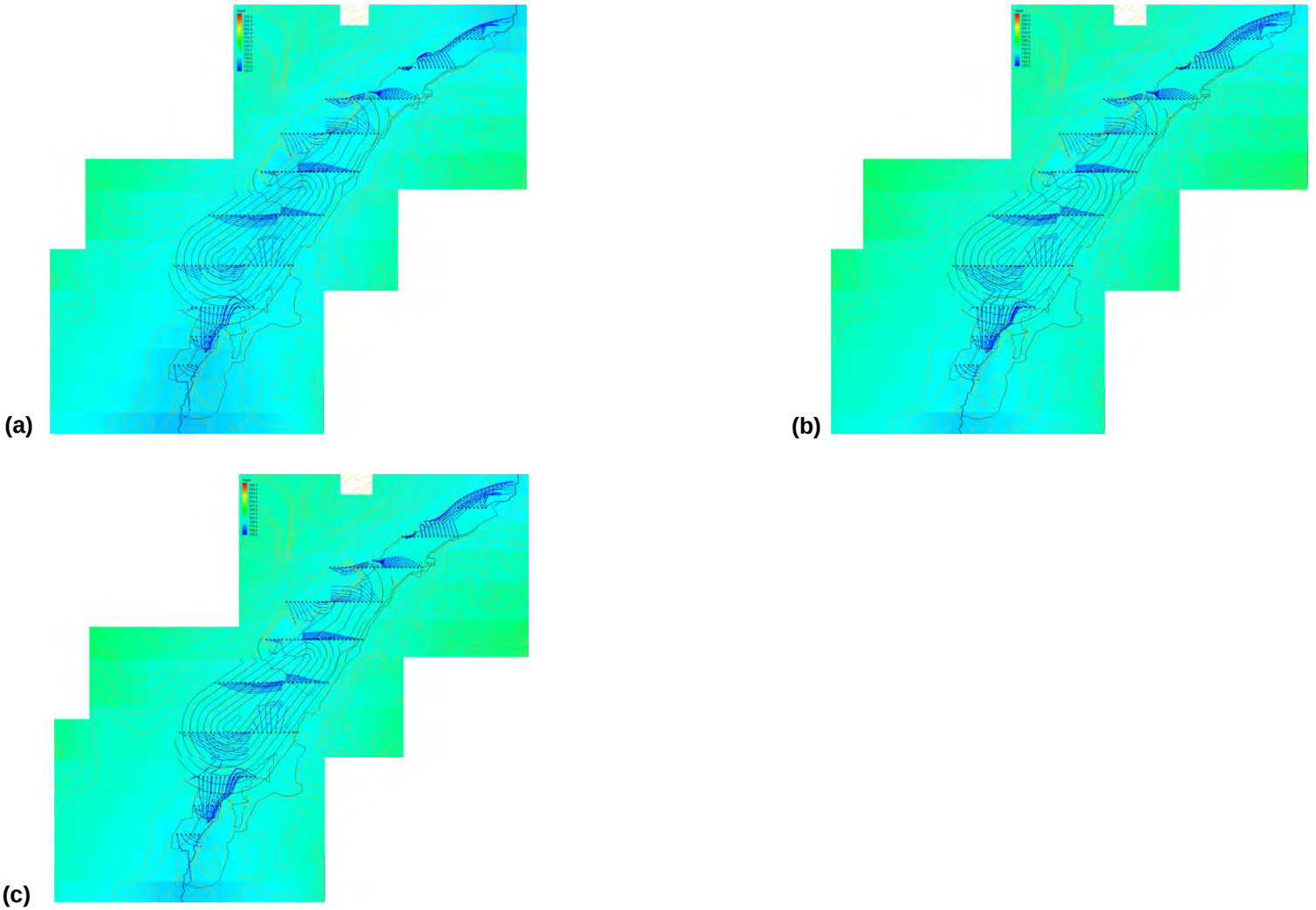


Figure 1-7: Predicted Piezometric Surface with particle tracks and topography for LOM Conditions in (a) summer, (b) winter and (c) average climate conditions

It can be seen in Figure 1-7 that at LOM:

- Generally, groundwater within the proposed TMF will flow south towards the Niesajoki river. The regional groundwater divide is located within the North Pond, and defines the divide between groundwater that ultimately flows north to the Kylmäoja stream or south to the Niesajoki River;
- There are some more complex 'local' groundwater movements within the TMF facility:
    - Seepage from the southern slope of the LIMS tailings flows south to the South Pond and subsequently to the Niesajoki River;
    - Low recharge beneath the High-S cell forms a local depression in the groundwater surface which draws water from the LIMS tailings and the North Pond;
    - Seepage in the LIMS tailings north of the summit of the pile is retained locally within the tailings;
    - Ultimately all of the water within the TMF, including all seepage from the High-S cell, will flow south to the Niesajoki River due to the regional groundwater divide;
- Groundwater in the North Pond tends to flow along the northwestern side of the valley, which corresponds to the position of the original river bed.

1.7.2 Lake Water Balance

A summary of the water balance for the North Pond and South Pond in current conditions is given in Table 1-5. The predicted water balance for the two ponds at LOM is given in Table 1-6.

These values were used in the geochemical modelling to calculate the geochemical composition of the lakes.

Water samples have been collected from both the North Pond and South Pond at Rautuvaara and so it was possible to compare the computed concentrations with measured values in order to evaluate the success of the groundwater and geochemical modelling to replicate the pit lake geochemistry. Generally, there was a good correlation between the calculated and observed values and so the same approach was taken to predict the geochemistry of the lakes under LOM conditions.

The details of the analysis and geochemical calculations are provided in Section 8.2.3 of the main report.

Table 1-5: Calculated Water Balance for Current Conditions at Rautuvaara

Parameter	June current conditions				Winter current conditions				Average annual current conditions			
	North Pond		South Pond		North Pond		South Pond		North Pond		South Pond	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Precipitation (m^3/d)	1,536.6		386.7		0.0		0.0		1,914.2		481.8	
Evaporation (m^3/d)		2,773.7		698.1		390.7		98.3		2,461.1		619.5
Runoff (m^3/d)	235.0		165.0		0.0		0.0		25.0		40.0	
Groundwater (m^3/d)	1,002.2	0.1	147.2	0.8	391.9	1.2	98.5	0.2	523.8	1.9	98.2	0.6
Surface water (m^3/d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	2,774	2,774	699	699	392	392	99	99	2,463	2,463	620	620
Stage (masl)	190.5		189.8		191.7		188.5		191.8		189.8	
Volume (m^3)	19,757,000		4,794,000		21,316,000		4,402,700		21,426,000		4,776,500	
Surface area (m^2)	1,302,200		327,750		1,302,200		327,750		1,302,200		327,750	
Precipitation (%)	55.4		55.3		0.0		0.0		77.7		77.7	
Evaporation (%)		100.0		99.9		99.7		99.8		99.9		99.9
Runoff (%)	8.5		23.6		0.0		0.0		1.0		6.5	
Groundwater (%)	36.1	0.0	21.1	0.1	100.0	0.3	100.0	0.2	21.3	0.1	15.8	0.1
Surface water (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 1-6: Predicted Water Balance for LOM Conditions at Rautuvaara

Parameter	June LOM conditions				Winter LOM conditions				Average annual LOM conditions			
	North Pond		South Pond		North Pond		South Pond		North Pond		South Pond	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Precipitation (m^3/d)	619.0		247.0		0.0		0.0		771.1		307.7	
Evaporation (m^3/d)		1,117.3		445.9		157.4		62.8		991.5		395.7
Runoff (m^3/d)	95.0		180.0		0.0		0.0		0.0		80.0	
Groundwater (m^3/d)	403.4	0.0	35.3	16.4	157.5	0.1	63.0	0.2	250.3	1.9	21.5	13.6
Surface water (m^3/d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	0.0	0.0
Total	1,117	1,117	462	462	157	157	63	63	1,021	1,023	409	409
Stage (masl)	190.5		190.0		191.3		186.3		190.6		190.0	
Volume (m^3)	7,872,800		3,426,800		8,290,600		2,665,600		7,887,500		3,432,300	
Surface area (m^2)	524,580		209,340		524,580		209,340		524,580		209,340	
Precipitation (%)	55.4		53.4		0.0		0.0		75.5		75.2	
Evaporation (%)		100.0		96.4		99.9		99.7		96.9		96.7
Runoff (%)	8.5		38.9		0.0		0.0		0.0		19.5	
Groundwater (%)	36.1	0.0	7.6	3.6	100.0	0.1	100.0	0.3	24.5	0.2	5.3	3.3
Surface water (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0

1.7.3 Dam Seepage

The predicted seepage north and south to the Kylmäoja stream and Niesajoki River respectively is summarised below in Table 1-7.

Table 1-7: Predicted Dam Seepage

	Current conditions			LOM conditions		
	Summer	Winter	Average	Summer	Winter	Average
Seepage north from the North Pond (m^3/d)	85	90	89	99	99	94
Seepage south from the South Pond (m^3/d)	79	84	84	77	60	76
Seepage north from the North Pond (% change)				16	10	6
Seepage south from the South Pond (% change)				-2	-28	-9

It can be seen that:

- Seepage is relatively insensitive to changes in climatic conditions. Seepage through the dam is controlled by the stage of the lake and the hydraulic properties of the dam. The hydraulic properties are constant so seepage is dependent on lake stage which generally varies by less than 1.3 m between climatic scenarios;
- Predicted seepage at LOM increases from the North Pond and decreases from the South Pond;
- Generally the predicted seepage at LOM is within 10% of the seepage under current conditions;
- Modelling predicts a 28% decrease in seepage from the South Pond at LOM in winter conditions. Predicted lake stage in this scenario is approximately 4 m below the expected level due to the assumption of zero surface water runoff during the winter months. While this will be true upon closure, during operational mining excess water from the mining process will maintain the stage in the clarification pond and so it is anticipate that seepage will not drop significantly during operational mining;
- Modelling predicts a 16% increase in seepage from the North Pond at LOM in summer conditions.

APPENDIX J

J GEOCHEMICAL MODELLING

APPENDIX C: PHASE 2 GEOCHEMICAL MODELLING

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Attachment A – Tailings model water balance, mass balance and equilibrated results

Attachment B – Example PhreeqC input Script for Life of Mine tailings under current conditions

1 INTRODUCTION

SRK Consulting (UK) Ltd (SRK) have undertaken a series of quantitative numerical predictions to determine water quality of seepage from various sources at the Hannukainen mine site. The following predictions have been made:

1) Prediction of seepage water quality emanating from the Hannukainen Waste Rock Dumps (WRD)

2) Prediction of water quality within the Hannukianen pit lakes following post closure filling.

3) Prediction of water quality at in the Rautuvaara tailings facility following emplacement of the Hannukainen LIMs and High S tailings.

Full details of the WRD water quality predictions and the pit lake water quality predictions are given in the Hannukainen waste rock geochemistry report (SRK, 2013a) and the methodology and results are summarised in Sections 2 and 2.4 of this report.

Prediction of water quality within the tailings clarification ponds and resulting loadings from the Tailings to the respective river catchments are reported here and detailed methodology calibration and results is given in Section 3.6.

2 HANNUKAINEN WASTE ROCK DUMPS

2.1 Waste rock dump design and material tonnages

It has been shown that 3 broad material type classifications are to be exposed during mine life:

1. Potentially Acid Forming (PAF) waste rock >0.1 wt% sulfur

2. Non Acid Forming (NAF) waste rock material ≤0.1 wt% sulfur

3. Non Acid Forming overburden (OB) material

It is intended that these materials will be segregated during mining and will be dumped in individual PAF, NAF and overburden cells within the three WRD (East Dump, West Dump and West Overburden Dump). Quantitative Numerical Predictions (QNP) have been carried out in order to predict the WRD seepage characteristics for both life of mine (LOM) and post closure scenarios as follows. Estimated breakdown of material tonnages are given in Table 2-1.

The location of Hannukainen waste rock dumps is shown Figure 2-1. In addition the WRD subdivisions based on PAF, NAF and overburden materials is shown in Figure 2-2. The locations of the WRD have been selected to ensure that all seepage from the PAF waste dumps is directed towards the Hannukainen or Kuervittiko pits during operation and to the Hannukainen pits following closure and groundwater rebound and pit lake refilling.

Table 2-1: Waste rock material tonnages at Hannukainen site

Material type		Year 5		Year 10		End Of Mine Life	
		East Dump	West Dump	East Dump	West Dump	East Dump	West Dump
		Tonnes*					
PAF	AMPHIBOLITE-Moderate	2,994,446	1,963,588	13,372,714	2,249,778	29,870,067	2,249,778
	DIORITE-Moderate	805,349.46	1,341,384	3,596,561	1,536,889	8,033,486	1,536,889
	AMPHIBOLITE-HIGH	4,970,492.62	5,865,806	22,197,417	6,720,742	49,581,436	6,720,742
	DIORITE-HIGH	5,983,819.83	14,144,922	26,722,773	16,206,530	59,689,532	16,206,530
	Schist	116,630.23	37	520,852	43	1,163,405	43
	SKARN	521,485.13	298,420	2,328,868	341,915	5,201,895	341,915
	PEG-HS	707,776.41	1,085,843	3,160,815	1,244,104	7,060,180	1,244,104
	Sum	**16,100,000**	**24,700,000**	**71,900,000**	**28,300,000**	**160,600,000**	**28,300,000**
NAF	AMPHIBOLITE-LOW	1,839,877	4,654,489	4,437,351	10,757,042	15,213,774	10,757,042
	DIORITE-LOW	4,265,395	9,438,156	10,287,128	21,812,627	35,270,155	21,812,627
	MONZONITE-LOW	5,271,589	20,324,749	12,713,832	46,972,754	43,590,282	46,972,754
	PEG-LS	523,139	1,582,606	1,261,688	3,657,577	4,325,789	3,657,577
	Sum	**11,900,000**	**36,000,000**	**28,700,000**	**83,200,000**	**98,400,000**	**83,200,000**
OVERBURDEN		**12,700,000**	**22,100,000**	**13,000,000**	**36,800,000**	**34,900,000**	**40,100,000**
Total		**40,700,000**	**82,800,000**	**113,600,000**	**148,300,000**	**293,900,000**	**151,600,000**
Mine stage Total		**123,500,000**		**261,900,000**		**445,500,000**	
* Mass of rock normalised to take into account 10% pegmatite dykes							

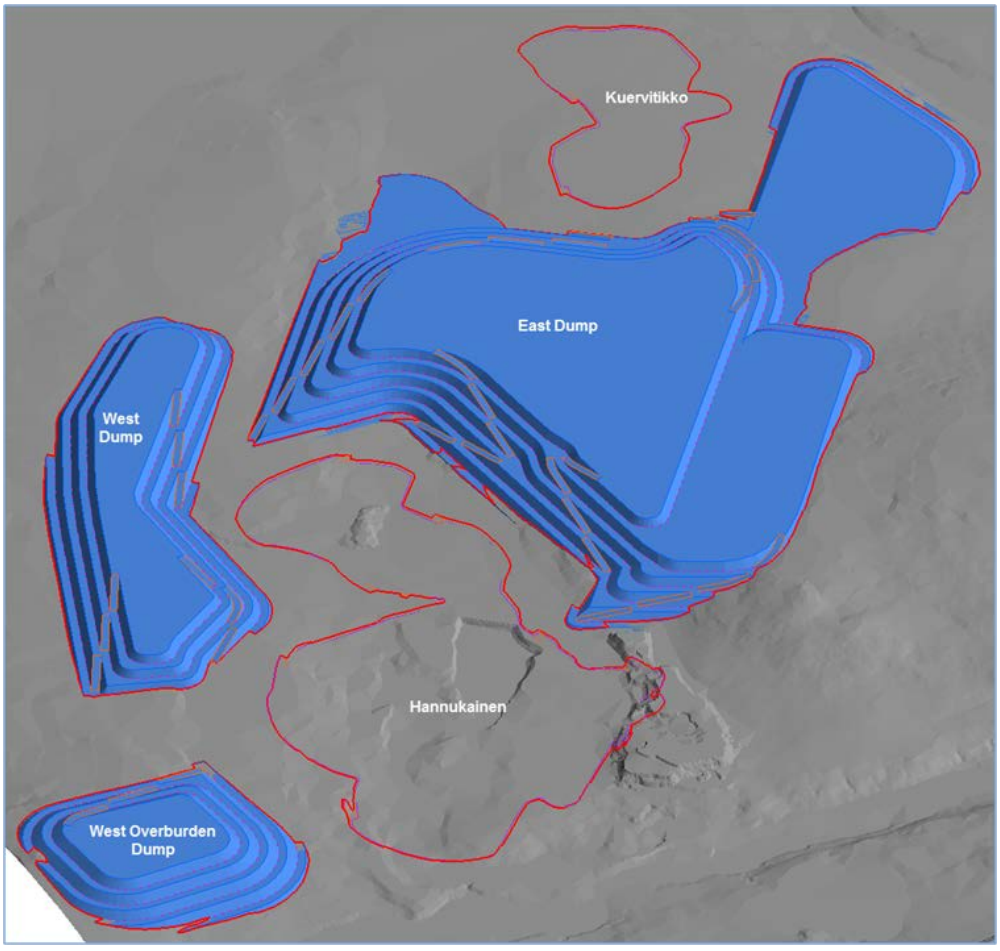


Figure 2-1: Proposed layout of the Hannukianen waste rock dumps

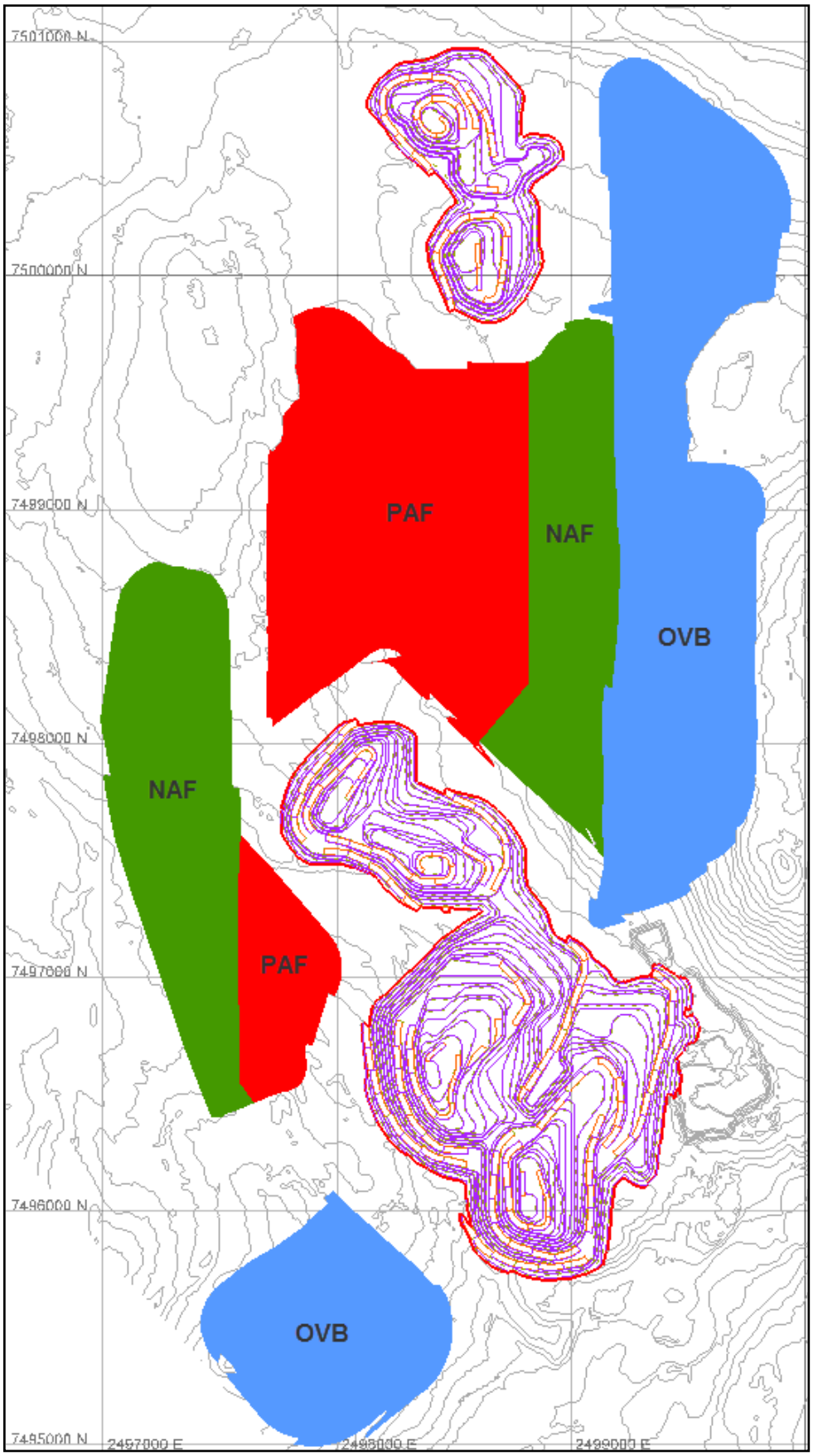


Figure 2-2: Segregation of the Hannukainen WRD by material type

2.1.1 Life of Mine Scenarios

Generation of ARDML leachate from the Hannukainen WRD during LOM is shown conceptually in Figure 2-3.

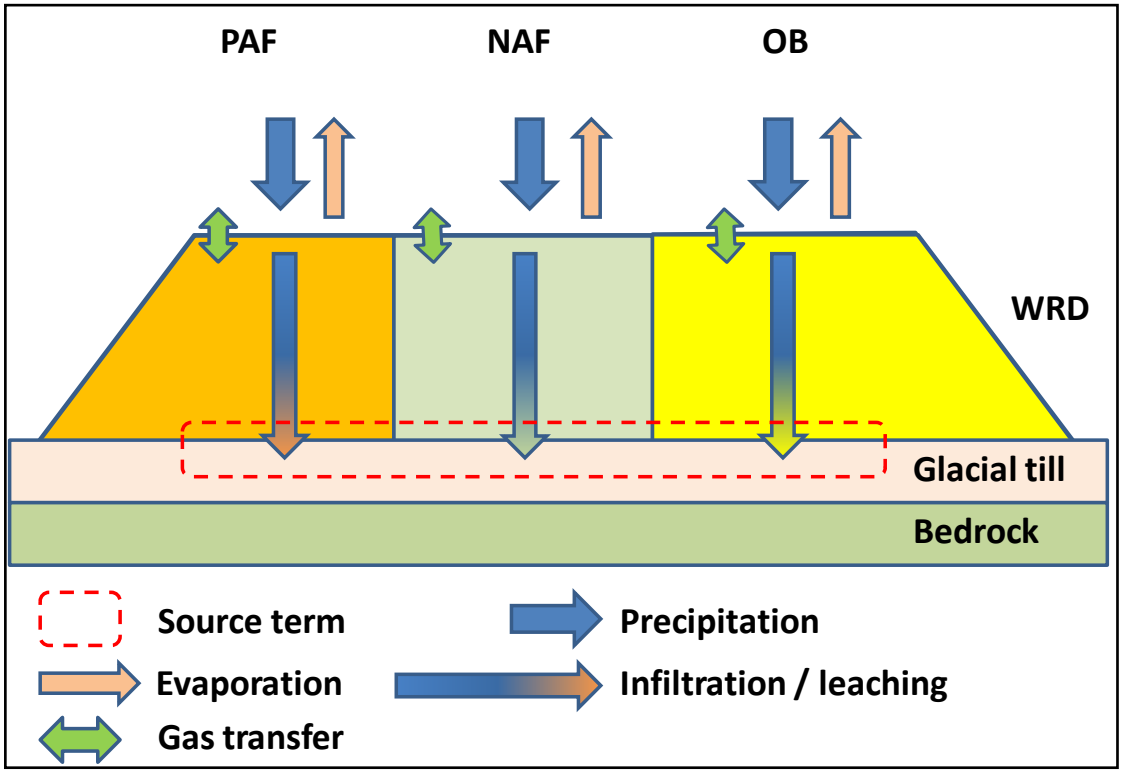


Figure 2-3: Conceptual model for generation of seepage water from WRD during life of mine

During life of mine it is intended that these material classes will be segregated and dumped in separate WRD cells. This will enable the PAF and NAF waste rock to be subjected to separate closure scenarios whilst leaving the overburden material available for use in construction of covers at closure. Northland do not intend to undertake significant progressive reclamation of the WRD and therefore during LOM it is likely that the WRD will remain uncovered and therefore infiltration into the dumps will only be limited by the course waste rock material itself. Therefore, estimates of infiltrations into the dumps during LOM are taken to be in the region of 50 % of annual precipitation (265 mm) (SRK, 2013a).

For purposes of predicting LOM water quality, 3 scenarios have been envisaged:

- Scenario 1: Average yearly conditions
- Scenario 2: Average May / June snow melt conditions
- Scenario 3: Average summer conditions

Scenario 1 and scenario 3 both model the average precipitation during the time period and assume constant release of elements from the WRD, In essence the average yearly and summer models should give similar results. Scenario 2 models the spring snow melt infiltration combined with the accumulated leaching products over the 8 month winter period. In this way a spring flush is simulated which is more characteristic of WRD leaching in high latitudes.

In addition to elemental release during sulfide oxidation, use of explosives during mining can

potentially lead to leaching of explosive residues from WRD and other mine waste facilities. Ammonium Nitrate Fuel Oil (ANFO) is commonly used for this process and results in highly soluble residual nitrogen compounds that can readily be leached from the waste. At Hannukainen it is calculated that 0.3kg ANFO per tonne of rock will be used of which 28% w/w will be nitrogen. Of the total nitrogen used in the ANFO mixture, Furguson and Leask (1988) advised that 99.8% will be consumed in the detonation and lost to the atmosphere leaving residue nitrogen content of 0.2% as soluble nitrogen salts within the waste mass. Due to the highly soluble nature of the nitrogen compounds ammonium and nitrate, it is assumed that explosive residue will be leached immediately from the WRD. Average calculated nitrogen release as nitrate for the Hannukainen WRD are shown in Table 2-2. Full calculations are given in SRK, 2013a. Annual average release is predicted to be 7.55 kg/day as nitrate with a spring flush of approximately 61.24 kg/day predicted to occur during snow melt.

Table 2-2: Calculated average nitrogen release as nitrate from the Hannukainen WRD during LOM

	kg/day nitrate	Average	Snow	Summer
EAST	IN	2.01	15.74	1.97
	PAF	3.27	25.69	3.21
	OB	n/a	n/a	n/a
	Total (PAF+NAF)	5.28	41.43	5.18
West	IN	1.70	13.31	1.66
	PAF	0.39	4.53	0.45
	OB	n/a	n/a	n/a
	Total (PAF+NAF)	2.27	19.82	2.23
All		7.55	61.24	7.41

2.1.2 WRD Closure Scenarios

Following mine closure it is intended that the NAF and PAF WRD will be capped with engineered covers. For the NAF and overburden, following closure and re-vegetation, it is predicted that infiltration will return to pre-mining values as predicted by the site hydrological modelling (SRK, 2013b). This equates to an average yearly infiltration of 74mm. This will be uniform for all dumps assuming the same basic cover design. For the PAF cells, it is intended that two cover options will be modelled for comparative purposes:

NAF and Overburden dump cover – Basic cover: Basic covering of till and growth medium to promote revegetation. Infiltration reduced to pre-mining levels of approximately 74mm per annum. This will implemented on the overburden and NAF WRD

PAF dump cover – Reduced permeability cover: Covering of the PAF dumps will incorporate a bentonite mat in addition to the till and growth medium to promote water shedding. The cover is estimated to reduce infiltration to between 10 and 15% of annual effective rainfall which equals 29.0 to 43.5 mm. A conservative value of 43.5 mm/year was used in the base case model. It is not expected that this cover system will be an effective oxygen barrier.

2.1.3 WRD model input solution options

As discussed in SRK, 2013a, humidity cell testing undertaken on the Hannukainen waste rock materials is experiencing a significant lag time in which acid generation is being buffered by carbonate mineral neutralisation. Humidity cell testing (HCT) is an industry standard test to determine sulfide oxidation rates and elemental release rates from sulfidic mine wastes. The tests involve repeated exposure of mine waste samples to dry air and wet air at room temperature followed by weekly flushing with deionised water and analysis of the collected leachate. At the time of writing, 86 weeks of humidity cell testing has been undertaken on 8 samples of moderate to high sulfur material all of which are predicted to be Potentially Acid Forming (PAF) and are destined for deposition within the PAF WRD. Leachates from all of these cells are currently leaching pH 6 to 7 solutions indicating that neutralising minerals within the solution have not yet been consumed and that a significant lag time is being experienced. Due to the lag time, use of the humidity cell data in the predictive numerical modelling may result in a significant underestimation of PAF WRD leachate water quality and may only be representative of the initial period of weathering within the dump.

In order to develop a water quality prediction for the WRD which is not overly optimistic, it was necessary to supplement the HCT data with data from a more aggressive leach test which use hydrogen peroxide (H_2O_2) as the oxidant. This test is commonly refered to as a Net Acid Generation (NAG) test, as it is designed to fully oxidise all sulfide minerals present in the sample and release all available acidity. In the process of this, all neutralisation potential within the sample is also consumed and the solution attains a pH representative of the potential final solution pH for the given material type.

Due to the very high rate of oxidation within a NAG test, it is necessary to first scale the data so that it can be used as a proxy for the HCT data once the neutralising lag period has been overcome. This has been achieved by scaling to the total sulfur content of the waste material in the respective test (assuming all sulfides are reacted in the NAG test and the reaction is complete). The average rate of sulfate release in the HCT test up to week 78 was found to be roughly 2500 times lower (in mg/kg/week) than the total NAG sulfate release (in mg/kg). This means that dividing the mass release from the NAG test by 2500 should result in a chemistry similar to that of the average HCT release. However, it is assumed that rates of sulfate release from the HCT will increase once acid neutralising capacity is fully consumed. Therefore, in order that the NAG data is used conservatively, a rate correction factor of 1000 was used in the model run base cases. Full details of the methods are given in SRK, 2013a.

2.1.4 PAF WRD amendment – Limestone addition:

In order to investigate the potential benefit of addition of limestone to the PAF WRD, both LOM and post closure scenarios were run simulating limestone addition to the WRD in quantities suitable to allow full neutralisation. This was done in PhreeqC by allowing seepage from the PAF WRD to reach equilibrium with respect to calcite ($CaCO_3$) at a saturation indicies of 0.

2.2 Numerical Modelling and Coding

The conceptual WRD model developed for the Hannukainen deposit incorporates aspects of both mass balance calculation incorporating scaled laboratory data and thermodynamic equilibriation using the USGS thermodynamic numerical code PHREEQC. The PHREEQC models used a modified version of the minteq.v4 thermodynamic database supplied with the

v2.18.5577 version of PHREEQC (released August 16th, 2011). This Minteq.v4 database was selected for this study because it includes a comprehensive range of elements and solid phases for consideration in ARDML water quality predictions as well as key sorption reactions for iron oxyhydroxides. The database was modified to include sorption data for manganese species together with corrections for weak strong site adsorption of anions to hydrous ferric oxide.

The mass balance calculation used in the current model is as follows:

$$WRD\ Seepage\ water\ quality \frac{mg}{L} = \frac{\sum Solute\ release\ rate \left(\frac{\frac{mg}{kg}}{week}\right) \times Reactive\ mass\ of\ material\ in\ WRD\ (kg)}{Total\ infiltration\ rate\ into\ WRD\ (\frac{L}{week})}$$

The basic step in calculating the seepage water quality through mass balance is as follows:

1) **Solute release rate** – The solute release rate is the mass of solute that can be released from the waste rock material into solution over a set time period. This rate is often determined from leaching tests in which samples of the particular waste rock material is leached for a set period of time and the leach solution analysed. It is necessary to determine a unique solute release rate for each solute for each material type present in the dump. Temperature factors affecting sulfide oxidation rates and solute release are taken into account by including a temperature correction factor based on the Arrhenius factor for oxidation of pyrite with the rate adjusted to field temperature. Details of input solutions and volumes are given in Attachment A.

2) **Reactive mass of material** – The reactive mass of material is the mass of each material type within each dump that will be effectively leached. It is acknowledged that only a small portion of the total mass of waste within a WRD will be effectively leached due to factors such as preferential fluid flow pathways and also due to reactive mass effects in which mass within larger particles is effectively encapsulated and therefore resistant to weathering. Based on observations made in the historic Hannukainen and Rautuvaara waste rock dumps an estimate of 20% reactive fines has been made. In addition, based on ElBoushi 1975 as reported in MEND, 1995 flow within the WRD is assumed to be restricted to movement along preferential flow paths contacting 20% of the waste rock volume. This therefore equates to a reactive mass of 20% of the rock mass contacted within 20% of the dump, 20% of 20% = 4% reactive mass effectively leached.

3) **Total infiltration rate into WRD**- The total infiltration rate into the WRD is a function of both the plan dump area, the effective precipitation on to the dump and the run-off coefficient of the dump surface. During life of mine, the WRD surface will be uncovered and have a low runoff co-efficient and an estimate infiltration into the dump of 50% of annual precipitation is assumed. Post closure, infiltration will be influenced by the cover system used. A basic cover as used on the NAF and overburden dumps is assumed to return infiltration back to the catchment average (74mm/year) whilst incorporation of a bentonite mat to the PAF dump is taken to reduce infiltration to 15% of effective rainfall (43.5 mm/year).

4) **Additional scaling considerations based on laboratory testwork used** – Humidity cell tests, NAG tests and Kappa tests were all used as input into the Hanukainen WRD seepage water quality predictions. Depending on the laboratory testwork results used as input to the WRD models, scaling factors were necessary to normalise the leachate results to the industry standard humidity cell test release rates. In this respect, the release rate for humidity cell tests is taken to be equal to 1. Based on the relationship between sulfate release from static NAG tests to sulphate release in humidity cell test a scaling factor of 1/1000 is used to correct mass release in the NAG test (mg/kg/day) to the equivalent sulphate release in a humidity cell (mg/kg/week) for use in further testing. The difference in rates of release are associated with differing sulfide oxidation rates in the presence of oxygen and or hydrogen peroxide as well as differences in particle size. The observed difference between sulphate release is taken to be analogous for all other solubilised elements. Scaling of Kappa test release rates in mg/kg/day have been scaled to take into account differences in test particle size and particle size in the field. A factor of 1/10 is taken in to account in this respect.

Once the mass release of solutes from the WRD has been undertaken, these can then be introduced to the volume of infiltration (solvent) to the WRD facilities. Predicted infiltration rates into the WRD are as follows.

Table 2-3: Predicted infiltration in the Hannukainen WRD

		Infiltration m3/year					
Mtonnes	**Surface Area (m^2)**	**EOML Summer**	**EOML Spring**	**EOML Average**	**Post Close Summer**	**Post Close Spring**	**Post Close Average**
East NAF Dump	798,663	296,761	1,353,147	211,683	8,865	141,843	59,101
East PAF Dump	1,635,455	607,690	2,770,894	433,471	11,039	176,629	73,595
East OVB Dump	2,052,073	762,494	3,476,755	543,894	22,778	364,448	151,853
West NAF Dump	997,569	370,669	1,690,146	264,402	11,073	177,168	73,820
West PAF Dump	329,980	122,611	559,074	87,460	2,227	35,638	14,849
West OVB Dump	743,539	276,279	1,259,752	197,072	8,253	132,053	55,022

Mass balance calculations and subsequent scaling of the data results in a preliminary source term which is then input PhreeqC. The mass balanced leach solution are allowed to attain thermodynamic equilibrium with respect to solid and gaseous phases which includes the following processes:

- Precipitation of saturated secondary mineral phases
- $CO_{2(g)}$ gas exchange
- Solute adsorption to the hydrous ferric oxide ‘ferrihydrite’ in accordance with Dzombak and Morel, 1999.

Details specific equilibrium criteria are given in SRK,2013a.

2.2.1 Model Assumptions and Limitations

Despite site-specific data collection activities, several assumptions and model boundaries must be defined to construct a numerical model that predicts future water quality. Specific boundaries and assumptions of the numeric model include:

- The geochemical model framework is defined by the water inputs and losses to/from the system.
- The models are defined by the elements, mineral phases, gas phases, and chemical species specified in the model input files;
- The models are limited to inorganic reactions and do not take into account the complexities associated with biologically mediated reactions;
- The models are limited to thermodynamic equilibrium reactions and do not simulate the effects of reaction kinetics and rates;
- The models rely on an external database of thermodynamic constants for mineral phase precipitates and sorbed surface complexes. These thermodynamic constants are valid at 25^{o}C and 1 atmosphere of pressure;
- The models do not consider the effects associated with the formation and precipitation of mineral species other than those specified. Due to kinetic constraints, a portion of the potentially oversaturated mineral phases will not actually precipitate. A select suite of minerals is therefore specified that are allowed to precipitate, based on relevance for the environment in question, site-specific knowledge, experience in evaluating kinetic constraints and relevance of key phases for given styles of mineralization (Eary, 1999).
- Biological processes are not taken into account and therefore mineral precipitates are the only sink for major nutrients such as potassium, phosphate and nitrate.
- The models assume that solution input chemistry can be simulated using laboratory leachate chemistries from static NAG tests which have been scaled to weekly release from a standard humidity cell test using a value of 1000.
- The model assumes that rates of solute release in a standard humidity cell test are comparable to rates of solute release from WRD fines under field conditions once adjustments are made for temperature. Therefore a humidity cell test is representative of solute release rates from 20% of the total WRD rock mass (the fines fraction). For the overburden dump it is assumed that 100% of material within the dump is reactive due to the generally fine particle size of this material.
- Although it is assumed that the entire WRD will be humid and therefore sulfide oxidation will take place, it is assumed that due to preferential flow paths within the PAF WRD only a fraction of the total mass of waste rock within the WRD will be effectively washed by infiltrating rainwater (ElBoushi 1975 as reported in MEND, 1995).
- The model assumes that the proportion of ferrihydrite available to partake in surface adsorption reactions can be calculated from the total mass of sulphate predicted to be released from the PAF and NAF WRDs. This is assuming that all sulphate is a product of pyrite oxidation and therefore the shares the mole ratio $2SO_4$:$1Fe(OH)_3$. It is also assumed that this will form a constantly replenished source of sorbent.

2.2.2 Prediction of loadings to rivers and pits

Predictions of seepage loadings from the WRD to rivers and pits were made based on taking the total mass loading from each of the WRD and proportioning this to the plan area of the WRD which was shown to drain towards either the river systems or the pits as determined in the hydrogeological model (SRK, 2013b)

2.2.3 Model Predictions

A number of model runs have been undertaken for EOML (pre-cover) and post closure (post cover) scenarios. These are shown in Table 2-4. Model simulations were undertaken utilising both NAG test and HCT test data in order to show the range of possible source term concentrations that may be attained for the PAF WRDs. The effects of addition of limestone to neutralise the waste rock dumps was trialled in both the EOML and post closure scenarios for the worst case NAG leach chemistry as was installation of a qualified cover post closure.

Table 2-4: Model runs undertaken

Mine Phase	Model undertaken
EOML	Spring snow melt using NAG test data
	Average condition using NAG test data
	Average conditions using HCT test data
	Limestone neutralised PAF dump using NAG test data
Post Closure	Average conditions using NAG test data
	Average conditions using HCT test data
	Limestone neutralised PAF dump using NAG test data

2.3 Predicted Source Term Concentrations

2.3.1 Predicted source terms at EOML

Table 2-6 shows the predicted source term water quality concentrations and mass loads for key elements released from the Hannukainen WRD at EOML during spring snow melt conditions.

Table 2-7 shows the same leach chemistry for average yearly releases. Both Table 2-6 and Table 2-7 predictions are based on the use of NAG test data for calculation of release of high sulfur data. Table 2-8 show EOML predicted chemistry using immature HCT data.

PAF dumps are predicted to generate acidic leachates with a high sulfate load. Metals content is predicted to contain elevated copper, iron, nickel and zinc at concentrations exceeding the International Finance Corporation (IFC, 2007) effluent quality guidelines. In addition, concentrations of aluminium, cobalt, manganese, and antimony are also predicted to be released at problematic concentrations despite absence of specific guideline values. Uranium is predicted to be released from the concentrations exceeding Action Values (AV) calculated for the Akasjoki River of 0.015 mg/L.

There is predicted to be a tenfold increase on annual average loadings of metals, sulfate and nitrate loading during snow melt however concentrations in the source term leachate are not predicted to change significantly.

The NAF WRDs are predicted to have a circum-neutral to mildly alkaline pH, with only chromium predicted to exceed the IFC guidelines. However chromium is largely predicted to be as chromium (III) which has low toxicity as compared to the chromium (VI) oxidation state and is unlikely to be problematic. Uranium release from the NAF dumps leachates is predicted also to exceed the Akasjoki AV. As with the PAF dumps, the spring melt is predicted to generate a tenfold increase in mass release. Due to the slower sulfide content of the NAF dump, it is unlikely that any benefit will be realized from installation of a qualified cover to reduce oxygen infiltration.

The Overburden dump is predicted to generate a mildly acidic leachate with generally good water quality. It is predicted that concentrations of mercury, iron and chromium may exceed the IFC guidelines in the source term leachates, however, this has been shown to possibly due to detection limits and limitations of testwork.

Table 2-5 shows the proportion of key solute loadings from each of the PAF, NAF and overburden sources. It is evident that In order to determine the potential risk posed by the above mentioned elements to generate a negative environmental impact on the aquatic environment it is recommended that field leach trials are undertaken with respect to all waste rock materials. As the PAF WRD contributes greater than 90% of the LOM load of SO_4, Co, Cu, Fe, Mn, Ni, and Pb and greater than 80% of Zn release to the catchment, reduction of loadings from the PAF dumps will be the most effective method of reducing water quality impacts from the Hannukainen site. Table 2-5 also shows the potential reduction in loadings from the PAF WRD source and total loading to the catchment with the neutralisation of the PAF WRD through limestone addition.

Table 2-5: Proportional Loading from each WRD source

Analyte	Total Load (g/day)		Standard			Limestone		
	No Limestone	Limestone	PAF	NAF	OVB	PAF	NAF	OVB
SO4	6,374,050	4,664,050	93.9%	4.9%	1.2%	91.8%	4.5%	1.6%
Cd	13	6	57.5%	4.5%	38.1%	8.0%	48.5%	82.4%
Co	6,093	882	99.0%	0.2%	0.8%	93.1%	3.7%	5.8%
Cr	830	817	1.6%	0.0%	98.5%	0.0%	51.9%	100.0%
Cu	56,303	86	99.8%	0.0%	0.1%	7.0%	29.2%	92.8%
Fe	944,176	7,436	99.1%	0.0%	0.7%	1.8%	24.1%	95.1%
Mn	15,111	3,611	98.2%	0.5%	1.4%	92.3%	4.0%	5.7%
Mo	168	163	14.7%	55.4%	30.2%	11.2%	46.0%	31.3%
Ni	7,013	290	99.2%	0.1%	0.8%	79.3%	10.9%	18.3%
Pb	52	1	98.1%	0.0%	1.9%	0.3%	7.2%	99.4%
Sb	51	51	26.0%	24.1%	49.9%	26.1%	39.8%	50.0%
U	1,007	1,004	51.0%	32.1%	17.0%	50.8%	25.9%	17.0%
Zn	3,035	487	84.7%	0.2%	14.9%	5.9%	49.9%	93.0%

Table 2-6: Predicted Hannukainen WRD source term leachate concentrations at EOML for snowmelt scenarios using NAG test input data

				Source Term Concentrations (mg/L)							Source Term Loading (g/day)						Loadings to Rivers / Pits (g/day)				
Analyte	Units	AV Akasjoki FS09	IFC (2002)	East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB		East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB	Hannukainen	Kuervitikko	Kuerjoki	Akasjoki	Valkeajoki
										Seepage m3/day	3707	7591	9525	4631	1532	3451					
pH	s.u.	6.5	6	7.27	3.33	5.84	7.13	3.35	5.89	mol	0.000199	3.56	0.0137	0.000346	0.68	0.00444	2.39	1.87	0	0.000458	0
Alkalinity	mg/L			91.7	-176	2.72	64.2	-146	2.27	g/day	340000	-1340000	25900	297000	-223000	7840	-347000	-542000	0	809	0
Cl	mg/L	150		45.8	45.2	21.7	30.7	37.5	60.5	g/day	170000	343000	207000	142000	57500	209000	746000	360000	0	21500	0
F	mg/L			2.68	24.4	1.79	2.89	20.9	5.66	g/day	9940	186000	17000	13400	32000	19500	165000	110000	0	2020	0
P	mg/L	0.01926		0.0162	4.71	1.76	0.062	4.66	4.24	g/day	60.1	35700	16800	287	7130	14600	45600	27500	0	1510	0
SO4	mg/L	65		331	5280	27.3	213	4820	80.6	g/day	1230000	40100000	260000	987000	7390000	278000	28500000	21600000	0	28700	0
Ag	mg/L			0.0134	0.0108	0.00895	0.00911	0.00942	0.0284	g/day	49.8	81.8	85.2	42.2	14.4	97.9	253	109	0	10.1	0
Al	mg/L	0.1		0.00511	166	0.911	0.0108	146	2.9	g/day	18.9	1260000	8680	50.1	223000	10000	838000	665000	0	1030	0
As	mg/L	0.005	0.1	0.00000753	0.0125	0.0081	0.0000145	0.0105	0.0237	g/day	0.0279	95	77.2	0.067	16.1	81.9	172	90.3	0	8.45	0
B	mg/L			1.14	0.702	0.604	0.601	0.621	1.91	g/day	4230	5330	5750	2780	951	6600	17400	7600	0	681	0
Ba	mg/L	0.01792		0.00717	0.00139	0.0486	0.00927	0.00145	0.0271	g/day	26.6	10.6	463	42.9	2.22	93.4	369	260	0	9.63	0
NO3	mg/L	20		0.572	0.457	0.396	0.388	0.399	1.25	g/day	2120	3470	3770	1790	611	4320	10900	4690	0	446	0
Ca	mg/L	6.542		144	372	32.6	105	380	103	g/day	532000	2830000	311000	485000	582000	354000	3190000	1870000	0	36500	0
Cd"	mg/L	0.00008	0.05	0.000592	0.00637	0.00179	0.000529	0.00497	0.00566	g/day	2.2	48.4	17	2.45	7.61	19.5	60	35.2	0	2.01	0
Co	mg/L	0.004		0.00969	4.86	0.0179	0.00787	4.47	0.0566	g/day	35.9	36900	170	36.4	6850	195	24700	19400	0	20.1	0
Cr*	mg/L	0.001	0.1	0.00000101	0.147	0.303	8.14E-07	0.103	0.904	g/day	0.00375	1120	2880	0.00377	158	3120	4860	2100	0	322	0
Cu	mg/L	0.005	0.3	0.000111	49.9	0.0413	0.000124	42.6	0.0567	g/day	0.412	379000	393	0.573	65200	196	246000	198000	0	20.2	0
Fe	mg/L	0.975	2	0.159	477	4.01	0.217	399	3.76	g/day	589	3620000	38200	1000	611000	13000	2370000	1920000	0	1340	0
Hg"	mg/L	0.00005	0.002	0.000786	0.0011	0.0018	0.000552	0.000936	0.00571	g/day	2.91	8.33	17.2	2.55	1.43	19.7	35.5	14.6	0	2.03	0
K	mg/L	0.888		169	501	18.2	104	471	56	g/day	627000	3810000	173000	480000	722000	193000	3630000	2350000	0	20000	0
Li	mg/L			0.134	0.562	0.178	0.0909	0.591	0.563	g/day	498	4260	1690	421	905	1940	6190	3330	0	200	0
Mg	mg/L	1.808		29.9	234	18.2	20.4	218	56.9	g/day	111000	1780000	173000	94600	335000	196000	1600000	1070000	0	20300	0
Mn	mg/L	0.7		0.0673	11.8	0.0716	0.0566	11.6	0.227	g/day	250	89800	682	262	17800	783	62000	47500	0	80.7	0
Mo	mg/L	1		0.0928	0.051	0.0178	0.0704	0.0291	0.0563	g/day	344	387	170	326	44.6	194	1010	437	0	20.1	0
Na	mg/L	2.794		118	156	39.4	80.4	141	121	g/day	436000	1190000	376000	372000	216000	417000	1960000	1000000	0	43000	0
Ni	mg/L	0.02	0.5	0.00648	5.77	0.0186	0.0068	4.34	0.0588	g/day	24	43800	177	31.5	6650	203	27800	23000	0	20.9	0
Pb	mg/L	0.0072		0.00000386	0.124	0.000544	0.00000318	0.0847	0.000134	g/day	0.0143	941	5.18	0.0147	130	0.464	581	495	0	0.0478	0
Sb	mg/L	0.00002802		0.0129	0.011	0.00894	0.00876	0.00925	0.0283	g/day	47.9	83.2	85.1	40.5	14.2	97.7	250	109	0	10.1	0
Se	mg/L			0.00114	0.229	0.0176	0.00146	0.176	0.0553	g/day	4.21	1740	168	6.76	269	191	1360	1000	0	19.7	0
Si	mg/L	9.62		30.7	29.8	30.7	30.7	29.9	30.6	g/day	114000	226000	293000	142000	45800	106000	595000	320000	0	10900	0
Sn	mg/L			0.0129	0.0103	0.00893	0.00875	0.00901	0.0283	g/day	47.9	78.3	85.1	40.5	13.8	97.6	247	106	0	10.1	0
Sr	mg/L	0.03014		0.512	1.59	0.236	0.344	1.5	0.748	g/day	1900	12100	2250	1590	2300	2580	14100	8310	0	266	0
Tl	mg/L			0.0129	0.0146	0.00894	0.00876	0.0119	0.0283	g/day	48	111	85.1	40.6	18.2	97.8	267	123	0	10.1	0
U	mg/L	0.015		0.325	0.424	0.0598	0.238	0.339	0.189	g/day	1210	3220	569	1100	519	653	4710	2490	0	67.4	0
V	mg/L			0.00184	0.177	0.898	0.00416	0.104	2.84	g/day	6.84	1350	8550	19.3	160	9820	13700	5190	0	1010	0
Zn	mg/L	0.03	0.5	0.00412	2.12	0.159	0.00517	1.72	0.5	g/day	15.3	16100	1510	23.9	2630	1730	12600	9220	0	178	0

Predicted to exceeeds action value determined for the Akasjoki River at FS09

Predicted to exceeed IFC (2007) environmental health and safety guidelines

" Concentrations of cadmium and mercury artefacts of detection limits available in testwork

* Seepage concentration from overburden influenced by elevataed release from NAG test

Table 2-7: Predicted Hannukainen WRD source term leachate concentrations at EOML for annual average precipitation leaching scenarios using NAG test input data

				Source Term Concentrations (mg/L)									Source Term Loading (g/day)								Loadings to Rivers / Pits (g/day)					
					East_PAF				West_PAF					East_PAF				West_PAF			Hannukainen		Kuervitikko		Akasjoki	
Analyte	Units	AV Akasjoki FS09	IFC (2002)	East_NAF	No Limestone	Limestone	East_OVB	West_NAF	No Limestone	Limestone	West_OVB		East_NAF	No Limestone	Limestone	East_OVB	West_NAF	No Limestone	Limestone	West_OVB	No Limestone	Limestone	No Limestone	Limestone	No Limestone	Limestone
												Seepage m3/d	580	1188		1490	724	240		540						
pH	s.u.	6.5	6	7.25	4.03	7.47	5.83	7.1	4.08	7.46	5.91	g/day	0.0000329	0.11	0.0000401	0.0022	0.0000571	0.0199	0.00000826	0.000671	0.0742	0.00175	0.0589	0.00119	0.0000692	0.0000692
Alkalinity	mg/L			84.3	-40.7	159	2.59	59.3	-28.1	155	2.51	g/day	48900	-48400	189000	3860	42900	-6740	37200	1360	44400	201000	-2560	122000	140	140
Cl	mg/L	150		41.4	40.1	39.9	19.8	27.8	33.3	33.4	54.5	g/day	24000	47600	47400	29500	20200	7970	8010	29400	105000	105000	50600	50400	3030	3030
F	mg/L			2.78	21.5	2.73	1.6	3.01	18.4	2.67	5.06	g/day	1610	25600	3250	2380	2180	4400	639	2730	23300	8880	15300	3630	282	282
P	mg/L	0.01926		0.0232	0.309	0.00237	1.48	0.0614	0.204	0.00000369	3.71	g/day	13.5	367	2.81	2200	44.5	49	0.000885	2000	3120	2900	1350	1160	207	207
SO4	mg/L	65		296	4270	3030	24.4	191	3830	2890	72.7	g/day	172000	5070000	3590000	36400	138000	917000	691000	39300	3620000	2690000	2750000	1970000	4050	4050
Ag	mg/L			0.012	0.00949	0.00761	0.008	0.00814	0.00826	0.00642	0.0254	g/day	6.95	11.3	9.04	11.9	5.89	1.98	1.54	13.7	35.2	33.7	15.1	13.9	1.41	1.41
Al	mg/L	0.1		0.00503	24.4	0.0028	0.793	0.0114	20.3	0.00275	2.48	g/day	2.92	29000	3.32	1180	8.28	4870	0.66	1340	20400	1780	15800	623	138	138
As	mg/L	0.005	0.1	0.00000678	0.000405	0.000000275	0.00711	0.0000135	0.000271	0.00000035	0.0208	g/day	0.00393	0.481	0.000326	10.6	0.0098	0.0649	0.0000838	11.3	15.4	15.1	5.81	5.56	1.16	1.16
B	mg/L			1.02	0.618	0.607	0.54	0.537	0.545	0.542	1.71	g/day	591	734	721	804	389	131	130	923	2420	2410	1060	1050	95.2	95.2
Ba	mg/L	0.01792		0.00793	0.00152	0.00174	0.0546	0.0103	0.00152	0.00169	0.0298	g/day	4.6	1.8	2.07	81.3	7.47	0.364	0.406	16.1	64.4	64.6	45.5	45.7	1.66	1.66
NO3	mg/L	20		0.512	0.402	0.399	0.354	0.347	0.35	0.351	1.12	g/day	297	478	474	527	251	83.9	84	605	1530	1520	652	650	62.4	62.4
Ca	mg/L	6.542		129	384	416	29.2	94.5	381	424	92.3	g/day	74900	456000	495000	43500	68500	91300	102000	49800	486000	514000	293000	314000	5140	5140
Cd	mg/L	0.00008	0.05	0.000484	0.00561	0.000365	0.0016	0.000441	0.00436	0.000255	0.00506	g/day	0.281	6.66	0.434	2.38	0.32	1.05	0.0612	2.73	8.28	4.33	4.85	1.59	0.282	0.282
Co	mg/L	0.004		0.00863	4.28	0.577	0.016	0.00702	3.93	0.567	0.0506	g/day	5	5090	685	23.8	5.09	943	136	27.3	3410	506	2680	373	2.82	2.82
Cr	mg/L	0.001	0.1	0.00000073	0.0103	2.98E-08	0.264	0.000000613	0.00403	1.55E-08	0.786	g/day	0.000423	12.2	0.0000353	393	0.000444	0.965	0.0000037	424	574	567	212	206	43.8	43.8
Cu	mg/L	0.005	0.3	0.0000963	40.6	0.00505	0.0367	0.000109	33.3	0.00000204	0.0463	g/day	0.0558	48200	6	54.7	0.0788	7970	0.000488	25	31000	51.4	25300	31.9	2.58	2.58
Fe	mg/L	0.975	2	0.147	680	0.0962	3.6	0.199	538	0.0979	3.17	g/day	85	807000	114	5360	144	129000	23.5	1710	518000	4350	426000	2910	176	176
Hg	mg/L	0.00005	0.002	0.000636	0.000965	0.0000456	0.00161	0.000453	0.000822	0.0000375	0.00511	g/day	0.369	1.15	0.0542	2.4	0.328	0.197	0.00899	2.76	4.9	4.19	2.02	1.44	0.284	0.284
K	mg/L	0.888		151	383	441	16.3	92.7	362	417	50.3	g/day	87700	455000	524000	24300	67100	86800	99900	27100	457000	503000	288000	324000	2800	2800
Li	mg/L			0.12	0.495	0.491	0.159	0.0813	0.519	0.52	0.503	g/day	69.6	588	583	237	58.9	124	125	272	860	858	461	459	28	28
Mg	mg/L	1.808		26.8	206	172	16.3	18.3	192	165	50.9	g/day	15500	245000	204000	24200	13300	46000	39500	27500	221000	195000	148000	126000	2840	2840
Mn	mg/L	0.7		0.059	10.4	2.59	0.064	0.05	10.2	1.05	0.203	g/day	34.2	12400	3080	95.4	36.2	2440	253	109	8550	1920	6550	1680	11.3	11.3
Mo	mg/L	1		0.0822	0.019	0.0135	0.0159	0.0628	0.0086	0.00958	0.0504	g/day	47.7	22.6	16	23.7	45.5	2.06	2.3	27.2	121	119	44.5	41	2.8	2.8
Na	mg/L	2.794		105	138	137	35.5	72.1	124	124	108	g/day	61100	164000	163000	52900	52200	29800	29800	58400	273000	272000	139000	139000	6020	6020
Ni	mg/L	0.02	0.5	0.0056	5.08	0.167	0.0166	0.00591	3.81	0.129	0.0525	g/day	3.25	6040	199	24.8	4.28	914	30.9	28.4	3830	169	3180	118	2.93	2.93
Pb	mg/L	0.0072		0.00000241	0.0388	0.00000266	0.00061	0.00000206	0.0193	0.000000184	0.00013	g/day	0.0014	46.1	0.00316	0.909	0.00149	4.61	0.000044	0.0699	27.1	0.499	24.6	0.479	0.00721	0.00721
Sb	mg/L	2.802E-05		0.0116	0.00962	0.00957	0.00799	0.00783	0.0081	0.00813	0.0253	g/day	6.7	11.4	11.4	11.9	5.67	1.94	1.95	13.7	34.8	34.8	15.1	15	1.41	1.41
Se	mg/L			0.00102	0.142	0.000733	0.0157	0.00134	0.0955	0.000782	0.0493	g/day	0.591	169	0.87	23.4	0.968	22.9	0.187	26.6	139	36.9	101	13	2.74	2.74
Si	mg/L	9.62		31.5	30.8	31.1	31.6	31.6	30.2	30.6	31.5	g/day	18300	36500	36900	47100	22900	7240	7320	17000	95700	96000	51600	51800	1750	1750
Sn	mg/L			0.0115	0.00906	0.00901	0.00799	0.00782	0.00788	0.00792	0.0253	g/day	6.7	10.8	10.7	11.9	5.67	1.89	1.9	13.7	34.4	34.4	14.7	14.7	1.41	1.41
Sr	mg/L	0.03014		0.458	1.4	1.39	0.211	0.308	1.32	1.32	0.668	g/day	266	1660	1650	314	223	316	316	361	1960	1950	1150	1140	37.2	37.2
Tl	mg/L			0.0116	0.0128	0.0127	0.00799	0.00783	0.0104	0.0104	0.0253	g/day	6.71	15.3	15.1	11.9	5.68	2.5	2.5	13.7	37.2	37.2	17.1	17	1.41	1.41
U	mg/L	0.015		0.291	0.373	0.37	0.0534	0.213	0.297	0.298	0.169	g/day	169	443	439	79.6	154	71.2	71.3	91.4	653	652	345	343	9.43	9.43
V	mg/L			0.00177	0.156	0.0000121	0.803	0.00411	0.0913	0.0000111	2.54	g/day	1.03	185	0.0143	1200	2.98	21.9	0.00265	1370	1910	1800	725	628	142	142
Zn	mg/L	0.03	0.5	0.00347	1.86	0.0209	0.142	0.00436	1.51	0.0168	0.447	g/day	2.01	2210	24.8	212	3.16	362	4.02	241	1740	337	1270	125	24.9	24.9

Predicted to exceeeds action value determined for the Akasjoki River at FS09

Predicted to exceeed IFC (2007) environmental health and safety guidelines

" Concentrations of cadmium and mercury artefacts of detection limits available in testwork

* Seepage concentration from overburden influenced by elevataed release from NAG test

Table 2-8: Predicted Hannukainen WRD source term leachate concentrations during EOML for annual average precipitation leaching scenarios using HCT test input data

				Source Term Concentrations (mg/L)							Source Term Loading (g/day)						Loadings to Rivers / Pits (g/day)				
Analyte	Units	AV Akasjoki FS09	IFC (2002)	East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB		East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB	Hannukainen	Kuervitikko	Kuerjoki	Akasjoki	Valkeajoki
										Seepage m3/day	580	1188	1490	724	240	540					
pH	s.u.	6.5	6	7.21	6.61	5.85	7.24	6.62	5.47	mol	0.0000358	0.000292	0.0021	0.0000417	0.0000575	0.00183	0.0029	0.00127	-	0.000189	-
Alkalinity	mg/L			98.8	32.5	1.85	101	31.5	-6.71	g/day	57300	38600	2750	73400	7540	-3620	130000	46000	-	-374	-
Cl	mg/L	150		276	575	61.1	209	522	185	g/day	160000	683000	91000	152000	125000	99900	827000	473000	-	10300	-
F	mg/L			1.71	1.51	5.72	1.74	1.55	18.1	g/day	992	1790	8520	1260	371	9780	15900	5830	-	1010	-
P	mg/L	0.01926		0.0015	0.00014	4.93	0.00156	0.000113	10.7	g/day	0.868	0.166	7340	1.13	0.0272	5770	8670	3850	-	596	-
SO4	mg/L	65		1290	944	81.4	886	663	258	g/day	746000	1120000	121000	642000	159000	139000	1950000	967000	-	14400	-
Ag	mg/L			0.143	0.504	0.0286	0.092	0.454	0.0906	g/day	82.7	599	42.6	66.7	109	48.9	573	371	-	5.05	-
Al	mg/L	0.1		0.00313	0.0109	2.94	0.00305	0.0141	10.4	g/day	1.82	12.9	4390	2.21	3.37	5610	7130	2310	-	579	-
As	mg/L	0.005	0.1	0.000592	0.00000341	0.0251	0.000534	0.00000194	0.0725	g/day	0.343	0.00405	37.4	0.387	0.000465	39.1	53.5	19.8	-	4.04	-
B	mg/L			4.06	4.19	1.93	2.29	3.7	6.11	g/day	2360	4980	2880	1660	888	3300	10600	5110	-	340	-
Ba	mg/L	0.01792		0.00658	0.025	0.0284	0.00803	0.0214	0.0183	g/day	3.81	29.7	42.4	5.82	5.13	9.86	56.3	39.4	-	1.02	-
NO3	mg/L	20		1.02	3.03	1.26	0.539	2.67	4.01	g/day	590	3600	1880	391	640	2160	5920	3120	-	223	-
Ca	mg/L	6.542		1040	3650	104	826	3120	323	g/day	602000	4340000	155000	598000	749000	174000	3990000	2610000	-	18000	-
Cd"	mg/L	0.00008	0.05	0.00121	0.0132	0.00572	0.000777	0.0103	0.0181	g/day	0.704	15.6	8.53	0.563	2.48	9.77	23.7	12.9	-	1.01	-
Co	mg/L	0.004		0.037	0.83	0.0571	0.0272	0.648	0.181	g/day	21.5	986	85.1	19.7	155	97.6	785	570	-	10.1	-
Cr*	mg/L	0.001	0.1	0.00000191	0.00000177	0.952	0.000001	0.00000131	2.97	g/day	0.00111	0.00211	1420	0.000727	0.000313	1610	2110	744	-	166	-
Cu	mg/L	0.005	0.3	0.0000984	0.000205	0.0781	0.0000933	0.000194	0.479	g/day	0.0571	0.244	116	0.0676	0.0466	259	287	61.2	-	26.7	-
Fe	mg/L	0.975	2	0.178	0.776	3.6	0.164	0.753	9.6	g/day	103	921	5370	119	181	5180	8000	3340	-	535	-
Hg"	mg/L	0.00005	0.002	0.00897	0.0108	0.00578	0.00684	0.00933	0.0183	g/day	5.2	12.8	8.61	4.96	2.24	9.87	29.2	13.4	-	1.02	-
K	mg/L	0.888		716	5000	56.7	481	4650	179	g/day	415000	5940000	84500	348000	1110000	96700	4660000	3330000	-	9970	-
Li	mg/L			6.81	20.4	0.569	5.8	17.9	1.8	g/day	3950	24300	847	4200	4280	972	23600	14800	-	100	-
Mg	mg/L	1.808		229	741	57.6	181	683	182	g/day	133000	880000	85800	131000	164000	98000	920000	562000	-	10100	-
Mn	mg/L	0.7		2.27	68.8	0.229	1.96	56.7	0.726	g/day	1310	81600	341	1420	13600	392	55200	43500	-	40.4	-
Mo	mg/L	1		0.294	0.076	0.057	0.243	0.0662	0.179	g/day	171	90.2	84.9	176	15.9	96.8	460	164	-	9.99	-
Na	mg/L	2.794		649	1300	122	492	1120	382	g/day	376000	1550000	182000	357000	268000	206000	1850000	1060000	-	21300	-
Ni	mg/L	0.02	0.5	0.0206	0.57	0.0593	0.0174	0.416	0.188	g/day	11.9	677	88.3	12.6	99.6	102	575	406	-	10.5	-
Pb	mg/L	0.0072		0.00000528	0.00000329	0.000315	0.00000356	0.00000284	0.00051	g/day	0.00306	0.00391	0.469	0.00258	0.00068	0.275	0.477	0.25	-	0.0284	-
Sb	mg/L	0.00002802		0.0447	3.62	0.0286	0.031	1.2	0.0903	g/day	25.9	4290	42.6	22.5	288	48.8	2440	2280	-	5.03	-
Se	mg/L			0.000755	0.000869	0.0563	0.000516	0.000646	0.178	g/day	0.438	1.03	83.9	0.374	0.155	95.9	127	44.7	-	9.89	-
Si	mg/L	9.62		30.9	28.9	31.5	30.9	28	31.2	g/day	17900	34400	46900	22400	6710	16800	93200	50200	-	1740	-
Sn	mg/L			0.0227	0.00148	0.0286	0.0121	0.00131	0.0902	g/day	13.1	1.76	42.6	8.77	0.313	48.7	81.4	28.9	-	5.02	-
Sr	mg/L	0.03014		4.57	30	0.755	3.64	23.3	2.39	g/day	2650	35700	1130	2630	5580	1290	28400	20400	-	133	-
Tl	mg/L			1.67	5.6	0.0286	1.44	4.93	0.0905	g/day	971	6650	42.6	1040	1180	48.9	6020	3920	-	5.04	-
U	mg/L	0.015		2.69	0.462	0.191	2.22	0.158	0.605	g/day	1560	548	285	1610	37.8	326	3230	1100	-	33.7	-
V	mg/L			0.00131	0.00115	2.87	0.000825	0.000805	9.07	g/day	0.759	1.36	4280	0.598	0.193	4900	6430	2250	-	505	-
Zn	mg/L	0.03	0.5	0.00765	0.165	0.507	0.00616	0.137	1.61	g/day	4.44	196	755	4.46	32.8	869	1270	501	-	89.6	-

Predicted to exceeeds action value determined for the Akasjoki River at FS09

Predicted to exceeed IFC (2007) environmental health and safety guidelines

" Concentrations of cadmium and mercury artefacts of detection limits available in testwork

* Seepage concentration from overburden influenced by elevataed release from NAG test

2.3.2 Predicted source terms Post closure

Table 2-9 and Table 2-10 show the predicted source term water quality concentrations and mass loads for key elements released from the Hannukainen WRD following closure.

Post closure, installation of a basic cover system over the PAF cells is unlikely to have a large impact on metals release and acid generation from the PAF WRD as sulfide oxidation rates will not be reduced unless oxygen mass transfer can also be limited. The lower infiltration rates associated with the basic cover are predicted to result in a increased concentration but generally, mass release from the dumps stays much the same as the LOM options. Closure option 2 in which a qualified cover is engineered and oxygen transfer is limited will have a positive impact on both metals concentration and loading as oxygen ingress into the dump is reduced. Uranium release is not predicted to be reduced due to the readily soluble mineral form and oxidized nature of the uranium (VI) present within the mineral.

Based on a constant release of sulphate from the eastern PAF dumps leachates and taking in to account 20% fines and 20% preferential flow within the waste material, estimated time for depletion of leachable sulfide from the eastern PAF WRD can be estimated at between 140 to 220 years for seepage rates of 4.2 tonnes of sulphate per day from humidity cell data and 6.7 tonnes of sulphate leaching per day as determined from NAG test data. However, the actual release of sulphate from the PAF WRD is likely to decrease with time with a largely steady state release which will last beyond the times predicted above. The period is likely to be characterised by acidic pH seepage.

Table 2-9: Predicted Hannukainen WRD source term leachate concentrations post closure for annual average precipitation leaching scenarios using NAG test input data

				Source Term Concentrations (mg/L)											Source Term Loading (g/day)											Loadings to Rivers / Pits (g/day)								
					East_PAF					West_PAF							East_PAF				West_PAF					Hannukainen			Kuerjoki			Akasjoki		
Analyte	Units	AV Akasjoki FS09	IFC (2002)	East_NAF	Standard	Limestone	Qualified	East_OVB	West_NAF	Standard	Limestone	Qualified	West_OVB		East_NAF	Standard	Limestone	Qualified	East_OVB	West_NAF	Standard	Limestone	Qualified	West_OVB	Standard	Limestone	Qualified	Standard	Limestone	Qualified	Standard	Limestone	Qualified
														Seepage m3/day	162		202		416	202		41		151									
pH	s.u.	6.5	6	7.4	2.91	7.68	2.91	5.88	7.43	7.67	7.66	7.67	5.53	mol	0.00000644	0.248	0.00000425	0.248	0.00055	0.00000756	0.00000087	0.000000888	0.00000087	0.000447	0.249	0.000377	0.249	0.000206	0.000206	0.000206	0.000433	0.000433	0.000433
Alkalinity	mg/L			134	-2150	278	-2150	2.09	138	276	263	276	-6.14	g/day	21700	-434000	56000	-434000	869	27900	11200	10700	11200	-926	-373000	117000	-373000	326	326	326	-897	-897	-897
Cl	mg/L	150		138	221	206	221	61	89.6	182	173	182	185	g/day	22300	44600	41400	44600	25400	18100	7420	7050	7420	27800	109000	106000	109000	9520	9520	9520	27000	27000	27000
F	mg/L			2.22	128	4.58	128	5.72	2.25	4.53	4.21	4.53	18.1	g/day	359	25900	924	25900	2380	456	184	171	184	2730	28500	3480	28500	892	892	892	2640	2640	2640
P	mg/L	0.01926		0.00186	24.7	0.0066	24.7	4.3	0.00186	0.00646	0.00000683	0.00646	7.9	g/day	0.301	4990	1.33	4990	1790	0.375	0.263	0.000278	0.263	1190	6150	1160	6150	671	671	671	1150	1150	1150
SO4	mg/L	65		1050	23700	9760	23700	82.6	675	9550	8720	9550	258	g/day	170000	4790000	1970000	4790000	34400	137000	388000	355000	388000	38800	5510000	2650000	5510000	12900	12900	12900	37600	37600	37600
Ag	mg/L			0.038	0.0566	0.0336	0.0566	0.0286	0.0223	0.0292	0.0214	0.0292	0.0905	g/day	6.15	11.4	6.78	11.4	11.9	4.52	1.19	0.869	1.19	13.6	31.1	26.2	31.1	4.46	4.46	4.46	13.2	13.2	13.2
Al	mg/L	0.1		0.00282	910	0.00289	910	2.9	0.00278	0.00289	0.00272	0.00289	10.1	g/day	0.456	183000	0.583	183000	1210	0.562	0.117	0.111	0.117	1530	184000	803	184000	452	452	452	1480	1480	1480
As	mg/L	0.005	0.1	0.00000654	0.0658	0.0000016	0.0658	0.0238	0.00000496	0.0556	0.00000269	0.0556	0.0639	g/day	0.00106	13.3	0.000323	13.3	9.92	0.001	2.26	0.00011	2.26	9.63	22	6.5	22	3.72	3.72	3.72	9.33	9.33	9.33
B	mg/L			3.63	3.69	3.28	3.69	1.93	1.92	3.28	3.01	3.28	6.11	g/day	588	744	661	744	803	388	134	122	134	921	2380	2290	2380	301	301	301	892	892	892
Ba	mg/L	0.01792		0.00445	0.000567	0.000887	0.000567	0.028	0.00558	0.000913	0.00073	0.000913	0.0182	g/day	0.721	0.114	0.179	0.114	11.7	1.13	0.0372	0.0297	0.0372	2.75	9.37	9.43	9.37	4.37	4.37	4.37	2.66	2.66	2.66
NO3	mg/L	20		1.82	2.4	2.23	2.4	1.27	1.24	2.11	2	2.11	4	g/day	295	484	449	484	526	250	85.8	81.5	85.8	603	1460	1420	1460	197	197	197	584	584	584
Ca	mg/L	6.542		388	256	300	256	104	299	303	306	303	322	g/day	62800	51500	60400	51500	43300	60500	12300	12500	12300	48600	216000	225000	216000	16200	16200	16200	47000	47000	47000
Cd"	mg/L	0.00008	0.05	0.000998	0.0335	0.00175	0.0335	0.00572	0.000723	0.0263	0.000822	0.0263	0.0181	g/day	0.162	6.75	0.354	6.75	2.38	0.146	1.07	0.0334	1.07	2.73	9.7	2.27	9.7	0.891	0.891	0.891	2.64	2.64	2.64
Co	mg/L	0.004		0.0193	25.5	1.46	25.5	0.0571	0.0139	23.7	1.09	23.7	0.181	g/day	3.12	5150	294	5150	23.8	2.81	962	44.4	962	27.3	6130	360	6130	8.91	8.91	8.91	26.4	26.4	26.4
Cr*	mg/L	0.001	0.1	0.00000155	0.774	7.29E-08	0.774	0.901	0.00000107	0.546	2.54E-08	0.546	2.81	g/day	0.000251	156	0.0000147	156	375	0.000216	22.2	0.00000103	22.2	424	426	248	426	141	141	141	411	411	411
Cu	mg/L	0.005	0.3	0.000143	262	0.0118	262	0.0578	0.000159	0.0158	5.93E-07	0.0158	0.352	g/day	0.0231	52900	2.38	52900	24	0.0322	0.643	0.0000241	0.643	53.1	52900	19.1	52900	9.01	9.01	9.01	51.4	51.4	51.4
Fe	mg/L	0.975	2	0.11	2510	0.0665	2510	3.39	0.101	0.0674	0.0683	0.0674	8.3	g/day	17.8	506000	13.4	506000	1410	20.5	2.74	2.78	2.74	1250	507000	975	507000	528	528	528	1210	1210	1210
Hg"	mg/L	0.00005	0.002	0.00278	0.00576	0.000517	0.00576	0.00577	0.00163	0.00495	0.000321	0.00495	0.0183	g/day	0.449	1.16	0.104	1.16	2.4	0.33	0.201	0.0131	0.201	2.75	3.73	2.48	3.73	0.899	0.899	0.899	2.67	2.67	2.67
K	mg/L	0.888		539	2650	2410	2650	56.8	331	2500	2340	2500	179	g/day	87400	535000	485000	535000	23700	66900	102000	95300	102000	27000	806000	750000	806000	8860	8860	8860	26100	26100	26100
Li	mg/L			0.429	2.95	2.68	2.95	0.569	0.291	3.12	2.92	3.12	1.8	g/day	69.4	595	540	595	237	58.8	127	119	127	271	1010	943	1010	88.7	88.7	88.7	263	263	263
Mg	mg/L	1.808		92	1230	255	1230	57.5	62.7	259	140	259	181	g/day	14900	248000	51500	248000	23900	12700	10500	5710	10500	27300	302000	101000	302000	8960	8960	8960	26500	26500	26500
Mn	mg/L	0.7		0.162	62.2	4.19	62.2	0.229	0.129	4.25	0.359	4.25	0.725	g/day	26.3	12500	846	12500	95.3	26.1	173	14.6	173	109	12800	976	12800	35.7	35.7	35.7	106	106	106
Mo	mg/L	1		0.234	0.268	0.0626	0.268	0.0569	0.18	0.154	0.051	0.154	0.178	g/day	37.8	54	12.6	54	23.7	36.4	6.26	2.07	6.26	26.9	150	105	150	8.87	8.87	8.87	26	26	26
Na	mg/L	2.794		371	814	738	814	122	253	738	690	738	382	g/day	60200	164000	149000	164000	50700	51100	30000	28100	30000	57500	339000	322000	339000	19000	19000	19000	55700	55700	55700
Ni	mg/L	0.02	0.5	0.00883	30.3	0.303	30.3	0.0593	0.00725	22.9	0.178	22.9	0.188	g/day	1.43	6110	61.2	6110	24.7	1.47	934	7.23	934	28.4	7070	87.6	7070	9.25	9.25	9.25	27.5	27.5	27.5
Pb	mg/L	0.0072		0.00000538	0.651	0.00000911	0.651	0.00032	0.00000433	0.00997	6.93E-08	0.00997	0.000426	g/day	0.000871	131	0.00184	131	0.133	0.000877	0.406	0.00000282	0.406	0.0642	132	0.0887	132	0.0498	0.0498	0.0498	0.0622	0.0622	0.0622
Sb	mg/L	0.00002802		0.0412	0.0158	0.0534	0.0158	0.0286	0.028	0.0489	0.0465	0.0489	0.0903	g/day	6.67	3.19	10.8	3.19	11.9	5.65	1.99	1.89	1.99	13.6	25.4	32.8	25.4	4.46	4.46	4.46	13.2	13.2	13.2
Se	mg/L			0.00109	1.2	0.00281	1.2	0.0558	0.000902	0.929	0.00334	0.929	0.175	g/day	0.176	243	0.567	243	23.2	0.182	37.8	0.136	37.8	26.3	296	16.4	296	8.7	8.7	8.7	25.5	25.5	25.5
Si	mg/L	9.62		31.3	27.7	30	27.7	31.5	31.4	30	28.3	30	31.2	g/day	5060	5580	6040	5580	13100	6350	1220	1150	1220	4700	26500	26900	26500	4910	4910	4910	4550	4550	4550
Sn	mg/L			0.0411	0.0542	0.0509	0.0542	0.0286	0.0279	0.0476	0.0456	0.0476	0.0901	g/day	6.65	10.9	10.3	10.9	11.9	5.64	1.94	1.86	1.94	13.6	33	32.3	33	4.45	4.45	4.45	13.2	13.2	13.2
Sr	mg/L	0.03014		1.64	4.67	5.59	4.67	0.755	1.1	5.66	5.28	5.66	2.39	g/day	265	941	1130	941	314	223	230	215	230	360	1870	2040	1870	118	118	118	349	349	349
Tl	mg/L			0.0413	0.0766	0.07	0.0766	0.0286	0.028	0.0627	0.0589	0.0627	0.0905	g/day	6.69	15.5	14.1	15.5	11.9	5.67	2.55	2.4	2.55	13.6	38.2	36.7	38.2	4.46	4.46	4.46	13.2	13.2	13.2
U	mg/L	0.015		1.03	2.23	2.13	2.23	0.191	0.754	1.79	1.73	1.79	0.603	g/day	166	449	429	449	79.5	153	72.8	70.5	72.8	90.9	894	871	894	29.8	29.8	29.8	88	88	88
V	mg/L			0.00105	0.932	0.0000328	0.932	2.87	0.00075	0.551	0.0000411	0.551	9.08	g/day	0.17	188	0.00661	188	1200	0.152	22.4	0.00167	22.4	1370	1000	790	1000	448	448	448	1330	1330	1330
Zn	mg/L	0.03	0.5	0.00498	11.1	0.0752	11.1	0.505	0.00424	9.1	0.0415	9.1	1.61	g/day	0.806	2250	15.2	2250	210	0.858	370	1.69	370	243	2760	158	2760	78.8	78.8	78.8	235	235	235

Predicted to exceeeds action value determined for the Akasjoki River at FS09

Predicted to exceeed IFC (2007) environmental health and safety guidelines

" Concentrations of cadmium and mercury artefacts of detection limits available in testwork

* Seepage concentration from overburden influenced by elevataed release from NAG test

Table 2-10: Predicted Hannukainen WRD source term leachate concentrations post closure for annual average precipitation leaching scenarios using HCT test input data

				Source Term Concentrations (mg/L)							Source Term Loading (g/day)						Loadings to Rivers / Pits (g/day)				
Analyte	Units	AV Akasjoki FS09	IFC (2002)	East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB		East_NAF	East_PAF	East_OVB	West_NAF	West_PAF	West_OVB	Hannukainen	Kuervitikko	Kuerjoki	Akasjoki	Valkeajoki
										Seepage m3/day	162	202	416	202	41	151					
pH	s.u.	6.5	6	7.25	3.34	5.83	7.1	3.36	5.91	mol	0.0000092	0.0932	0.000614	0.0000159	0.0178	0.000187	0.111	-	0.00023	0.000182	-
Alkalinity	mg/L			84.3	-148	2.59	59.3	-123	2.51	g/day	13700	-29800	1080	12000	-5020	379	-8460	-	404	367	-
Cl	mg/L	150		41.4	40.8	19.8	27.8	34	54.5	g/day	6700	8230	8230	5630	1380	8210	27300	-	3090	7960	-
F	mg/L			2.78	21.9	1.6	3.01	18.7	5.06	g/day	451	4410	665	608	760	763	6660	-	249	740	-
P	mg/L	0.01926		0.0232	4.21	1.48	0.0614	4.16	3.71	g/day	3.76	849	615	12.4	169	559	1440	-	230	542	-
SO4	mg/L	65		296	4840	24.4	191	4430	72.7	g/day	47900	976000	10200	38500	180000	11000	1250000	-	3810	10600	-
Ag	mg/L			0.012	0.00964	0.008	0.00814	0.00842	0.0254	g/day	1.94	1.94	3.33	1.65	0.342	3.82	8.07	-	1.25	3.7	-
Al	mg/L	0.1		0.00503	148	0.793	0.0114	129	2.48	g/day	0.814	29800	330	2.31	5270	374	35300	-	124	363	-
As	mg/L	0.005	0.1	6.78E-06	0.0112	0.00711	0.0000135	0.00941	0.0208	g/day	0.0011	2.26	2.96	0.00274	0.383	3.14	4.59	-	1.11	3.04	-
B	mg/L			1.02	0.628	0.54	0.537	0.555	1.71	g/day	165	127	224	109	22.6	258	571	-	84.1	250	-
Ba	mg/L	0.01792		0.00793	0.00151	0.0546	0.0103	0.00157	0.0298	g/day	1.28	0.305	22.7	2.08	0.0639	4.5	18.1	-	8.51	4.36	-
NO3	mg/L	20		0.512	0.408	0.354	0.347	0.356	1.12	g/day	82.8	82.3	147	70.1	14.5	169	347	-	55.1	164	-
Ca	mg/L	6.542		129	384	29.2	94.5	392	92.3	g/day	20900	77400	12100	19100	15900	13900	141000	-	4550	13500	-
Cd"	mg/L	0.00008	0.05	0.000484	0.0057	0.0016	0.000441	0.00444	0.00506	g/day	0.0784	1.15	0.665	0.0892	0.181	0.763	1.94	-	0.249	0.739	-
Co	mg/L	0.004		0.00863	4.35	0.016	0.00702	4	0.0506	g/day	1.4	876	6.64	1.42	163	7.62	1050	-	2.49	7.39	-
Cr*	mg/L	0.001	0.1	7.3E-07	0.132	0.264	6.13E-07	0.0924	0.786	g/day	0.000118	26.5	110	0.000124	3.76	118	103	-	41.1	115	-
Cu	mg/L	0.005	0.3	0.0000963	44.6	0.0367	0.000109	38.1	0.0463	g/day	0.0156	8990	15.3	0.022	1550	6.98	10600	-	5.73	6.76	-
Fe	mg/L	0.975	2	0.147	427	3.6	0.199	356	3.17	g/day	23.7	86000	1500	40.3	14500	477	102000	-	561	462	-
Hg"	mg/L	0.00005	0.002	0.000636	0.000981	0.00161	0.000453	0.000837	0.00511	g/day	0.103	0.198	0.67	0.0916	0.0341	0.77	0.869	-	0.251	0.746	-
K	mg/L	0.888		151	448	16.3	92.7	421	50.3	g/day	24500	90300	6780	18700	17100	7580	155000	-	2540	7340	-
Li	mg/L			0.12	0.502	0.159	0.0813	0.528	0.503	g/day	19.4	101	66.1	16.4	21.5	75.9	202	-	24.8	73.5	-
Mg	mg/L	1.808		26.8	209	16.3	18.3	195	50.9	g/day	4340	42200	6770	3700	7950	7680	62700	-	2540	7440	-
Mn	mg/L	0.7		0.059	10.6	0.064	0.05	10.4	0.203	g/day	9.55	2130	26.6	10.1	422	30.6	2590	-	9.98	29.6	-
Mo	mg/L	1		0.0822	0.0456	0.0159	0.0628	0.026	0.0504	g/day	13.3	9.19	6.62	12.7	1.06	7.59	40.6	-	2.48	7.36	-
Na	mg/L	2.794		105	140	35.5	72.1	126	108	g/day	17100	28200	14800	14600	5140	16300	74800	-	5530	15800	-
Ni	mg/L	0.02	0.5	0.0056	5.16	0.0166	0.00591	3.88	0.0525	g/day	0.907	1040	6.91	1.19	158	7.92	1200	-	2.59	7.67	-
Pb	mg/L	0.0072		2.41E-06	0.111	0.00061	0.00000206	0.0757	0.00013	g/day	0.00039	22.3	0.254	0.000417	3.08	0.0195	25.6	-	0.0951	0.0189	-
Sb	mg/L	0.00002802		0.0116	0.00979	0.00799	0.00783	0.00827	0.0253	g/day	1.87	1.97	3.32	1.58	0.336	3.82	7.96	-	1.25	3.7	-
Se	mg/L			0.00102	0.205	0.0157	0.00134	0.157	0.0493	g/day	0.165	41.3	6.54	0.27	6.39	7.43	52.4	-	2.45	7.2	-
Si	mg/L	9.62		31.5	30.7	31.6	31.6	30.8	31.5	g/day	5110	6190	13100	6380	1250	4750	27300	-	4930	4600	-
Sn	mg/L			0.0115	0.00922	0.00799	0.00782	0.00805	0.0253	g/day	1.87	1.86	3.32	1.58	0.328	3.81	7.83	-	1.25	3.69	-
Sr	mg/L	0.03014		0.458	1.42	0.211	0.308	1.34	0.668	g/day	74.2	287	87.7	62.2	54.5	101	536	-	32.9	97.6	-
Tl	mg/L			0.0116	0.013	0.00799	0.00783	0.0106	0.0253	g/day	1.87	2.63	3.32	1.58	0.431	3.82	8.72	-	1.25	3.7	-
U	mg/L	0.015		0.291	0.379	0.0534	0.213	0.303	0.169	g/day	47.1	76.4	22.2	43	12.3	25.5	194	-	8.33	24.7	-
V	mg/L			0.00177	0.159	0.803	0.00411	0.0931	2.54	g/day	0.287	32	334	0.832	3.79	383	258	-	125	372	-
Zn	mg/L	0.03	0.5	0.00347	1.9	0.142	0.00436	1.54	0.447	g/day	0.561	382	59.1	0.881	62.6	67.4	485	-	22.1	65.3	-

Predicted to exceeeds action value determined for the Akasjoki River at FS09

Predicted to exceeed IFC (2007) environmental health and safety guidelines

" Concentrations of cadmium and mercury artefacts of detection limits available in testwork

* Seepage concentration from overburden influenced by elevataed release from NAG test

2.4 References

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3 PIT LAKE WATER QUALITY PREDICTION

3.1 Introduction

Pit lake water quality predictions have been made for the Hannukainen and Kuervittiko pits to simulate both the water quality at the time of the initial spill and the evolved water quality for steady state hydrogeochemical conditions within the pit lakes. Details of the pit lake water quality predictions are given in full in the Hannukainen DFS Waste Rock Geochemical Characterisation Report (SRK, 2013a) and are summarised in the following sections.

3.2 Pit Lake Water Balance

Pit lake water quality predictions were made based on pit lake water balances undertaken by Kaya Consulting (Kaya, 2012) and are summarised in Table 3-1 and Table 3-2 for Hannukainen pit and Kuervittiko pits respectively. The water balance predictions are based themselves on groundwater simulations undertaken by SRK (SRK, 2013b).

Table 3-1: Hannukainen pit lake re-filling water balance

Hannukainen pit									
Time (yr)	Flows (m^3/year)								
Time (yr)	Precipitation on Pit Lake	Precipitation on Pit Walls	Groundwater Inflow	Pumped Inflows	All Inflows	Evaporation	Overflow from Pit Lake	Load Mixing Volume	**Pit Volume**
1	122,340	867,500	2,091,300	9,978,300	13,190,000	72,754	0		13,117,246
2	241,550	760,210	1,727,500	8,678,300	11,538,000	135,580	0		24,519,666
3	342,010	669,800	1,522,100	8,678,300	11,343,000	189,910	0		35,672,756
4	420,040	599,570	1,366,100	8,678,300	11,195,000	231,140	0		46,636,616
5	481,950	543,850	1,235,400	8,678,300	11,070,000	265,180	0		57,441,436
6	546,490	485,770	1,123,100	8,678,300	10,964,000	300,020	0		68,105,416
7	617,340	422,010	1,025,700	8,678,300	10,874,000	339,260	0		78,640,156
8	680,710	364,970	938,750	8,678,300	10,793,000	372,490	0		89,060,666
9	729,470	321,080	858,970	8,678,300	10,718,000	399,220	0		99,379,446
10	782,980	272,930	785,590	8,678,300	10,650,000	428,530	0		109,600,916
11	826,990	233,320	716,630	8,678,300	10,586,000	451,750	0		119,735,166
12	863,730	200,250	651,100	8,678,300	10,524,000	471,480	0		129,787,686
13	890,580	176,090	588,850	8,678,300	10,464,000	485,790	0		139,765,896
14	906,060	162,160	525,850	8,678,300	10,403,000	493,070	2,197,700		147,478,126
Steady State	**906,060**	**162,160**	**496,950**	**0**	**1,695,700**	**493,070**	**1,202,600**	**1,202,630**	147,478,156
At Spill	**8,452,240**	**6,079,510**	**15,156,940**	**122,796,200**	**154,312,000**	**4,636,174**	**2,197,700**	**149,675,826**	
EOML	**0**	**989,840**	**2,091,300**	**0**	**3,081,140**	**0**	**0**	**3,081,140**	

Table 3-2: Kuervittiko pit lake re-filling water balance

Kuervittiko Pit									
Time (yr)	Flows (m^3/year)								
	Precipitation on Pit Lake	Precipitation on Pit Walls	Groundwater Inflow	Pumped Inflows	All Inflows	Evaporation	Overflow from Pit Lake	Load Mixing volume	**Pit Volume**
1	24,131	242,230	1,185,100	0	1,451,461	14,367	0		1,437,094
2	53,704	217,930	1,069,900	0	1,341,534	30,005	0		2,748,623
3	77,033	196,330	1,012,800	0	1,286,163	42,291	0		3,992,495
4	92,725	180,500	970,980	0	1,244,205	50,897	0		5,185,803
5	104,370	172,330	934,250	0	1,210,950	56,900	0		6,339,853
6	116,990	160,370	902,570	0	1,179,930	63,811	0		7,455,972
7	130,080	146,870	877,840	0	1,154,790	71,357	0		8,539,405
8	143,400	137,210	853,700	0	1,134,310	78,001	0		9,595,714
9	151,770	129,060	831,460	0	1,112,290	82,493	0		10,625,511
10	159,240	120,640	812,360	0	1,092,240	87,105	0		11,630,646
11	168,520	114,590	793,410	0	1,076,520	91,573	0		12,615,593
12	175,140	108,030	775,360	0	1,058,530	95,104	0		13,579,019
13	180,820	101,210	760,050	0	1,042,080	98,832	0		14,522,267
14	189,130	96,046	743,930	0	1,029,106	102,730	0		15,448,643
15	196,520	88,790	728,810	0	1,014,120	106,730	0		16,356,033
16	224,500	61,904	668,400	8,669,700	9,624,504	125,920	0		25,854,617
17	250,760	40,582	558,980	8,695,700	9,546,022	135,940	0		35,264,699
Steady State	**250,180**	**40,490**	**530,700**	**0**	**821,370**	**135,560**	**685,810**	**685,810**	**35,264,699**
At Spill	**2,438,833**	**2,314,622**	**14,479,900**	**17,365,400**	**36,598,755**	**1,334,056**	**0**	**35,264,699**	
EOML	**0**	**266,361**	**1,185,100**	**0**	**1,451,461**	**0**	**0**	**1,451,461**	

3.3 Numerical modelling

Numerical predictions of pit lake water quality have been made using a combination of mass balance and geochemical equilibration using the USG geochemical equilibrium code software PhreeqC (Parkhurst and Appelo, 2010). The pit lake model is coupled with the WRD model so that changes to the WRD model scenarios are automatically incorporated into the pit lake model predictions.

The following input and output parameters were considered in the pit lake water quality prediction. Details of the input solution chemistry is given in SRK, 2013a.

- Inflow of seepage from the WRD in proportion to the area of the WRD within the pit catchments.
- Inflow of baseline groundwater quality into the pit lakes
- Direct precipitation onto the pit lakes
- Evaporation from the pit lake surface
- Runoff from exposed high wall

Water quality predictions have been made for the scenarios given in Table 3-3.

Table 3-3: Pit lake water quality prediction scenarios

Mine Phase	Model undertaken
First Spill	Average condition using NAG test data
	Average conditions using HCT test data
	Limestone neutralised PAF dump using NAG test data
	Average conditions using NAG test data and lime (CaO) addition to lakes to attain a pH of 7
Steady state	Average conditions using NAG test data
	Average conditions using HCT test data
	Limestone neutralised PAF dump using NAG test data

3.3.1 WRD model input solution options

As discussed in more detail in Section 2.1.3 and SRK, 2013a, humidity cell testing undertaken on the Hannukainen waste rock materials is experiencing a significant lag time in which acid generation has not developed within cells. Therefore, In order to develop a water quality prediction for the WRD which is not overly optimistic, it was necessary to supplement the HCT data with data from a more aggressive leach test which use hydrogen peroxide (H_2O_2) as the oxidant. This test is commonly referred to as a Net Acid Generation (NAG) test, as it is designed to fully oxidise all sulfide minerals present in the sample and release all available acidity. In the process of this, all neutralisation potential within the sample is also consumed and the solution attains a pH representative of the potential final solution pH for the given material type. In the current model scenarios it has been found that a factor of 1000 is suitable for correction of NAG data to field conditions (assuming that HCT data is representative of field conditions.

3.4 Assumptions and limitations

The following assumptions and limitations apply to the pit lake models:

- The geochemical model framework is defined by the water inputs and losses to/from the system.
- The models are defined by the elements, mineral phases, gas phases, and chemical species specified in the model input files;
- The models are limited to inorganic reactions and do not take into account the complexities associated with biologically mediated reactions;

- The models are limited to thermodynamic equilibrium reactions and do not simulate the effects of reaction kinetics and rates;
- The models rely on an external database of thermodynamic constants for mineral phase precipitates and sorbed surface complexes. These thermodynamic constants are valid at 25^{o}C and 1 atmosphere of pressure;
- The models do not consider the effects associated with the formation and precipitation of mineral species other than those specified. Due to kinetic constraints, a portion of the potentially oversaturated mineral phases will not actually precipitate. A select suite of minerals is therefore specified that are allowed to precipitate, based on relevance for the environment in question, site-specific knowledge, experience in evaluating kinetic constraints and relevance of key phases for given styles of mineralization (Eary, 1999).
- Biological processes are not taken into account and therefore mineral precipitates are the only sink for major nutrients such as potassium, phosphate and nitrate.
- The models assume that solution input chemistry can be simulated using laboratory leachate chemistries from static NAG tests which have been scaled to weekly release from a standard humidity cell test using a value of 1000.
- The model assumes that the proportion of ferrihydrite available to partake in surface adsorption reactions can be calculated from the total mass of sulphate predicted to be released from the PAF and NAF WRDs. This is assuming that all sulphate is a product of pyrite oxidation and therefore the shares the mole ratio $2SO_4$:$1Fe(OH)_3$. It is also assumed that this will form a constantly replenished source of sorbent.
- Pit lake predictions are based on a mass balance steady state approach and therefore do not take into account pit lake evolution with time
- Stratification based on density is not considered in the model and solutes are presumed to be fully mixed.
- Oxygen transfer into the lake is assumed to be limited based on observations made In the current pit and sulfide oxidation in submerged highwall is taken to be minimal below a depth of approximately 15m. Therefore solute loading from high wall oxidation is not considered in the steady state model.

3.5 Water Quality Predictions

The results of pit lake water quality predictions at the initial first spill are shown for the following scenarios in Table 3-4 to Table 3-7:

- Predicted first spill water quality and loadings using HCT test data for PAF dump seepage calculations. Table 3-4
- Predicted first spill water quality and loadings using NAG test data for PAF dump seepage calculations. Table 3-5
- Predicted first spill water quality and loadings using NAG test data for PAF dump seepage calculations and with the addition of lime (CaO) to the lakes in order to neutralise the initial flush. Table 3-6

- Predicted first spill water quality and loadings using NAG test data for PAF dump seepage calculations with the addition of limestone ($CaCO_3$) ameliorant to the PAF dump to neutralise seepage. Table 3-7

First spill water quality is strongly influenced by the rapid filling of the pit lakes with river water from the Akasjoki. The greatest influence from the Akasjoki river water is seen in the Hannukainen pit which will receive water from the Akasjoki River for 10 years of filling. The Kuervittiko pit receives river water for only two years and therefore has much greater influence from both high wall run-off and seepage from the east PAF WRD. The increased seepage from this dump results in a mildly acidic pH and elevated concentrations of metals such as Co, Cu, Ni, Cr, and Zn which will be discharged into the Kuerjoki river at first spill.

Despite the rapid filling, predictions made using NAG test data for both the Hannukainen and Kuervittiko pit lakes show water quality to be mildly acidic. This is largely due to inflow of PAF dump seepage into the pit lakes and through oxidation of exposed high wall prior to submergence.

Improvements to the pit lake water quality have been demonstrated conceptually through addition of limestone to the PAF WRD and also through the liming (CaO) addition to the pit lakes themselves. Both of these methods significantly improve the discharge water quality from the pit lakes during initial discharge conditions.

Table 3-4: Predicted first spill water quality and loading from pits using HCT test input data

				Concentration in pit Lakes			Pit lake loading to river		Total loading to river including direct load from WRD		
				Time of First Spill			First Spill		First Spill		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen First Spill	Kuervittiko First Spill		Hannukainen First Spill	Kuervittiko First Spill	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	6,021	1,879			
pH	s.u.	6.5	6	6.08	5.66	mol/day	0.00497	0.00415	0.00497	0.00422	-
Alkalinity	mg/L			5.15	1.9	g/day	31000	3570	31000	3690	-
Cl	mg/L	150		2.27	3.93	g/day	13600	7380	13600	10400	-
F	mg/L			0.0481	0.102	g/day	289	192	289	474	-
PO4	mg/L	0.01926		0.0533	0.116	g/day	321	218	321	461	-
SO4	mg/L	65		31	30.8	g/day	187000	57800	187000	61800	-
Ag	mg/L			0.000619	0.00198	g/day	3.73	3.72	3.73	5.13	-
Al	mg/L	0.1		0.0109	0.074	g/day	65.8	139	65.8	282	-
As	mg/L	0.005	0.1	0.000612	0.00106	g/day	3.69	1.99	3.69	3.22	-
B	mg/L			0.0133	0.0305	g/day	80	57.4	80	153	-
Ba	mg/L	0.01792		0.0129	0.0119	g/day	77.7	22.3	77.7	23.9	-
NO3	mg/L	20		0.487	0.207	g/day	2930	389	2930	451	-
Bi	mg/L			0	0	g/day	-	-	-	-	-
Ca	mg/L	6.542		15.7	25.4	g/day	94500	47700	94500	52900	-
Cd	mg/L	0.00008	0.05	0.000124	0.000178	g/day	0.748	0.335	0.748	0.617	-
Co	mg/L	0.004		0.00129	0.00367	g/day	7.76	6.89	7.76	9.71	-
Cr	mg/L	0.001	0.1	0.00404	0.00792	g/day	24.3	14.9	24.3	61.1	-
Cu	mg/L	0.005	0.3	0.00213	0.00297	g/day	12.8	5.59	12.8	9.18	-
Fe	mg/L	0.975	2	0.295	0.364	g/day	1770	684	1770	875	-
Hg	mg/L	0.00005	0.002	0.0000438	0.000084	g/day	0.264	0.158	0.264	0.442	-
K	mg/L	0.888		5.47	16.4	g/day	32900	30800	32900	33600	-
Li	mg/L			0.025	0.0722	g/day	150	136	150	164	-
Mg	mg/L	1.808		2.71	4.29	g/day	16300	8050	16300	10900	-
Mn	mg/L	0.7		0.0974	0.256	g/day	587	482	587	493	-
Mo	mg/L	1		0.00287	0.0079	g/day	17.3	14.8	17.3	17.6	-
Na	mg/L	2.794		5.46	10.7	g/day	32900	20100	32900	26100	-
Ni	mg/L	0.02	0.5	0.00353	0.0111	g/day	21.3	20.9	21.3	23.8	-
Pb	mg/L	0.0072		0.000417	0.000249	g/day	2.51	0.468	2.51	0.477	-
Sb	mg/L	0.00002802		0.00311	0.012	g/day	18.7	22.5	18.7	23.9	-
Se	mg/L			0.000541	0.00179	g/day	3.26	3.37	3.26	6.14	-
Si	mg/L	9.62		2.39	2.93	g/day	14400	5510	14400	7270	-
Sn	mg/L			0.000112	0.000206	g/day	0.676	0.387	0.676	1.8	-
Sr	mg/L	0.03014		0.0679	0.114	g/day	409	213	409	251	-
Ti	mg/L			0	0	g/day	-	-	-	-	-
Tl	mg/L			0.00626	0.0189	g/day	37.7	35.5	37.7	36.9	-
U	mg/L	0.015		0.00594	0.00646	g/day	35.7	12.1	35.7	21.6	-
V	mg/L			0.0125	0.0301	g/day	75	56.5	75	198	-
W	mg/L			0	0	g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.00873	0.0158	g/day	52.6	29.6	52.6	54.6	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

Table 3-5: Predicted first spill loading from pits using NAG test input data

				Concentration in pit Lakes			Pit lake loading to river		Total loading to river including direct load from WRD		
				Time of First Spill			First Spill		First Spill		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen First Spill	Kuervittiko First Spill		Hannukainen First Spill	Kuervittiko First Spill	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	6,021	1,879			
pH	s.u.	6.5	6	4.57	3.86	mol/day	0.162	0.257	0.162	0.257	-
Alkalinity	mg/L			-1.59	-9.34	g/day	-9570	-17600	-9570	-17400	-
Cl	mg/L	150		1.74	2.37	g/day	10400	4440	10400	7480	-
F	mg/L			0.123	0.409	g/day	738	769	738	1050	-
PO4	mg/L	0.01926		0.0531	0.118	g/day	320	222	320	429	-
SO4	mg/L	65		41.6	76.6	g/day	251000	144000	251000	148000	-
Ag	mg/L			0.000176	0.00039	g/day	1.06	0.734	1.06	2.15	-
Al	mg/L	0.1		0.206	0.61	g/day	1240	1150	1240	1290	-
As	mg/L	0.005	0.1	0.00051	0.000622	g/day	3.07	1.17	3.07	2.33	-
B	mg/L			0.0121	0.0273	g/day	72.9	51.4	72.9	147	-
Ba	mg/L	0.01792		0.012	0.00973	g/day	72	18.3	72	19.9	-
NO3	mg/L	20		0.488	0.199	g/day	2940	374	2940	436	-
Bi	mg/L			0	0	g/day	-	-	-	-	-
Ca	mg/L	6.542		11.4	12.1	g/day	68700	22800	68700	27900	-
Cd	mg/L	0.00008	0.05	0.000114	0.000142	g/day	0.688	0.267	0.688	0.549	-
Co	mg/L	0.004		0.0187	0.071	g/day	112	133	112	136	-
Cr	mg/L	0.001	0.1	0.0035	0.00603	g/day	21.1	11.3	21.1	55.1	-
Cu	mg/L	0.005	0.3	0.162	0.653	g/day	975	1230	975	1230	-
Fe	mg/L	0.975	2	2.98	11.3	g/day	18000	21300	18000	21400	-
Hg	mg/L	0.00005	0.002	0.0000332	0.0000572	g/day	0.2	0.107	0.2	0.392	-
K	mg/L	0.888		3.21	8.17	g/day	19300	15300	19300	18100	-
Li	mg/L			0.00426	0.0117	g/day	25.7	22	25.7	50.1	-
Mg	mg/L	1.808		2.83	5.24	g/day	17000	9840	17000	12700	-
Mn	mg/L	0.7		0.0826	0.198	g/day	497	372	497	383	-
Mo	mg/L	1		0.00139	0.00237	g/day	8.36	4.45	8.36	7.25	-
Na	mg/L	2.794		4.72	8.74	g/day	28400	16400	28400	22400	-
Ni	mg/L	0.02	0.5	0.0213	0.0837	g/day	128	157	128	160	-
Pb	mg/L	0.0072		0.000549	0.000804	g/day	3.31	1.51	3.31	1.52	-
Sb	mg/L	0.00002802		0.000182	0.000394	g/day	1.1	0.741	1.1	2.15	-
Se	mg/L			0.000761	0.0027	g/day	4.58	5.07	4.58	7.81	-
Si	mg/L	9.62		2.91	4.06	g/day	17500	7620	17500	9370	-
Sn	mg/L			0.000172	0.00038	g/day	1.04	0.714	1.04	2.12	-
Sr	mg/L	0.03014		0.0493	0.0478	g/day	297	89.8	297	127	-
Ti	mg/L			0	0	g/day	-	-	-	-	-
Tl	mg/L			0.000186	0.00044	g/day	1.12	0.827	1.12	2.24	-
U	mg/L	0.015		0.00496	0.00906	g/day	29.8	17	29.8	26.4	-
V	mg/L			0.00947	0.0186	g/day	57	35	57	177	-
W	mg/L			0	0	g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.0136	0.0359	g/day	81.9	67.5	81.9	92.4	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

Table 3-6: Predicted first spill concentrations and loading from pits using NAG test input data with addition of lime to the pit lakes to neutralise acidity

				Concentration in pit Lakes			Pit lake loading to river		Total loading to river including direct load from WRD		
				Time of First Spill			First Spill		First Spill		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen First Spill	Kuervittiko First Spill		Hannukainen First Spill	Kuervittiko First Spill	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	6,021	1,879			
pH	s.u.	6.5	6	7	7	mol/day	0.000602	0.000188	0.000602	0.000263	-
Alkalinity	mg/L			43.2	43.7	g/day	260000	82100	260000	82300	-
Cl	mg/L	150		1.74	2.36	g/day	10400	4440	10400	7480	-
F	mg/L			0.123	0.409	g/day	738	769	738	1050	-
PO4	mg/L	0.01926		0.00581	0.00282	g/day	35	5.29	35	249	-
SO4	mg/L	65		41.6	76.3	g/day	250000	143000	250000	147000	-
Ag	mg/L			0.000176	0.00039	g/day	1.06	0.732	1.06	2.14	-
Al	mg/L	0.1		0.00253	0.0027	g/day	15.3	5.08	15.3	148	-
As	mg/L	0.005	0.1	0.00000163	0.000000257	g/day	0.00982	0.000483	0.00982	1.23	-
B	mg/L			0.0121	0.0273	g/day	72.9	51.4	72.9	147	-
Ba	mg/L	0.01792		0.012	0.00973	g/day	72	18.3	72	19.9	-
NO3	mg/L	20		0.488	0.199	g/day	2940	374	2940	436	-
Bi	mg/L					g/day	-	-	-	-	-
Ca	mg/L	6.542		28	36.7	g/day	169000	69000	169000	74100	-
Cd	mg/L	0.00008	0.05	0.000113	0.000136	g/day	0.679	0.256	0.679	0.538	-
Co	mg/L	0.004		0.0185	0.0696	g/day	112	131	112	134	-
Cr	mg/L	0.001	0.1	0.0000012	0.000000566	g/day	0.00725	0.00106	0.00725	46.2	-
Cu	mg/L	0.005	0.3	0.0127	0.0165	g/day	76.5	30.9	76.5	34.5	-
Fe	mg/L	0.975	2	0.221	0.223	g/day	1330	420	1330	610	-
Hg	mg/L	0.00005	0.002	0.0000291	0.0000397	g/day	0.175	0.0746	0.175	0.359	-
K	mg/L	0.888		3.21	8.17	g/day	19300	15300	19300	18100	-
Li	mg/L			0.00426	0.0117	g/day	25.7	22	25.7	50.1	-
Mg	mg/L	1.808		2.83	5.23	g/day	17000	9830	17000	12700	-
Mn	mg/L	0.7		0.0824	0.196	g/day	496	369	496	380	-
Mo	mg/L	1		0.00135	0.002	g/day	8.11	3.76	8.11	6.57	-
Na	mg/L	2.794		4.72	8.73	g/day	28400	16400	28400	22400	-
Ni	mg/L	0.02	0.5	0.0209	0.0783	g/day	126	147	126	150	-
Pb	mg/L	0.0072		0.0000101	0.00000425	g/day	0.0606	0.00799	0.0606	0.0173	-
Sb	mg/L	0.00002802		0.000182	0.000394	g/day	1.1	0.741	1.1	2.15	-
Se	mg/L			0.000372	0.000375	g/day	2.24	0.704	2.24	3.47	-
Si	mg/L	9.62		2.91	4.05	g/day	17500	7620	17500	9370	-
Sn	mg/L			0.000172	0.00038	g/day	1.04	0.713	1.04	2.12	-
Sr	mg/L	0.03014		0.0493	0.0478	g/day	297	89.8	297	127	-
Ti	mg/L					g/day	-	-	-	-	-
Tl	mg/L			0.000186	0.00044	g/day	1.12	0.827	1.12	2.24	-
U	mg/L	0.015		0.00496	0.00905	g/day	29.8	17	29.8	26.4	-
V	mg/L			0.000313	0.0000799	g/day	1.88	0.15	1.88	142	-
W	mg/L					g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.0126	0.0288	g/day	76.1	54.2	76.1	79.1	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

Table 3-7: Predicted first spill concentrations and loading from pits using NAG test input data with addition of limestone to the PAF waste rock dumps

				Concentration in pit Lakes			Pit lake loading to river		Total loading to river including direct load from WRD		
				Time of First Spill			First Spill		First Spill		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen First Spill	Kuervittiko First Spill		Hannukainen First Spill	Kuervittiko First Spill	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	6,021	1,879			
pH	s.u.	6.5	6	5.18	4.44	mol/day	0.0394	0.0679	0.0394	0.068	-
Alkalinity	mg/L			0.344	-2.27	g/day	2070	-4260	2070	-4120	-
Cl	mg/L	150		1.73	2.36	g/day	10400	4440	10400	7470	-
F	mg/L			0.0525	0.116	g/day	316	218	316	500	-
PO4	mg/L	0.01926		0.052	0.114	g/day	313	213	313	420	-
SO4	mg/L	65		37.1	57.3	g/day	223000	108000	223000	112000	-
Ag	mg/L			0.000169	0.000361	g/day	1.02	0.679	1.02	2.09	-
Al	mg/L	0.1		0.115	0.23	g/day	695	432	695	571	-
As	mg/L	0.005	0.1	0.000508	0.000616	g/day	3.06	1.16	3.06	2.32	-
B	mg/L			0.0121	0.0272	g/day	72.7	51.1	72.7	146	-
Ba	mg/L	0.01792		0.012	0.00973	g/day	72	18.3	72	20	-
NO3	mg/L	20		0.488	0.199	g/day	2940	373	2940	436	-
Bi	mg/L					g/day	-	-	-	-	-
Ca	mg/L	6.542		11.6	12.6	g/day	69600	23700	69600	28800	-
Cd	mg/L	0.00008	0.05	0.000095	0.0000604	g/day	0.572	0.114	0.572	0.395	-
Co	mg/L	0.004		0.00453	0.0132	g/day	27.3	24.8	27.3	27.6	-
Cr	mg/L	0.001	0.1	0.00347	0.00587	g/day	20.9	11	20.9	54.8	-
Cu	mg/L	0.005	0.3	0.0116	0.0212	g/day	70	39.8	70	42.4	-
Fe	mg/L	0.975	2	0.489	0.727	g/day	2950	1370	2950	1540	-
Hg	mg/L	0.00005	0.002	0.0000298	0.0000429	g/day	0.179	0.0805	0.179	0.365	-
K	mg/L	0.888		3.43	9.08	g/day	20700	17100	20700	19900	-
Li	mg/L			0.00425	0.0117	g/day	25.6	21.9	25.6	50	-
Mg	mg/L	1.808		2.7	4.7	g/day	16300	8820	16300	11700	-
Mn	mg/L	0.7		0.0503	0.0755	g/day	303	142	303	153	-
Mo	mg/L	1		0.00137	0.00228	g/day	8.27	4.28	8.27	7.09	-
Na	mg/L	2.794		4.71	8.72	g/day	28400	16400	28400	22400	-
Ni	mg/L	0.02	0.5	0.00349	0.0071	g/day	21	13.3	21	16.3	-
Pb	mg/L	0.0072		0.00042	0.0002	g/day	2.53	0.375	2.53	0.382	-
Sb	mg/L	0.00002802		0.000182	0.000393	g/day	1.1	0.739	1.1	2.15	-
Se	mg/L			0.000262	0.000499	g/day	1.58	0.937	1.58	3.68	-
Si	mg/L	9.62		2.92	4.06	g/day	17600	7620	17600	9380	-
Sn	mg/L			0.000172	0.000379	g/day	1.03	0.712	1.03	2.12	-
Sr	mg/L	0.03014		0.0493	0.0476	g/day	297	89.4	297	127	-
Ti	mg/L					g/day	-	-	-	-	-
Tl	mg/L			0.000186	0.000439	g/day	1.12	0.825	1.12	2.24	-
U	mg/L	0.015		0.00495	0.00901	g/day	29.8	16.9	29.8	26.4	-
V	mg/L			0.00893	0.0162	g/day	53.8	30.5	53.8	172	-
W	mg/L					g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.00678	0.00718	g/day	40.8	13.5	40.8	38.4	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

The results of pit lake water quality predictions for steady state conditions are shown for the following scenarios in Table 3-9 to Table 3-11.

- Predicted steady state water quality and loadings using HCT test data for PAF dump seepage calculations. Table 3-9
- Predicted steady state water quality and loadings using NAG test data for PAF dump seepage calculations. Table 3-10
- Predicted steady state water quality and loadings using NAG test data for PAF dump seepage calculations with the addition of limestone ($CaCO_3$) ameliorant to the PAF dump to neutralise seepage. Table 3-11

The initial spill water quality of the Kuervittiko pit lake is strongly influenced by seepage from the eastern PAF dump that is partially within the EOML cone of depression of the pit . Following groundwater recovery, no seepage from the eastern PAF dump is predicted to flow towards the Kuervittiko pit lake and therefore a significant improvement in water quality is predicted under steady state conditions. Assessment of the steady state Kuervittiko water quality against the Action Values determined for the Akasjoki River at FS09 has shown that exceedences are restricted to major ions only and that no exceedence of the IFC effluent guidelines occurs.

Water quality within the Hannukainen pit lake is predicted to decrease in quality under steady state conditions. The main cause of the decreasing water quality within the Hannukianen pit lake is that all of the seepage from the east and west PAF WRD is shown to discharge into the Hannukainen pit lake. Predictions made using HCT data for the PAF materials shows that SO_4, Al, Cd, Co, Cr, Cu, Hg, Mn, Ni, Sb, U and Zn are likely to exceed Akasjoki River action values whilst Hg is also predicted to exceed IFC guidelines with pH of around 6. Analysis of the predicted Hannukainen pit lake water quality calculated using NAG test data predicts an acidic pH (pH 3.5) and elevated concentrations of SO_4, Al, Cd, Co, Cr, Cu, Hg, Mn, Ni, Sb, U and Z above the Akasjoki river Action Values. In addition, exceedences of Cr, Cu, Fe, Ni and Zn are predicted to also exceed the IFC water quality guidelines. Release of Hg is not predicted to be problematic when using NAG test data.

As described previously, the use of NAG test data is likely to slightly overestimate solute release from the WRD whilst use of the immature HCT data is likely to underestimate solute release. Therefore it is most likely that predicted concentrations within the Hannukainen pit lake will likely be between the HCT and NAG predicted concentrations.

Due to the high dependence on seepage from the Hannukianen PAF WRD on the Hannukainen pit water quality, predicted water quality with limestone addition to the PAF dumps shows a marked improvement in overall pit lake water quality. This is demonstrated in Figure 3-1 which shows a significant reduction in concentrations of elements: Pb, Co, Cu, Zn, Al, Mn, and Fe as well in a significant improvement to the leach pH. Table 3-8 shows that the reduction in most metals will be between 40 and 100% of the NAG scenario without limestone amendment.

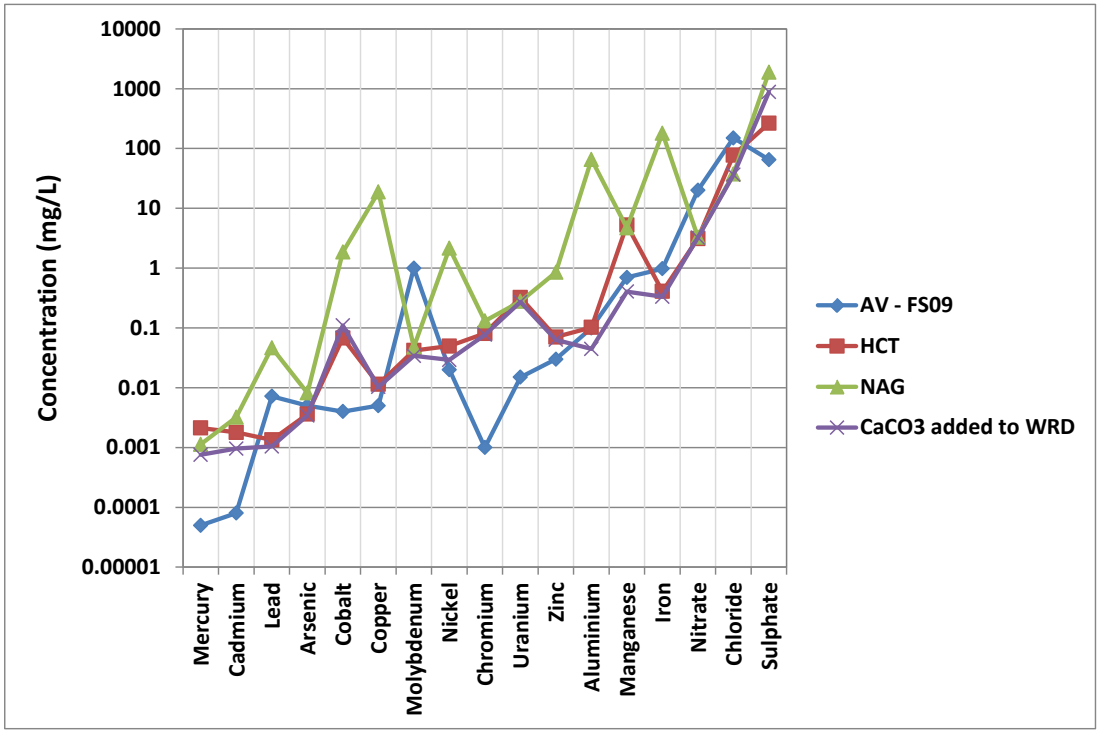


Figure 3-1: Comparison between steady state Hannukainen pit lake water quality for alternative scenarios

Table 3-8: Reduction in steady state load of key parameters to the Akasjoki river from the Hannukainen Pit lake through limestone amendment of the PAF dump

Analyte	Load to Akasjoki (g/day)		% Reduction
	NAG	NAG CaCO3	
SO4	6,200,000	2,890,000	53%
Al	216,000	147	100%
Co	6,130	363	94%
Cr	430	253	41%
Cu	61,900	34	100%
Fe	592,000	1,090	100%
Hg	4	2	34%
Mn	15,500	1,340	91%
Mo	158	112	29%
Ni	7,080	96	99%
Pb	154	3	98%
U	917	892	3%
Zn	2,800	208	93%

Table 3-9: Predicted steady state water quality and loading from pits using HCT test input data

							Pit lake loading to river		Total loading to river including direct load from WRD		
				Steady State			Steady State		Steady State		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen Steady State	Kuervittiko Steady state		Hannukainen Steady State Spill	Kuervittiko Steady State Spill	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	3,295	1,879			
pH	s.u.	6.5	6	6.06	6.27	mol/day	0.00285	0.000999	0.00285	0.00149	-
Alkalinity	mg/L			6	7.86	g/day	19800	14800	19800	13800	-
Cl	mg/L	150		77.5	2.06	g/day	255000	3870	255000	30900	-
F	mg/L			0.779	0	g/day	2570	-	2570	2640	-
PO4	mg/L	0.01926		0.391	0.0827	g/day	1290	155	1290	1720	-
SO4	mg/L	65		264	3.71	g/day	871000	6960	871000	44700	-
Ag	mg/L			0.0516	0	g/day	170	-	170	13.2	-
Al	mg/L	0.1		0.102	0.00598	g/day	337	11.2	337	1530	-
As	mg/L	0.005	0.1	0.00361	0.000737	g/day	11.9	1.38	11.9	12	-
B	mg/L			0.803	0	g/day	2650	-	2650	893	-
Ba	mg/L	0.01792		0.0167	0.00582	g/day	55.1	10.9	55.1	13.6	-
NO3	mg/L	20		3.12	0.0911	g/day	10300	171	10300	756	-
Bi	mg/L			0	0	g/day	-	-	-	-	-
Ca	mg/L	6.542		396	3.93	g/day	1310000	7390	1310000	54500	-
Cd	mg/L	0.00008	0.05	0.00179	0.0000156	g/day	5.89	0.0293	5.89	2.67	-
Co	mg/L	0.004		0.068	0.000207	g/day	224	0.389	224	26.8	-
Cr	mg/L	0.001	0.1	0.0808	0.000455	g/day	266	0.855	266	435	-
Cu	mg/L	0.005	0.3	0.0114	0.000897	g/day	37.6	1.69	37.6	71.6	-
Fe	mg/L	0.975	2	0.409	0.23	g/day	1350	433	1350	1830	-
Hg	mg/L	0.00005	0.002	0.00212	0	g/day	6.97	-	6.97	2.67	-
K	mg/L	0.888		435	0.973	g/day	1430000	1830	1430000	28000	-
Li	mg/L			2.2	0	g/day	7230	-	7230	263	-
Mg	mg/L	1.808		84.6	1.56	g/day	279000	2930	279000	29400	-
Mn	mg/L	0.7		5.27	0.0397	g/day	17400	74.7	17400	181	-
Mo	mg/L	1		0.0419	0.00175	g/day	138	3.29	138	29.5	-
Na	mg/L	2.794		175	6.86	g/day	577000	12900	577000	68700	-
Ni	mg/L	0.02	0.5	0.0497	0.000764	g/day	164	1.44	164	29	-
Pb	mg/L	0.0072		0.00134	0.00013	g/day	4.43	0.244	4.43	0.319	-
Sb	mg/L	0.00002802		0.243	0	g/day	800	-	800	13.2	-
Se	mg/L			0.00483	0	g/day	15.9	-	15.9	25.9	-
Si	mg/L	9.62		5.46	2.06	g/day	18000	3880	18000	8430	-
Sn	mg/L			0.00435	0	g/day	14.3	-	14.3	13.2	-
Sr	mg/L	0.03014		2.74	0.0191	g/day	9030	35.8	9030	385	-
Ti	mg/L			0	0	g/day	-	-	-	-	-
Tl	mg/L			0.577	0	g/day	1900	-	1900	13.2	-
U	mg/L	0.015		0.321	0.000148	g/day	1060	0.279	1060	88.6	-
V	mg/L			0.24	0	g/day	790	-	790	1320	-
W	mg/L			0	0	g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.0703	0.00345	g/day	232	6.48	232	241	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

Table 3-10: Predicted steady state water quality and loading from pits using NAG test input data

				Steady State			Steady State		Steady State		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen Steady State	Kuervittiko Steady state		Hannukainen Steady State	Kuervittiko Steady state	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	3,295	1,879			
pH	s.u.	6.5	6	3.47	6.27	mol/day (H+)	1.12	0.00101	1.12	0.00144	-
Alkalinity	mg/L			-54.7	7.87	g/day	-180000	14800	-180000	13900	-
Cl	mg/L	150		37.3	2.06	g/day	123000	3880	123000	30800	-
F	mg/L			9.94	0	g/day	32700	-	32700	2640	-
PO4	mg/L	0.01926		2.28	0.0828	g/day	7530	156	7530	1310	-
SO4	mg/L	65		1880	3.71	g/day	6200000	6960	6200000	44500	-
Ag	mg/L			0.00972	0	g/day	32	-	32	13.2	-
Al	mg/L	0.1		65.6	0.00597	g/day	216000	11.2	216000	1490	-
As	mg/L	0.005	0.1	0.00818	0.000737	g/day	26.9	1.39	26.9	10.7	-
B	mg/L			0.724	0	g/day	2380	-	2380	893	-
Ba	mg/L	0.01792		0.00235	0.00582	g/day	7.74	10.9	7.74	13.6	-
NO3	mg/L	20		3.29	0.0911	g/day	10800	171	10800	755	-
Bi	mg/L			0	0	g/day	-	-	-	-	-
Ca	mg/L	6.542		88.6	3.93	g/day	292000	7380	292000	54400	-
Cd	mg/L	0.00008	0.05	0.00321	0.0000156	g/day	10.6	0.0294	10.6	2.67	-
Co	mg/L	0.004		1.86	0.000207	g/day	6130	0.388	6130	26.8	-
Cr	mg/L	0.001	0.1	0.131	0.000455	g/day	430	0.855	430	412	-
Cu	mg/L	0.005	0.3	18.8	0.000895	g/day	61900	1.68	61900	53.1	-
Fe	mg/L	0.975	2	180	0.23	g/day	592000	433	592000	1650	-
Hg	mg/L	0.00005	0.002	0.00113	0	g/day	3.73	-	3.73	2.67	-
K	mg/L	0.888		247	0.974	g/day	813000	1830	813000	28000	-
Li	mg/L			0.304	0	g/day	1000	-	1000	263	-
Mg	mg/L	1.808		106	1.56	g/day	350000	2930	350000	29400	-
Mn	mg/L	0.7		4.71	0.0397	g/day	15500	74.6	15500	181	-
Mo	mg/L	1		0.0479	0.00175	g/day	158	3.3	158	29.4	-
Na	mg/L	2.794		112	6.85	g/day	371000	12900	371000	68600	-
Ni	mg/L	0.02	0.5	2.15	0.000763	g/day	7080	1.43	7080	29	-
Pb	mg/L	0.0072		0.0466	0.00013	g/day	154	0.244	154	0.306	-
Sb	mg/L	0.00002802		0.00733	0	g/day	24.2	-	24.2	13.2	-
Se	mg/L			0.0892	0	g/day	294	-	294	25.5	-
Si	mg/L	9.62		5.45	2.06	g/day	18000	3880	18000	8430	-
Sn	mg/L			0.01	0	g/day	33	-	33	13.2	-
Sr	mg/L	0.03014		0.661	0.0191	g/day	2180	35.9	2180	385	-
Ti	mg/L			0	0	g/day	-	-	-	-	-
Tl	mg/L			0.0116	0	g/day	38.2	-	38.2	13.2	-
U	mg/L	0.015		0.278	0.000148	g/day	917	0.279	917	88.2	-
V	mg/L			0.304	0	g/day	1000	-	1000	1320	-
W	mg/L			0	0	g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.85	0.00345	g/day	2800	6.48	2800	241	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

Table 3-11: Predicted steady state water quality and loading from pits using NAG test input data with limestone addition to PAF waste rock dumps

				Steady State			Steady State		Steady State		
Analyte	Units	FS09 AV	IFC (2007)	Hannukainen Steady State	Kuervittiko Steady state		Hannukainen Steady State	Kuervittiko Steady state	Akasjoki	Kuerjoki	Valkeajoki
						Volume (m3/day)	3,295	1,879			
pH	s.u.	6.5	6	6.31	6.27	mol/day (H+)	0.0016	0.000999	0.0016	0.00143	-
Alkalinity	mg/L			9.95	7.86	g/day	32800	14800	32800	13900	-
Cl	mg/L	150		36.3	2.06	g/day	120000	3870	120000	30800	-
F	mg/L			1.06		g/day	3480	-	3480	2640	-
PO4	mg/L	0.01926		0.468	0.0827	g/day	1540	155	1540	1310	-
SO4	mg/L	65		878	3.71	g/day	2890000	6960	2890000	44600	-
Ag	mg/L			0.00796		g/day	26.2	-	26.2	13.2	-
Al	mg/L	0.1		0.0445	0.00598	g/day	147	11.2	147	1490	-
As	mg/L	0.005	0.1	0.00344	0.000737	g/day	11.3	1.38	11.3	10.7	-
B	mg/L			0.694		g/day	2290	-	2290	892	-
Ba	mg/L	0.01792		0.00304	0.00582	g/day	10	10.9	10	13.6	-
NO3	mg/L	20		3.24	0.0911	g/day	10700	171	10700	755	-
Bi	mg/L					g/day	-	-	-	-	-
Ca	mg/L	6.542		91.9	3.93	g/day	303000	7390	303000	54400	-
Cd	mg/L	0.00008	0.05	0.000959	0.0000156	g/day	3.16	0.0293	3.16	2.67	-
Co	mg/L	0.004		0.11	0.000207	g/day	363	0.389	363	26.8	-
Cr	mg/L	0.001	0.1	0.0767	0.000455	g/day	253	0.855	253	412	-
Cu	mg/L	0.005	0.3	0.0103	0.000897	g/day	34	1.69	34	53.1	-
Fe	mg/L	0.975	2	0.332	0.23	g/day	1090	433	1090	1640	-
Hg	mg/L	0.00005	0.002	0.000754		g/day	2.48	-	2.48	2.67	-
K	mg/L	0.888		230	0.973	g/day	757000	1830	757000	28000	-
Li	mg/L			0.284		g/day	937	-	937	263	-
Mg	mg/L	1.808		34.1	1.56	g/day	112000	2930	112000	29400	-
Mn	mg/L	0.7		0.405	0.0397	g/day	1340	74.7	1340	181	-
Mo	mg/L	1		0.0341	0.00175	g/day	112	3.29	112	29.3	-
Na	mg/L	2.794		107	6.86	g/day	353000	12900	353000	68600	-
Ni	mg/L	0.02	0.5	0.0292	0.000764	g/day	96.3	1.44	96.3	28.9	-
Pb	mg/L	0.0072		0.00104	0.00013	g/day	3.42	0.244	3.42	0.306	-
Sb	mg/L	0.00002802		0.00997		g/day	32.9	-	32.9	13.2	-
Se	mg/L			0.00498		g/day	16.4	-	16.4	25.5	-
Si	mg/L	9.62		5.52	2.06	g/day	18200	3880	18200	8430	-
Sn	mg/L			0.00979		g/day	32.3	-	32.3	13.2	-
Sr	mg/L	0.03014		0.722	0.0191	g/day	2380	35.8	2380	385	-
Ti	mg/L					g/day	-	-	-	-	-
Tl	mg/L			0.0111		g/day	36.7	-	36.7	13.2	-
U	mg/L	0.015		0.271	0.000148	g/day	892	0.279	892	88.3	-
V	mg/L			0.24		g/day	790	-	790	1330	-
W	mg/L					g/day	-	-	-	-	-
Zn	mg/L	0.03	0.5	0.0633	0.00345	g/day	208	6.48	208	241	-

Exceedence of Akasjoki FS09 trigger values
Exceedence of IFC 2009 effluent water quality guidelines

3.6 References

Dzombak, D. and Morel, F., 1990. Surface Complexation Modeling: Hydrous Ferric Oxide. J. Wiley, New York.

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4 RAUTUVAARA TAILINGS FACILITY MODELLING

4.1 Introduction

This section provides details of the numerical water quality prediction work that has been undertaken to determine water quality and mass loadings as a result of the Hannukainen mine development and deposition of tailings material at the Rautuvaara site.

Predicted source term water quality was used in conjunction with calculated volumetric flows to determine mass loadings through seepage and decant pathways. The calculated loadings were subsequently used for prediction of water quality impacts in the respective receiving water courses in the hydrological impact assessment SRK (2013a)

4.2 Model Objectives

Water quality predictions were made for the north and south Rautuvaara tailings facility ponds for current pre-mining conditions, life of mine tailings emplacement conditions and for the tailings facility post closure. In each case steady state conditions were assumed in line with the steady state groundwater modelling described in the main report. A summary of the modelled scenarios is given below:

- **Water quality prediction for the Rautuvaara TSF under current conditions**– In order to test the assumptions made in the water quality prediction model, the current water quality in the northern and southern Rautuvaara ponds has been determined based on the volume fluxes determined in the groundwater model and measured concentrations of chemical constituents in the north and south ponds.

- **Water quality prediction for the Rautuvaara TSF during LOM** – During the Hannukainen LOM, water quality at the Rautuvaara tailings facility will be impacted through deposition of both de-sulferised LIMS tailings, deposition of the Hannukainen high-S tailings into both the existing Rautuvaara open pits and also into a specially constructed containment facility. Water quality has been predicted assuming that all seepage from the TSF is mixed in the tailings ponds to the north and south of the site prior to discharge to the receiving water courses. Predictions have been made for three hydrological and hydrogeological model scenarios for yearly average, June average and winter average conditions.

- **Water quality prediction for the Rautuvaara TSF following closure** – Post closure water quality predictions have been made based on adaptation of the LOM groundwater model for the three model scenarios given above. For each flow condition predicted in the groundwater model, four water quality scenarios have been run. Scenario 1 assumes that the high-S tailings are either completely encapsulated or are removed from the site following closure and therefore zero release is assumed. Three further scenarios are run assuming 10, 50 and 100% of the potential load from the high-S tailings is released into the catchment. These scenarios are intended to simulate the

potential impacts of gradual breakdown of the integrity of the synthetic liner used for containment of the High-S tails corresponding to assumptions made in Erikson (2012).

The water quality predictions are subject to a number of global assumptions and limitations as listed below.

- Predictions are made for inorganic chemical constituents only.
- Only abiotic processes are incorporated into the model and reduction in nutrient load due to biological activity is not taken into account.
- Attenuation of chemical constituents along groundwater flow paths is not considered in the current model
- Mass loadings from the Hannukainen tailings materials is taken to be equivalent to those calculated in the Phase 1 Hannukainen tailings characterisation report (Erikson, 2012).

4.3 Model Set Up

4.3.1 Mass Balance

A numerical mass balance approach was used to calculate chemical concentrations in the Rautuvaara TSF ponds. The mass balance calculated concentrations were then subjected to thermodynamic equilibration to determine if any components were oversaturated with respect to common mineral phases using the USGS thermodynamic numerical speciation code PhreeqC (Version 2.18.3.5570) released August 16, 2011 coupled with an adapted Minteq.v4 thermodynamic database. The basic characteristics of the mass balance model are shown in Figure 4-1. A description of the modelling approach is given in the following section.

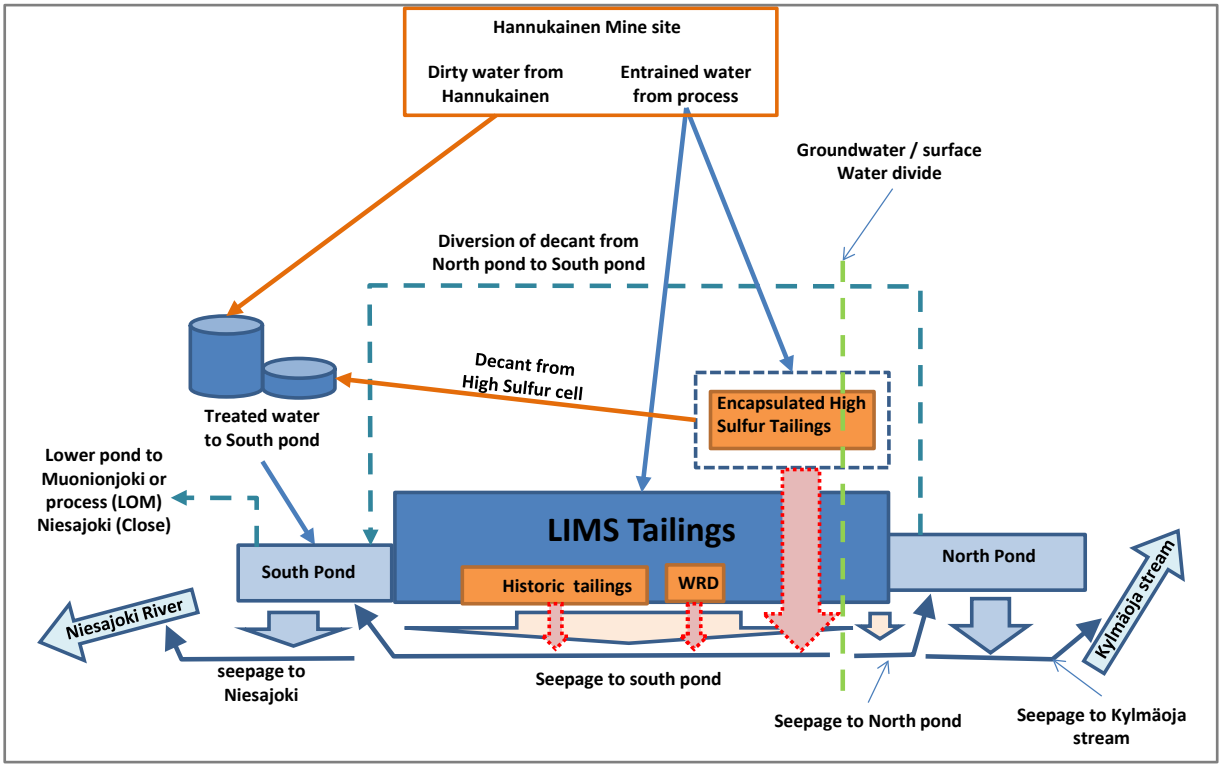


Figure 4-1: Mass balance sources used in the Rautuvaara LOM and Closure models

The mass balance numerical model was undertaken using Microsoft Excel spread sheet. The mass balance water quality prediction model has coupled the predicted source flows from the numerical groundwater model (as described in the main report) with concentrations of chemical constituents from the various sources as shown in Figure 4-1. In each case a chemical load was calculated from each source as follows:

$$Chemical\ load\ from\ source\ \left(\frac{mg}{day}\right) = \frac{Concentration\ in\ individual\ source\ \left(\frac{mg}{litre}\right)}{Volume\ flux\ from\ individual\ \ source\ \left(\frac{litres}{day}\right)}$$

The concentration in the TSF ponds was calculated as the sum of each chemical load divided by the total groundwater flux minus evaporative losses as follows:

$$Concentration\ in\ TSF\ pond\ \left(\frac{mg}{litre}\right) = \frac{\sum Chemical\ load\ from\ all\ sources\ \left(\frac{mg}{day}\right)}{\sum Volume\ flux\ from\ all\ sources\left(\frac{litres}{day}\right) - evaporative\ losses\ from\ pond\left(\frac{litres}{day}\right)}$$

Some sources were included as a chemical load only with no contribution to the overall water balance. This included both loadings from the Hannukainen LIMS and high-S tailings which were taken directly from the Phase 1 tailings characterisation report (Erikson, 2012). The various sources and their descriptions are given in Table 4-1 below.

pH was calculated based on a mass balance of hydrogen ion loadings as calculated from measured source pH. In addition, the acid buffering capacity of the source loadings was determined through mass balancing of measured, calculated or assumed source alkalinity concentrations.

Table 4-1: Table describing details of mass balance model inputs and sources for the Rautuvaara water quality predictions model.

Source	Applicable to	Chemical constituent	Volumetric flow constituent
Historic tailings Seepage (Fines)	**Current / LOM (years 5, 10 and 18) / Close**	Average water quality of pore water reported in tailings fines area trial pits (TP06, 07 and 08).	Seepage volumes from the historic tailings are assumed to be equal to the predicted LOM seepage volumes for winter, June and Average scenarios. Chemical load taken to be constant following closure and increased rate of pore water release through additional loading is assumed to be negligible
Historic tailings seepage (Corse acidic tailings)	**Current**	Water quality taken to be equal to the toe seepage at the Northern boundary to the historic TSF. Following closure, load from the high sulphur tailings is not incorporated into the model as it is assumed that sulphide oxidation will largely cease due to emplacement of LIMS tailings and onset of saturated conditions. Therefore this source term is removed from the closure model and total seepage load is assumed to share fines seepage characteristics.	Seepage volumes as predicted in the current conditions groundwater scenario
Historic waste rock dump seepage	**Current / LOM (years 5, 10 and 18) / Close**	Water quality of seepage from the historic WRD taken to be equal to the average water quality of pore water from 4 trial pits. loading release from the dump is taken to stay constant once LIMS tailings cover is taken into account .	Seepage volume taken to be equal to 50% annual average precipitation onto WRD area. Due to oxidised nature of WRD,
Clean groundwater inflow to the South pond and tailings	**Current / LOM (years 5, 10 and 18) / Close**	Water quality taken to be equal to the average of all deep and shallow groundwater quality for wells showing no impact from historic mining or mineralisation	Flows taken as the total groundwater flow into the pond proportioned by the non-mine impacted flow path
Groundwater impacted by historic mining flowing into the south pond and tailings area	**Current / LOM (years 5, 10 and 18) / Close**	Water quality taken to be equal to the average of HYD01 and HYD02 wells located down gradient of the historic mine workings	Flows taken as the total groundwater flow into the pond proportioned by the mine impacted flow path
Clean groundwater inflow into the North pond	**Current / LOM (years 5, 10 and 18) / Close**	Water quality taken to be the average water quality of all groundwater wells in the flow path entering the northern pond	Flows taken to be the total predicted groundwater inflow into the Northern pond
LIMS tailings seepage water quality and quantity LOM and Closure	**LOM (years 5, 10 and 18)**	LOM chemical loadings taken from Erikson (2012) – Hannukainen DFS tailings characterisation report – These loadings were calculated for the Phase 1 tailings placement and have been taken to be equal to the loadings in the LIMS tailings at the Phase 2 Rautuvaara site.	LOM Seepage volumes as predicted from hydrogeological modelling undertaken as part of this study + the additional contribution from entrained process water. Seepage volumes in the post closure seepage scenario are assumed to be identical to the LOM scenario with the exception of the entrained process water volume no longer contributes to the total seepage volume. Addition of a till cover is assumed to have no impact on infiltration into the tailings itself. In each case loadings are proportioned to estimated seepage volumes flowing into the north or south TSF pond (10% of load assumed to report to the north pond and 90% of the south pond)
	Close	Closure Chemical loadings taken from Erikson 2012 – Hannukainen DFS tailings characterisation report – These loadings were calculated for the Phase 1 tailings placement and have been taken to be roughly equal to the loadings in the Phase 2 tailings placement at Rautuvaara.	
High S tailings seepage water quality and quantity LOM and closure	**LOM (years 5, 10 and 18)**	High S source term chemical loadings were (mass/time) were taken from the Hannukainen DFS tailings characterisation report for predicted seepage through liner. This assumes that tailings are neutralised with lime to prevent ARD generation during LOM. No segregation was made between seepage from the pyrite and pyrrhotite tailings fractions in the high sulphur impoundment.	Chemical constituents added as direct loadings the receiving TSF ponds proportioned to approximate seepage volumes (10% of load assumed to report to north pond and 90% to south pond).
	Close	Source terms taken to be a proportion of the total load predicted in the Erikson 2012 report for post closure oxidation of High S tailings. Four scenarios were run: 1) Zero release – assuming full encapsulation of the tailings post closure 2) 10% load release – assuming 10% of the potential predicted load is release 3) 50% load release – assuming 50% of the predicted total load is released 4) 100% load release – assuming that 100% of the predicted total load is released Each of the four scenarios highlights potential variation between idealised planned closure case in which the tailings are drained down and fully encapsulated post closure assuming zero release of seepage to the environment and the case highlighted by Erikson 2012 in which the integrity of a HDPE lined cell degrades over time (100 to 1000 year timescale) and therefore full seepage to the environment should be assumed.	
Precipitation and catchment runoff	**Current / LOM (years 5, 10 and 18) / Close**	Direct precipitation to the Northern and southern pond and also all non-impacted runoff is assumed to show characteristics of pure rainwater (global mean estimate).	Volumes are taken directly from the groundwater modelling undertaken in the current study
Water from the Hannukainen site (LOM model only)	**LOM (years 5, 10 and 18)**	Volumes and water quality of Hannukainen drainage taken from Pöyry 2012 (Kirsi-Marja-Haanpaa pers comm). This source is excluded from the post closure water quality prediction	
Treated water from the High S tailings decant during LOM operation	**LOM (years 5, 10 and 18)**		
Backfilled tailings in the Rautuvaara pits	**LOM (years 5, 10 and 18) / Close**	Source term for the backfilled tailings in the Rautuvaara pits taken to be equal to the loading calculated for backfilling of the high sulphur tailings in the Hannukainen pits proportioned to a reduced final backfilled volume of 2Mt of tailings. The loading from this material was added to the model without a flow component (I.e. was assumed to be additive to the background water quality	

4.3.2 Equilibration Component

Thermodynamic equilibration of the final mass balanced solutions was undertaken using PhreeqC for the common mineral phases shown in Table 4-2.

Table 4-2: Common minerals phases used in equilibration model

Solid Phase Stoichiometry	Common Mineral Name
Common carbonate	
$Cu_2CO_3(OH)_2$	Malachite
$ZnCO_3$	Smithsonite
$FeCO_3$	Siderite
$MnCO_3$	Rhodochrosite
$CdCO_3$	Otavite
$CaCO_3$	Calcite
Common oxyhydroxides	
$Fe(OH)_3$	Ferrihydrite
AlOOH	Gibbsite
$Co(OH)_2$	
$Cr(OH)_3$	
$Cu(OH)_2$	
$Ni(OH)_2$	
Common sulfates	
$KAl(SO_4)_2(OH)_6$	Alunite
$BaSO_4$	Barite
$CaSO_4.4H_2O$	Gypsum
$ZnSO_4$	Zincosite
Others	
CaF_2	Fluorite
$Pb_5(PO_4)_3Cl$	Pyromorphite

Reaction temperatures were varied to reflect seasonality as follows:

- Average June conditions – 18 ^oC
- Average Winter Conditions – 4 ^oC
- Average yearly Conditions – 7 ^oC

Carbon dioxide equilibration was set to slightly above atmospheric conditions with a partial pressure of 0.00245 to take into account the disequilibrium that has been calculated from the current pond water quality.

Water within the tailings ponds were assumed to be fully oxygenated which is a likely due to the low depth to surface area ratio of the tailings ponds. Although oxygen has not been

directly included as an input parameter to the equilibration model, redox conditions were fixed to an arbitrary pe value roughly equivalent to a 12 – pH which is typical for disequilibrium in mine water impacted surface water. The pe was adjusted manually for each model iteration. Other than solute control through solid phase equilibration, solute attenuation through adsorption to freshly precipitated ferrihydrite was permitted in accordance with Dzombak and Morel (1990).

Following solid and gas phase equilibration and adsorption, the output solute concentration was returned to the mass balance model. From this, an equilibrated mass loading was generated for both seepage and decant waters.

4.3.3 Model Calibration

Calibration of the Rautuvaara seepage pond models was undertaken to current observed conditions in order to allow better determination of LOM and post closure predictions. Prediction of current conditions incorporated chemical sources from the following existing mine site facilities:

- Existing waste rock dump seepage water quality and quantity
- Existing TSF seepage water quality and quantity
- Measured quality and predicted quantity of both groundwater impacted by and unimpacted by the historic Rautuvaara mine site
- Direct precipitation and run-off to the north and south ponds
- Evaporative losses from the pond and TSF surfaces

The current condition model sources are illustrated in Figure 4-2.

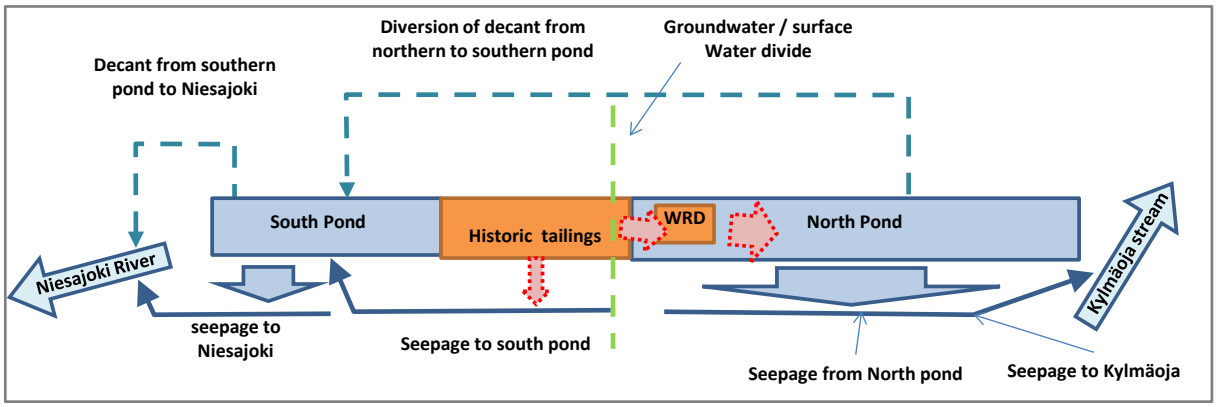


Figure 4-2: Mass balance sources used in the Rautuvaara current conditions model

Comparison between current conditions actual observed concentrations in the north and south pond and modelled concentrations are shown in Figure 4-3 for the south pond and Figure 4-4 for the north pond. The models show generally good agreement with current conditions being generally within double or half of the observed concentrations especially with respect to the major ion concentrations.

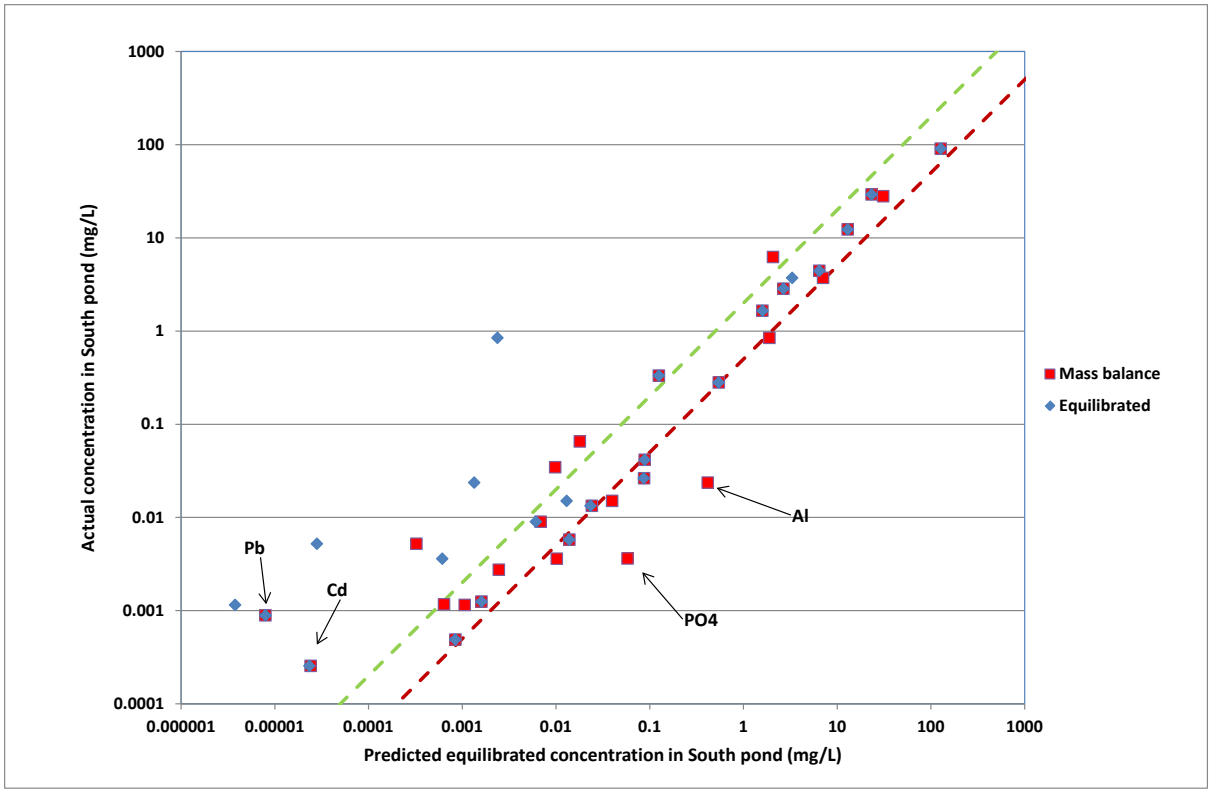


Figure 4-3: Figure showing agreement between measured and predicted water quality in the Rautuvaara south pond

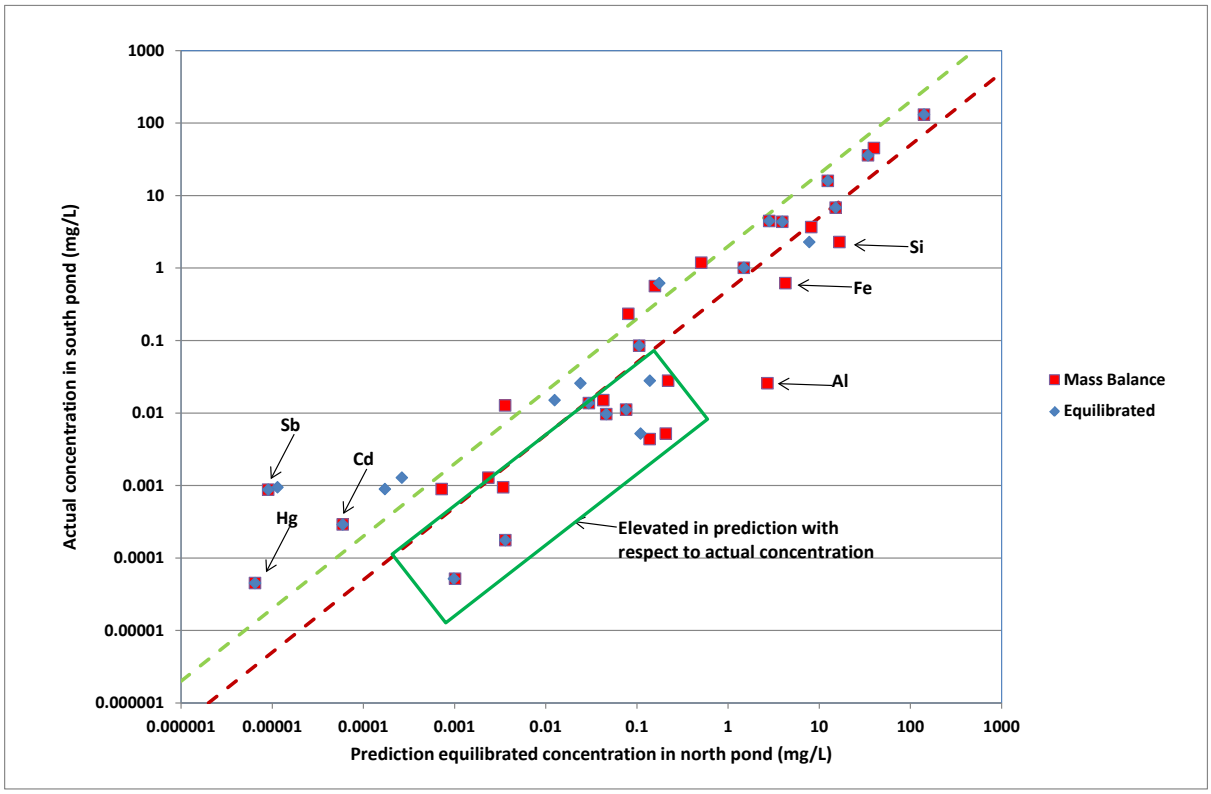


Figure 4-4: Figure showing agreement between measured and predicted water quality in the Rautuvaara north pond

4.4 Model results

Details of model results for the scenarios given in Table 4-3 and individual water balances and mass balance inputs and results are given in Attachment A. An example PhreeqC input Script for the model Life of Mine Year 5 data is given in Attachment B.

Table 4-3: Model scenarios shown in detail in Attachment A

Mine stage	Model Run	Season
Life Of Mine	**Year 5**	**Winter, May / June, Average**
	Year 10	**Winter, May / June, Average**
	End Of mine life	**Winter, May / June, Average**
Post Closure	**Fully Encapsulated High S**	**Winter, May / June, Average**
	10% High S Load release	**Winter, May / June, Average**
	50% High S Load release	**Winter, May / June, Average**
	100% High S Load release	**Winter, May / June, Average**

4.5 References

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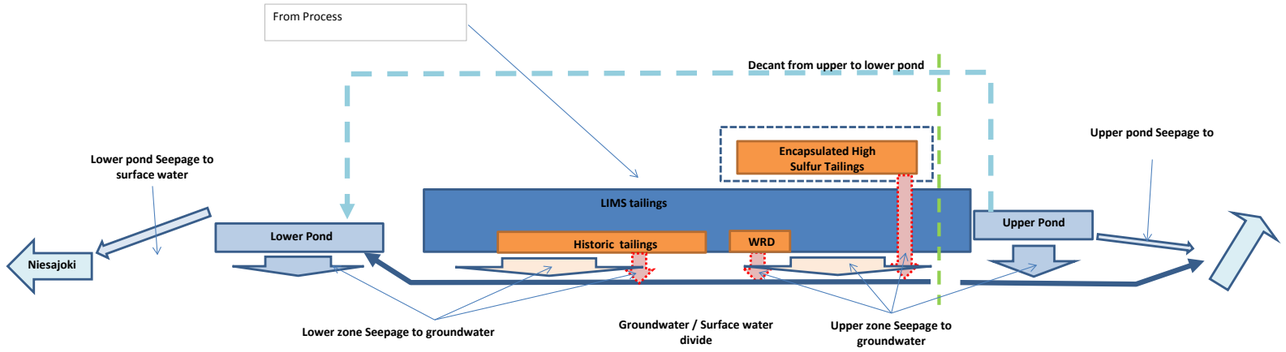
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SRK. 2013a. Hannukainen DFS Waste Rock Geochemical Characterisation Report. SRK Consulting (UK) Ltd. January 2013.

SRK. 2013b. Hannukainen Hydrological Impact Assessment (HIA). SRK Consulting (UK) Ltd. January 2013.

ATTACHMENT A – TAILINGS MODEL WATER BALANCE, MASS BALANCE AND EQUILIBRATED RESULTS

Life of Mine - Average Yearly Conditions
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

LIMS LOM process water seepage	1342.465753	m3/day							4.49
Year	**5**	**10**	**18**			**5**	**10**	**18**	
LIMS divide %	**100%**	**100%**	**90%**			**0%**	**0%**	**10%**	
High S divide %	**70%**	**70%**	**70%**			**30%**	**30%**	**30%**	

Year 5

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	80.00				**Inflowa**	Runoff	0.00			
	Direct precipitation on lower pond	307.73					Direct precipitation to pond	771.13			
	Decant from upper pond	178.31					Unimpacted groundwater seepage to pond	240.13			
	Treated water from Hannukainen and High S TSF	10461.61									
	Unimpacted groundwater seepage to pond	21.52									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	442.08	**PPT source**	1342.47	**Entrained water**		LIMS tailings Seepage North	0.00	**PPT source**	0	**Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23					Unimpacted groundwater seepage to LIMS	79.25			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	79.25			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	316.99					**Total Inflows**	**1169.76**			
	Impacted groundwater from UG to LIMS	396.24									
	From Upper pond	178.31									
	Total inputs	**14480.07**									
	Total Flow in	**14438.48**									
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**		**290.1477**	**Outflows**	Evaporation from upper pond	897.50	**Adjusted (/1.1)**		**815.9052**
	Decant from lower pond to Neisajoki	14071.85	586.32698				Decant to lower pond	178.31			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	93.95			
	Total Outflows	**14467.50**	167.447888				**Total Outflows**	**1169.76**			

Year 10

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	80.00				**Inflowa**	Runoff	0.00			
	Direct precipitation on lower pond	307.73					Direct precipitation to pond	771.13			
	Decant from upper pond	178.31					Unimpacted groundwater seepage to pond	240.13			
	Treated water from Hannukainen and High S TSF	15556.60									
	Unimpacted groundwater seepage to pond	21.52									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	442.08	**PPT source**	1342.4658	**Entrained water**		LIMS tailings Seepage North	0.00	**PPT source**	0	**Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23					Unimpacted groundwater seepage to LIMS	79.25			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	79.25			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	316.99					**Total Inflows**	**1169.76**			
	Impacted groundwater from UG to LIMS	396.24									
	From Upper pond	178.31									
	Total inputs	**19575.06**									
	Total Flow in	**19533.47**									
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**		**290.1477**	**Outflows**	Evaporation from upper pond	897.50	**Adjusted (/1.1)**		**815.9052**
	Decant from lower pond to Neisajoki	19166.84	798.618203				Decant to lower pond	178.31			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	93.95			
	Total Outflows	**19562.49**	226.417672				**Total Outflows**	**1169.76**			

Year 18

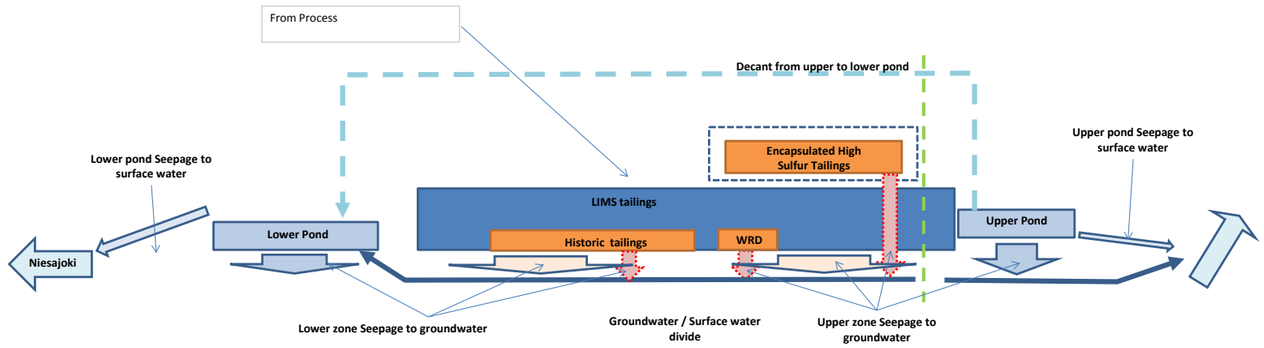
Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	80.00				**Inflowa**	Runoff	0.00			
	Direct precipitation on lower pond	307.73					Direct precipitation to pond	771.13			
	Decant from upper pond	356.76					Unimpacted groundwater seepage to pond	240.13			
	Treated water from Hannukainen and High S TSF	25809.44									
	Unimpacted groundwater seepage to pond	21.52									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	397.87	**PPT source**	1208.2192	**Entrained water**		LIMS tailings Seepage North	44.21	**PPT source**	134.2466	**Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23					Unimpacted groundwater seepage to LIMS	79.25			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	79.25			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	316.99					**Total Inflows**	**1348.21**			
	Impacted groundwater from UG to LIMS	396.24									
	From Upper pond	356.76									
	Total inputs	**30006.36**									
	Total Flow in	**29964.77**									
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**		**290.1477**	**Outflows**	Evaporation from upper pond	897.50	**Adjusted (/1.1)**		**815.9052**
	Decant from lower pond to Neisajoki	29598.14	1233.25571				Decant to lower pond	356.76			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	93.95			
	Total Outflows	**29993.79**	347.150314				**Total Outflows**	**1348.21**			

Life of Mine - Average Year Conditions
Time Data Summary Predicted Water Quality

			Guidelines			Concentration									Loading to River based on groundwater seepage									Loading to River based on decant volumes assumed all discharge to Mounionjoki during LOM		
			Niasjoki		IFC	Current Mean		South Pond			North Pond				Current Mean		South Pond			North Pond				South Pond		
			AV	TV	Guidelines	South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		5 Years	10 Years	18 Years
		m3/day													83.73	88.80	76.49	76.49	76.49	93.95	93.95	93.95		14,072	19,167	29,598
Mass Balance Data	pH	S.U.				7.15	6.89	5.81	5.97	6.07	5.06	5.06	5.24													
	Alkalinity	mmol/l				0.752	0.343	0.39	0.383	0.395	0.691	0.691	2.21	g/day	63	30.5	29.8	29.3	30.2	64.9	64.9	207	g/day	5483	7342	11680
	NO3	µg/l	217	20,000		332	1181	1927	1280	915	3747	1444	6829	mg/day	27790	104900	147400	97870	70020	352100	135600	641600	mg/day	27110000	24530000	27100000
	PO4	µg/l				26.3	27.8	32.3	22.2	15.3	110	109	130	mg/day	2204	2472	2471	1696	1169	10310	10240	12210	mg/day	454700	425000	452400
	Chloride	mg/l	2.3	150		1.65	4.44	0.53	0.39	0.272	9.89	9.89	6.57	g/day	138	394	40.6	29.8	20.8	929	929	617	g/day	7463	7474	8064
	Fluoride	mg/l						0.00481	0.00354	0.0023				g/day			0.368	0.271	0.176				g/day	67.7	67.8	67.9
	TOC	mg/l	9	21		6.21	3.66	0.435	0.32	0.218	5.14	5.14	3.41	g/day	520	325	33.3	24.5	16.7	483	483	321	g/day	6127	6136	6446
	SO4	mg/l	71	154		90.6	131	245	427	293	39.8	37.7	133	g/day	7588	11620	18750	32640	22380	3736	3539	12490	g/day	3449000	8179000	8662000
	Ca	mg/l				29.2	35.9	37	34.2	25.8	14.6	14.4	25.2	g/day	2443	3185	2834	2617	1976	1372	1355	2365	g/day	521400	655700	764600
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.232	0.237	0.158	0.559	0.413	0.44	g/day	70.5	54.7	17.7	18.1	12.1	52.5	38.8	41.3	g/day	3263	4543	4674
	K	mg/l				2.85	4.33	28.7	38.6	26.8	3.04	2.83	16.3	g/day	238	385	2192	2953	2051	286	266	1531	g/day	403200	739900	793600
	Mg	mg/l				12.3	15.9	10.4	12.1	8.86	5.58	5.52	9.2	g/day	1029	1409	796	927	677	524	519	865	g/day	146500	232200	262200
	Na	mg/l				4.43	6.82	26.6	36	26.2	13.6	13.5	25.1	g/day	371	605	2038	2751	2000	1280	1264	2356	g/day	374900	689500	774100
	Si	mg/l				3.72	2.28	1.07	0.789	0.53	9.1	9.1	6.05	g/day	311	202	82.1	60.4	40.5	855	855	569	g/day	15110	15130	15680
	Ag	µg/l						0.0000544	0.00004	0.0000259				mg/day			0.00416	0.00306	0.00198				mg/day	0.765	0.766	0.767
	Al	µg/l	56	100		23.6	25.7	145	102	69.2	495	486	495	mg/day	1980	2281	11100	7804	5293	46530	45630	46520	mg/day	2042000	1956000	2048000
	As	µg/l	0.56	5	100	5.21	0.889	1.05	1.76	1.15	0.233	0.231	0.361	mg/day	436	78.9	80.1	135	87.9	21.9	21.7	33.9	mg/day	14730	33770	34020
	Ba	µg/l				15.1	15	10.6	7.44	5.05	30.3	30.2	33.3	mg/day	1260	1335	812	569	386	2851	2840	3133	mg/day	149500	142700	149400
	Cd	µg/l	0.01	0.08	50	0.254	0.29	1.27	4.3	2.81	0.0136	0.012	0.0245	mg/day	21.3	25.8	97	329	215	1.28	1.13	2.3	mg/day	17840	82410	83050
	Co	µg/l	1.4	4		5.78	11.1	41.9	36.5	37.2	4.43	2.4	3.73	mg/day	484	987	3201	2794	2847	416	225	350	mg/day	588900	700200	1102000
	Cr	µg/l	0.36	1	100	1.17	0.941	13.2	19.6	12.8	1.14	1.09	1.74	mg/day	97.9	83.6	1008	1500	975	107	102	163	mg/day	185500	375900	377400
	Cu	µg/l	2	5	300	3.61	5.19	236	199	154	146	50.7	102	mg/day	302	460	18040	15250	11740	13700	4761	9599	mg/day	3319000	3823000	4544000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	0.342	0.556	0.395	0.00232	0.000774	0.0149	mg/day	2.87	4.01	26.2	42.5	30.2	0.218	0.0727	1.4	mg/day	4820	10650	11700
	Mn	µg/l	180	700		281	1003	201	164	155	173	172	143	mg/day	23500	89070	15400	12570	11850	16210	16110	13470	mg/day	2833000	3149000	4585000
	Mo	µg/l	0.2	1000		0.489	0.0516	14.7	16.1	11.4	0.989	0.711	27.1	mg/day	41	4.58	1126	1228	870	93	66.8	2546	mg/day	207100	307800	336700
	Ni	µg/l	4.5	20	500	13.3	9.63	61.3	84	64.5	5.92	3.97	9.01	mg/day	1113	855	4692	6426	4934	556	373	846	mg/day	863200	1610000	1909000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.67	1.18	0.796	1.28	1.28	1.1	mg/day	96.3	114	51.2	90.3	60.9	120	120	104	mg/day	9425	22620	23570
	Sb	µg/l	0.02	0.08		0.891	0.873	1.69	2.61	1.81	0.0232	0.00774	0.921	mg/day	74.6	77.5	130	200	138	2.18	0.727	86.6	mg/day	23830	50120	53530
	Se	µg/l						0.0016	0.00117	0.000762				mg/day			0.122	0.0899	0.0583				mg/day	22.5	22.5	22.5
	Sr	µg/l				41.6	84.7	16.1	11.8	7.8	68.8	68.8	45.8	mg/day	3483	7522	1229	904	596	6466	6466	4299	mg/day	226100	226500	230800
	Th	µg/l						0.00936	0.00688	0.00446				mg/day			0.716	0.526	0.341				mg/day	132	132	132
	Tl	µg/l						0.000306	0.000225	0.000146				mg/day			0.0234	0.0172	0.0112				mg/day	4.31	4.32	4.32
	U	µg/l	0.23	15		1.25	0.176	18.3	20.9	15	0.176	0.16	7.48	mg/day	105	15.6	1400	1601	1144	16.5	15	702	mg/day	257600	401100	442600
	Zn	µg/l	2.2	30	500	8.97	13.7	119	92.5	65.2	7.37	6.74	8.83	mg/day	751	1217	9108	7075	4989	692	633	829	mg/day	1676000	1773000	1930000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.89	6.86	6.88	7.15	7.11	7.64													
	Alkalinity	mmol/l				0.752	0.343	25.8	24.5	24.9	44.8	40.8	143	g/day	63	30.5	1974	1876	1908	4207	3834	13470	g/day	363100	470000	738400
	NO3	µg/l	217	20,000		332	1181	1928	1277	918	3745	1445	6820	mg/day	27790	104900	147500	97690	70180	351800	135700	640800	mg/day	27130000	24480000	27160000
	PO4	µg/l				26.3	27.8	80.2	55.2	38.9	271	285	357	mg/day	2204	2472	6133	4222	2972	25440	26780	33560	mg/day	1128000	1058000	1150000
	Chloride	mg/l	2.3	150		1.65	4.44	0.533	0.391	0.273	9.9	9.9	6.57	g/day	138	394	40.7	29.9	20.9	931	931	617	g/day	7493	7485	8080
	Fluoride	mg/l						0.00481	0.00353	0.0023				g/day			0.368	0.27	0.176				g/day	67.6	67.7	68
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day			
	SO4	mg/l	71	154		90.6	131	245	426	293	39.7	37.6	132	g/day	7588	11620	18720	32600	22400	3734	3536	12450	g/day	3445000	8170000	8666000
	Ca	mg/l				29.2	35.9	37.1	34.2	25.9	14.6	14.4	25.2	g/day	2443	3185	2834	2619	1978	1371	1356	2366	g/day	521400	656400	765500
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00282	0.00331	0.003	0.00122	0.00136	0.00039	g/day	70.5	54.7	0.216	0.253	0.229	0.115	0.127	0.0366	g/day	39.7	63.5	88.8
	K	mg/l				2.85	4.33	28.7	38.6	26.8	3.04	2.83	16.3	g/day	238	385	2192	2952	2051	286	266	1532	g/day	403300	739600	793900
	Mg	mg/l				12.3	15.9	10.4	12.1	8.85	5.59	5.52	9.19	g/day	1029	1409	796	926	677	525	518	863	g/day	146400	232000	261900
	Na	mg/l				4.43	6.82	26.7	35.9	26.2	13.6	13.4	25.1	g/day	371	605	2040	2743	2005	1279	1264	2354	g/day	375300	687400	775700
	Si	mg/l				3.72	2.28	0.502	0.368	0.248	4.24	4.24	2.83	g/day	311	202	38.4	28.1	18.9	398	398	266	g/day	7070	7047	7327
	Ag*	µg/l						0.0000544	0.0000399	0.0000259				mg/day			0.00416	0.00305	0.00198				mg/day	0.765	0.765	0.766
	Al	µg/l	56	100		23.6	25.7	1.85	1.9	1.87	1.61	1.62	1.82	mg/day	1980	2281	141	145	143	151	152	171	mg/day	25970	36410	55260
	As	µg/l	0.56	5	100	5.21	0.889	0.174	0.266	0.161	0.0534	0.0824	0.0717	mg/day	436	78.9	13.3	20.3	12.3	5.02	7.74	6.74	mg/day	2446	5098	4768
	Ba	µg/l				15.1	15	10.6	7.44	5.04	30.3	30.2	33.4	mg/day	1260	1335	812	569	385	2852	2839	3135	mg/day	149400	142700	149200
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	1.27	4.29	2.81	0.0135	0.012	0.0243	mg/day	21.3	25.8	97.2	328	215	1.27	1.13	2.28	mg/day	17870	82300	83180
	Co	µg/l	1.4	4		5.78	11.1	41.8	36.5	37.2	4.42	2.4	3.7	mg/day	484	987	3200	2795	2849	415	225	348	mg/day	588800	700300	1102000
	Cr	µg/l	0.36	1	100	1.17	0.941	12.1	18.5	12	0.00738	0.0108	0.0207	mg/day	97.9	83.6	927	1416	919	0.694	1.01	1.95	mg/day	170500	354800	355500
	Cu	µg/l	2	5	300	3.61	5.19	53.3	66.1	57.4	23	17.3	14.2	mg/day	302	460	4073	5055	4389	2161	1624	1337	mg/day	749300	1267000	1698000
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	0.343	0.556	0.395	0.00233	0.000774	0.0149	mg/day	2.87	4.01	26.2	42.5	30.2	0.219	0.0727	1.4	mg/day	4827	10650	11700
	Mn	µg/l	180	700		281	1003	201	164	155	173	171	143	mg/day	23500	89070	15380	12560	11850	16210	16100	13420	mg/day	2829000	3148000	4585000
	Mo	µg/l	0.2	1000		0.489	0.0516	14.7	16	11.3	0.988	0.71	27.1	mg/day	41	4.58	1123	1225	866	92.8	66.7	2542	mg/day	206600	307100	335100
	Ni	µg/l	4.5	20	500	13.3	9.63	61	83.9	64.6	5.87	3.96	8.8	mg/day	1113	855	4669	6420	4938	551	372	827	mg/day	859000	1609000	1911000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.576	1.05	0.725	0.204	0.269	0.269	mg/day	96.3	114	44.1	80.2	55.5	19.1	25.3	25.3	mg/day	8106	20100	21460
	Sb	µg/l	0.02	0.08		0.891	0.873	1.69	2.62	1.81	0.0233	0.00774	0.921	mg/day	74.6	77.5	129	200	139	2.19	0.728	86.5	mg/day	23820	50180	53700
	Se*	µg/l						0.00156	0.00114	0.000742				mg/day			0.119	0.0876	0.0568				mg/day	21.9	21.9	22
	Sr	µg/l				41.6	84.7	16	11.8	7.8	68.8	68.8	45.7	mg/day	3483	7522	1226	905	596	6462	6462	4297	mg/day	225600	226700	230800
	Th*	µg/l												mg/day									mg/day			
	Tl*	µg/l						0.000307	0.000225	0.000146				mg/day			0.0234	0.0172	0.0112				mg/day	4.31	4.31	4.33
	U	µg/l	0.23	15		1.25	0.176	18.3	20.9	14.9	0.175	0.16	7.47	mg/day	105	15.6	1400	1600	1143	16.5	15	702	mg/day	257600	401000	442400
	Zn	µg/l	2.2	30	500	8.97	13.7	119	92.2	65.2	7.26	6.67	8.31	mg/day	751	1217	9105	7054	4988	682	627	780	mg/day	1675000	1768000	1930000

	Exceeds water quality action value for the Niesajoki river
	Exceeds water quality trigger value for the Niesajoki river
	Exceeds IFC effluent water quality guidelines
0.001	Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model
*	**Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**
^	**Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Life of Mine - Average Spring Conditions
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

LIMS LOM process water seepage	1342.465753	m3/day		4.49
Year	**5**	**10**	**18**	
LIMS divide %	**100%**	**100%**	**90%**	**5** **0%** **10** **0%** **18** **10%**
High S divide %	**70%**	**70%**	**70%**	**30%** **30%** **30%**

Year 5

Lower (Tailings) Pond							Upper Pond						
Inflows	Runoff	180.00					Inflowa	Runoff	95.00				
	Direct precipitation on lower pond	247.02						Direct precipitation to pond	619.00				
	Decant from upper pond	356.26						Unimpacted groundwater seepage to pond	385.23				
	Treated water from Hannukainen and High S TSF	34102.81											
	Unimpacted groundwater seepage to pond	3.76											
	High S Tailings Seepage South	3.14						High S Tailings Seepage North	1.35				
	LIMS tailings Seepage South	543.05	**PPT source**	1342.4658	**Entrained water**			LIMS tailings Seepage North	0.00	**PPT source**	0	**Entrained water**	
	Unimpacted groundwater seepage to LIMS	836.00						Unimpacted groundwater seepage to LIMS	92.89				
	WRD Seepage to lower pond	20.99						Impacted groundwater seepage from OP to LIMS	92.89				
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid			**Total Inflows**	**1285.01**				
	Impacted Groundwater from OP to LIMS	371.56											
	Impacted groundwater from UG to LIMS	464.44											
	From Upper pond	356.26											
	Total inputs	**38845.21**											
	Total Flow in	**38803.62**											
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**		**335.2725**		Outflows	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**		**925.8236**	
	Decant from lower pond to Neisajoki	38391.26	1599.6357					Decant to lower pond	167.26				
	Seepage from lower pond to groundwater	77.09						Seepage from upper pond to river	99.34				
	Total Outflows	**38837.15**	449.504014					**Total Outflows**	**1285.01**				

Year 10

Lower (Tailings) Pond							Upper Pond						
Inflows	Runoff	180.00					Inflowa	Runoff	95.00				
	Direct precipitation on lower pond	247.02						Direct precipitation to pond	619.00				
	Decant from upper pond	356.26						Unimpacted groundwater seepage to pond	385.23				
	Treated water from Hannukainen and High S TSF	57064.99											
	Unimpacted groundwater seepage to pond	3.76											
	High S Tailings Seepage South	3.14						High S Tailings Seepage North	1.35				
	LIMS tailings Seepage South	543.05	**PPT source**	1342.4658	**Entrained water**			LIMS tailings Seepage North	0.00	**PPT source**	0	**Entrained water**	
	Unimpacted groundwater seepage to LIMS	836.00						Unimpacted groundwater seepage to LIMS	92.89				
	WRD Seepage to lower pond	20.99						Impacted groundwater seepage from OP to LIMS	92.89				
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid			**Total Inflows**	**1285.01**				
	Impacted Groundwater from OP to LIMS	371.56											
	Impacted groundwater from UG to LIMS	464.44											
	From Upper pond	356.26											
	Total inputs	**61807.38**											
	Total Flow in	**61765.80**											
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**		**335.2725**		Outflows	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**		**925.8236**	
	Decant from lower pond to Neisajoki	61353.43	2556.39302					Decant to lower pond	167.26				
	Seepage from lower pond to groundwater	77.09						Seepage from upper pond to river	99.34				
	Total Outflows	**61799.32**	715.269936					**Total Outflows**	**1285.01**				

Year 18

Lower (Tailings) Pond							Upper Pond						
Inflows	Runoff	180.00					Inflowa	Runoff	95.00				
	Direct precipitation on lower pond	247.02						Direct precipitation to pond	619.00				
	Decant from upper pond	356.26						Unimpacted groundwater seepage to pond	385.23				
	Treated water from Hannukainen and High S TSF	73305.66											
	Unimpacted groundwater seepage to pond	3.76											
	High S Tailings Seepage South	3.14						High S Tailings Seepage North	1.35				
	LIMS tailings Seepage South	488.74	**PPT source**	1208.2192	**Entrained water**			LIMS tailings Seepage North	54.30	**PPT source**	134.2466	**Entrained water**	
	Unimpacted groundwater seepage to LIMS	836.00						Unimpacted groundwater seepage to LIMS	92.89				
	WRD Seepage to lower pond	20.99						Impacted groundwater seepage from OP to LIMS	92.89				
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid			**Total Inflows**	**1473.56**				
	Impacted Groundwater from OP to LIMS	371.56											
	Impacted groundwater from UG to LIMS	464.44											
	From Upper pond	356.26											
	Total inputs	**77859.51**											
	Total Flow in	**77817.92**											
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**		**335.2725**		Outflows	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**		**925.8236**	
	Decant from lower pond to Neisajoki	77405.56	3225.23159					Decant to lower pond	355.82				
	Seepage from lower pond to groundwater	77.09						Seepage from upper pond to river	99.34				
	Total Outflows	**77851.45**	901.058427					**Total Outflows**	**1473.56**				

Life of Mine - Average Spring Conditions
Time Data Summary Predicted Water Quality

			Guidelines			Concentration									Loading to River based on groundwater seepage									Loading to River based on decant volumes assumed all discharge to Mounionjoki during LOM		
			Niasjoki		IFC	Current Mean		South Pond			North Pond				Current Mean		South Pond			North Pond				South Pond		
			AV	TV	Guidelines	South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		5 Years	10 Years	18 Years
		m3/day													83.73	88.80	77.09	77.09	77.09	99.34	99.34	99.34		38,391	61,353	77,406
Mass Balance Data	pH	S.U.				7.15	6.89	6.09	6.22	6.25	5.09	5.09	5.27													
	Alkalinity	mmol/l				0.752	0.343	0.373	0.37	0.378	0.981	0.981	2.44	g/day	63	30.5	28.8	28.5	29.1	97.4	97.4	242	g/day	14330	22700	29260
	NO3	µg/l	217	20,000		332	1181	716	408	356	3813	1544	6717	mg/day	27790	104900	55180	31430	27480	378800	153300	667200	mg/day	27480000	25010000	27590000
	PO4	µg/l				26.3	27.8	12.5	7.36	6.22	159	158	160	mg/day	2204	2472	967	567	480	15780	15720	15850	mg/day	481400	451300	481700
	Chloride	mg/l	2.3	150		1.65	4.44	0.211	0.13	0.111	9.76	9.76	6.4	g/day	138	394	16.3	10	8.58	970	970	636	g/day	8109	7967	8613
	Fluoride	mg/l						0.00177	0.00111	0.000879				g/day			0.136	0.0855	0.0678				g/day	68	68	68
	TOC	mg/l	9	21		6.21	3.66	0.188	0.118	0.0995	7.1	7.1	4.66	g/day	520	325	14.5	9.09	7.67	705	705	462	g/day	7230	7235	7706
	SO4	mg/l	71	154		90.6	131	263	571	461	47.4	45.4	135	g/day	7588	11620	20290	44040	35560	4712	4506	13370	g/day	10100000	35050000	35710000
	Ca	mg/l				29.2	35.9	25.8	25.3	22	18.8	18.6	27.3	g/day	2443	3185	1990	1953	1697	1865	1848	2716	g/day	991100	1554000	1704000
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.146	0.204	0.164	0.717	0.573	0.536	g/day	70.5	54.7	11.2	15.8	12.7	71.2	56.9	53.2	g/day	5597	12540	12720
	K	mg/l				2.85	4.33	30.5	47.7	38.8	3.67	3.46	16.3	g/day	238	385	2354	3678	2992	364	344	1617	g/day	1172000	2927000	3004000
	Mg	mg/l				12.3	15.9	9.16	12.9	10.7	6.93	6.87	9.88	g/day	1029	1409	706	993	829	688	682	981	g/day	351800	790400	831900
	Na	mg/l				4.43	6.82	27.2	43.9	36.3	17	16.8	26.7	g/day	371	605	2095	3384	2796	1685	1668	2652	g/day	1044000	2694000	2808000
	Si	mg/l				3.72	2.28	0.462	0.289	0.24	12.9	12.9	8.48	g/day	311	202	35.6	22.3	18.5	1284	1284	842	g/day	17720	17740	18600
	Ag	µg/l						0.00002	0.0000125	0.00000992				mg/day			0.00154	0.000965	0.000765				mg/day	0.767	0.768	0.768
	Al	µg/l	56	100		23.6	25.7	56.3	33.9	28.2	723	714	635	mg/day	1980	2281	4342	2611	2177	71830	70880	63120	mg/day	2162000	2078000	2186000
	As	µg/l	0.56	5	100	5.21	0.889	1.92	2.9	2.31	0.334	0.333	0.419	mg/day	436	78.9	148	223	178	33.2	33	41.6	mg/day	73710	177700	178400
	Ba	µg/l				15.1	15	4.24	2.54	2.11	40.6	40.5	39.4	mg/day	1260	1335	327	196	162	4033	4020	3916	mg/day	162600	155700	163000
	Cd	µg/l	0.01	0.08	50	0.254	0.29	2.42	7.19	5.71	0.0183	0.0168	0.027	mg/day	21.3	25.8	187	554	440	1.82	1.67	2.68	mg/day	92930	441100	441900
	Co	µg/l	1.4	4		5.78	11.1	25	19.4	21.9	4.88	2.89	3.96	mg/day	484	987	1929	1497	1685	485	287	394	mg/day	960400	1191000	1692000
	Cr	µg/l	0.36	1	100	1.17	0.941	24.9	32.5	25.8	1.62	1.58	2.02	mg/day	97.9	83.6	1917	2505	1987	161	157	201	mg/day	954500	1993000	1996000
	Cu	µg/l	2	5	300	3.61	5.19	134	97.5	91	145	51.4	100	mg/day	302	460	10320	7514	7017	14410	5102	9957	mg/day	5138000	5980000	7046000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	0.631	0.907	0.735	0.00229	0.000763	0.0145	mg/day	2.87	4.01	48.7	69.9	56.6	0.227	0.0758	1.44	mg/day	24230	55630	56860
	Mn	µg/l	180	700		281	1003	103	73.1	81.2	233	232	181	mg/day	23500	89070	7977	5638	6259	23160	23070	17960	mg/day	3973000	4487000	6284000
	Mo	µg/l	0.2	1000		0.489	0.0516	12.6	17.7	14.5	1.23	0.96	26.5	mg/day	41	4.58	970	1365	1114	123	95.3	2633	mg/day	483000	1086000	1119000
	Ni	µg/l	4.5	20	500	13.3	9.63	52.6	92.5	78.3	7.07	5.14	9.56	mg/day	1113	855	4054	7129	6038	702	511	950	mg/day	2019000	5673000	6062000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.679	1.56	1.26	1.88	1.88	1.48	mg/day	96.3	114	52.3	120	96.8	187	186	147	mg/day	26060	95850	97200
	Sb	µg/l	0.02	0.08		0.891	0.873	2.44	3.84	3.1	0.0229	0.00763	0.895	mg/day	74.6	77.5	188	296	239	2.27	0.758	88.9	mg/day	93570	235700	239900
	Se	µg/l						0.000588	0.000368	0.000292				mg/day			0.0453	0.0284	0.0225				mg/day	22.6	22.6	22.6
	Sr	µg/l				41.6	84.7	6.88	4.31	3.49	89.1	89.1	58.4	mg/day	3483	7522	530	332	269	8852	8852	5805	mg/day	264000	264200	270200
	Th	µg/l						0.00344	0.00215	0.00171				mg/day			0.265	0.166	0.132				mg/day	132	132	132
	Tl	µg/l						0.000113	0.0000705	0.0000559				mg/day			0.00868	0.00544	0.00431				mg/day	4.33	4.33	4.33
	U	µg/l	0.23	15		1.25	0.176	21.9	25.7	21.1	0.237	0.221	7.31	mg/day	105	15.6	1687	1979	1623	23.5	22	726	mg/day	840000	1575000	1630000
	Zn	µg/l	2.2	30	500	8.97	13.7	52.8	38.3	33	10.1	9.45	10.4	mg/day	751	1217	4073	2951	2541	1001	939	1036	mg/day	2028000	2348000	2552000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.85	6.83	6.84	7.27	7.25	7.67													
	Alkalinity	mmol/l				0.752	0.343	23.4	22.8	23.3	60.7	56.7	156	g/day	63	30.5	1806	1754	1796	6029	5635	15510	g/day	899300	1396000	1804000
	NO3	µg/l	217	20,000		332	1181	713	407	357	3813	1544	6696	mg/day	27790	104900	54970	31400	27480	378800	153400	665200	mg/day	27370000	24990000	27600000
	PO4	µg/l				26.3	27.8	33.2	20.1	16.9	403	418	439	mg/day	2204	2472	2556	1553	1304	40010	41520	43600	mg/day	1273000	1236000	1309000
	Chloride	mg/l	2.3	150		1.65	4.44	0.212	0.13	0.111	9.76	9.76	6.39	g/day	138	394	16.3	10	8.59	970	970	635	g/day	8123	7972	8628
	Fluoride	mg/l						0.00177	0.00111	0.00088				g/day			0.137	0.0855	0.0678				g/day	68	68.1	68.1
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day			
	SO4	mg/l	71	154		90.6	131	263	571	461	47.4	45.3	134	g/day	7588	11620	20280	44030	35520	4711	4501	13350	g/day	10100000	35050000	35670000
	Ca	mg/l				29.2	35.9	25.8	25.3	22	18.8	18.6	27.3	g/day	2443	3185	1991	1954	1697	1864	1848	2717	g/day	991400	1555000	1704000
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00327	0.00398	0.00364	0.000888	0.000949	0.000361	g/day	70.5	54.7	0.252	0.307	0.28	0.0882	0.0943	0.0359	g/day	125	244	281
	K	mg/l				2.85	4.33	30.5	47.7	38.8	3.66	3.46	16.3	g/day	238	385	2354	3677	2993	364	343	1616	g/day	1172000	2927000	3005000
	Mg	mg/l				12.3	15.9	9.16	12.9	10.7	6.93	6.85	9.87	g/day	1029	1409	706	993	828	688	681	980	g/day	351800	790300	831600
	Na	mg/l				4.43	6.82	27.1	43.9	36.3	17	16.8	26.7	g/day	371	605	2091	3385	2800	1685	1667	2649	g/day	1041000	2694000	2812000
	Si	mg/l				3.72	2.28	0.216	0.135	0.112	6.03	6.03	3.96	g/day	311	202	16.6	10.4	8.66	599	599	393	g/day	8276	8283	8690
	Ag*	µg/l						0.00002	0.0000125	0.00000992				mg/day			0.00154	0.000965	0.000765				mg/day	0.766	0.768	0.768
	Al	µg/l	56	100		23.6	25.7	1.9	1.97	1.93	1.58	1.58	1.86	mg/day	1980	2281	147	152	149	157	157	185	mg/day	73130	120700	149700
	As	µg/l	0.56	5	100	5.21	0.889	0.255	0.435	0.33	0.0832	0.127	0.0832	mg/day	436	78.9	19.6	33.5	25.4	8.26	12.7	8.26	mg/day	9780	26660	25520
	Ba	µg/l				15.1	15	4.23	2.54	2.1	40.5	40.5	39.4	mg/day	1260	1335	326	196	162	4024	4024	3915	mg/day	162400	155900	162600
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	2.42	7.19	5.71	0.0182	0.0166	0.0266	mg/day	21.3	25.8	186	555	440	1.81	1.65	2.65	mg/day	92780	441400	442000
	Co	µg/l	1.4	4		5.78	11.1	25	19.4	21.9	4.87	2.88	3.92	mg/day	484	987	1926	1495	1686	484	286	390	mg/day	959300	1190000	1692000
	Cr	µg/l	0.36	1	100	1.17	0.941	24.2	31.6	25	0.00692	0.00733	0.0162	mg/day	97.9	83.6	1864	2433	1928	0.687	0.728	1.61	mg/day	928200	1936000	1936000
	Cu	µg/l	2	5	300	3.61	5.19	61.8	78.2	72.4	18.7	10.5	14	mg/day	302	460	4767	6025	5585	1862	1048	1395	mg/day	2374000	4795000	5607000
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	0.632	0.907	0.734	0.00229	0.000762	0.0145	mg/day	2.87	4.01	48.7	69.9	56.6	0.227	0.0757	1.44	mg/day	24260	55630	56830
	Mn	µg/l	180	700		281	1003	103	73.1	81.3	233	232	180	mg/day	23500	89070	7962	5633	6268	23140	23030	17900	mg/day	3965000	4483000	6294000
	Mo	µg/l	0.2	1000		0.489	0.0516	12.6	17.7	14.5	1.24	0.959	26.5	mg/day	41	4.58	969	1361	1117	123	95.3	2630	mg/day	482500	1083000	1121000
	Ni	µg/l	4.5	20	500	13.3	9.63	52.6	92.7	78.1	6.98	5.09	9.33	mg/day	1113	855	4054	7149	6018	694	505	927	mg/day	2019000	5690000	6042000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.626	1.44	1.16	0.211	0.215	0.292	mg/day	96.3	114	48.2	111	89.8	21	21.4	29	mg/day	24020	88100	90140
	Sb	µg/l	0.02	0.08		0.891	0.873	2.44	3.85	3.1	0.0229	0.00762	0.895	mg/day	74.6	77.5	188	297	239	2.27	0.757	88.9	mg/day	93490	236100	240300
	Se*	µg/l						0.000572	0.000358	0.000284				mg/day			0.0441	0.0276	0.0219				mg/day	22	21.9	22
	Sr	µg/l				41.6	84.7	6.88	4.31	3.49	89.4	89.4	58.4	mg/day	3483	7522	530	332	269	8878	8878	5797	mg/day	264100	264500	269900
	Th*	µg/l												mg/day									mg/day			
	Tl*	µg/l						0.000113	0.0000705	0.000056				mg/day			0.00868	0.00544	0.00432				mg/day	4.32	4.33	4.33
	U	µg/l	0.23	15		1.25	0.176	21.9	25.7	21.1	0.237	0.221	7.31	mg/day	105	15.6	1686	1982	1624	23.5	22	726	mg/day	839800	1577000	1631000
	Zn	µg/l	2.2	30	500	8.97	13.7	52.8	38.3	33	9.75	9.16	9.55	mg/day	751	1217	4069	2950	2541	968	910	949	mg/day	2026000	2348000	2552000

Exceeds water quality action value for the Niesajoki river

Exceeds water quality trigger value for the Niesajoki river

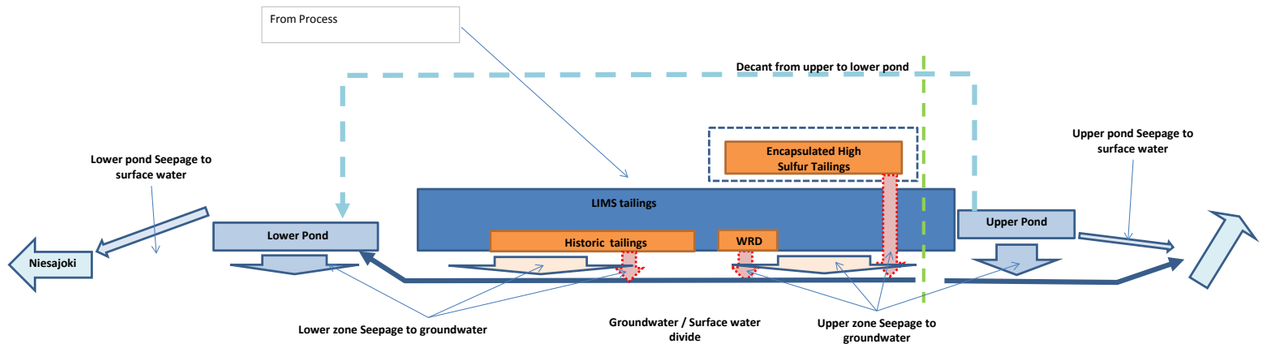
Exceeds IFC effluent water quality guidelines

0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model

* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**

^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Life of Mine - Average Winter Conditions
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

LIMS LOM process water seepage	1342.465753	m3/day		4.49
Year	5	10	18	
LIMS divide %	100%	100%	90%	
High S divide %	70%	70%	70%	

	5	10	18
LIMS divide %	0%	0%	10%
High S divide %	30%	30%	30%

Year 5

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	0.00				Inflowa	Runoff	0.00			
	Direct precipitation on lower pond	0.00					Direct precipitation to pond	0.00			
	Decant from upper pond	151.44					Unimpacted groundwater seepage to pond	151.12			
	Treated water from Hannukainen and High S TSF	4219.47									
	Unimpacted groundwater seepage to pond	28.50									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	422.98	PPT source	1342.47	Entrained water		LIMS tailings Seepage North	0.00	PPT source	0	Entrained water
	Unimpacted groundwater seepage to LIMS	709.61					Unimpacted groundwater seepage to LIMS	78.85			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	78.85			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	315.38					Total Inflows	308.81			
	Impacted groundwater from UG to LIMS	394.23									
	From Upper pond	327.98									
	Total inputs	7953.65									
	Total Flow in	7912.06									
Outflows	Evaporation from Lower pond	2.63	Adjusted (/1.1)	2.390943		Outflows	Evaporation from upper pond	58.03	Adjusted (/1.1)	52.75839	
	Decant from lower pond to Neisajoki	7833.18	326.38242				Decant to lower pond	151.44			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	99.34			
	Total Outflows	7912.30	91.5774956				Total Outflows	308.81			

Year 10

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	0.00				Inflowa	Runoff	0.00			
	Direct precipitation on lower pond	0.00					Direct precipitation to pond	0.00			
	Decant from upper pond	151.44					Unimpacted groundwater seepage to pond	151.12			
	Treated water from Hannukainen and High S TSF	5152.16									
	Unimpacted groundwater seepage to pond	28.50									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	422.98	PPT source	1342.4658	Entrained water		LIMS tailings Seepage North	0.00	PPT source	0	Entrained water
	Unimpacted groundwater seepage to LIMS	709.61					Unimpacted groundwater seepage to LIMS	78.85			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	78.85			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	315.38					Total Inflows	308.81			
	Impacted groundwater from UG to LIMS	394.23									
	From Upper pond	327.98									
	Total inputs	8886.34									
	Total Flow in	8844.75									
Outflows	Evaporation from Lower pond	2.63	Adjusted (/1.1)	2.390943		Outflows	Evaporation from upper pond	58.03	Adjusted (/1.1)	52.75839	
	Decant from lower pond to Neisajoki	8765.87	365.244712				Decant to lower pond	151.44			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	99.34			
	Total Outflows	8844.99	102.372577				Total Outflows	308.81			

Year 18

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	0.00				Inflowa	Runoff	0.00			
	Direct precipitation on lower pond	0.00					Direct precipitation to pond	0.00			
	Decant from upper pond	327.98					Unimpacted groundwater seepage to pond	151.12			
	Treated water from Hannukainen and High S TSF	13876.83									
	Unimpacted groundwater seepage to pond	28.50									
	High S Tailings Seepage South	3.14					High S Tailings Seepage North	1.35			
	LIMS tailings Seepage South	380.68	PPT source	1208.2192	Entrained water		LIMS tailings Seepage North	42.30	PPT source	134.2466	Entrained water
	Unimpacted groundwater seepage to LIMS	709.61					Unimpacted groundwater seepage to LIMS	78.85			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	78.85			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	315.38					Total Inflows	485.35			
	Impacted groundwater from UG to LIMS	394.23									
	From Upper pond	327.98									
	Total inputs	17611.01									
	Total Flow in	17569.42									
Outflows	Evaporation from Lower pond	2.63	Adjusted (/1.1)	2.390943		Outflows	Evaporation from upper pond	58.03	Adjusted (/1.1)	52.75839	
	Decant from lower pond to Neisajoki	17490.54	728.772408				Decant to lower pond	327.98			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	99.34			
	Total Outflows	17569.66	203.352492				Total Outflows	485.35			

Life of Mine - Average Winter Conditions
Time Data Summary Predicted Water Quality

			Guidelines			Concentration									Loading to River based on groundwater seepage									Loading to River based on decant volumes assumed all discharge to Mounionjoki during LOM		
			Niasjoki		IFC	Current Mean		South Pond			North Pond				Current Mean		South Pond			North Pond				South Pond		
			AV	TV	Guidelines	South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		South Pond	North Pond	Year 5	Year 10	18 Years	Year 5	Year 10	Year 18		5 Years	10 Years	18 Years
		m3/day													83.73	88.80	76.49	76.49	76.49	99.34	99.34	99.34		7,833	8,766	17,491
Mass Balance Data	pH	S.U.				7.15	6.89	5.64	5.75	5.96	5.23	5.23	5.45													
	Alkalinity	mmol/l				0.752	0.343	0.406	0.402	0.421	0.722	0.722	2.55	g/day	63	30.5	31.1	30.8	32.2	71.7	71.7	254	g/day	3184	3526	7371
	NO3	µg/l	217	20,000		332	1181	3449	2776	1556	5091	1908	8352	mg/day	27790	104900	263800	212400	119000	505700	189500	829600	mg/day	27020000	24340000	27220000
	PO4	µg/l				26.3	27.8	57.5	48	25.8	112	111	137	mg/day	2204	2472	4400	3672	1970	11170	11070	13580	mg/day	450600	420900	450500
	Chloride	mg/l	2.3	150		1.65	4.44	0.573	0.679	0.346	1.82	1.82	1.08	g/day	138	394	43.9	51.9	26.5	181	181	107	g/day	4491	5953	6056
	Fluoride	mg/l						0.00861	0.0077	0.00388				g/day			0.659	0.589	0.297				g/day	67.5	67.5	67.8
	TOC	mg/l	9	21		6.21	3.66	0.771	0.69	0.361	5.68	5.68	3.36	g/day	520	325	59	52.8	27.6	564	564	334	g/day	6040	6046	6314
	SO4	mg/l	71	154		90.6	131	209	197	123	50.2	47.3	161	g/day	7588	11620	15980	15090	9392	4984	4695	15970	g/day	1636000	1729000	2148000
	Ca	mg/l				29.2	35.9	43.5	41.9	26.4	17.5	17.2	29.4	g/day	2443	3185	3325	3204	2020	1734	1710	2917	g/day	340500	367200	462000
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.307	0.268	0.141	0.642	0.441	0.464	g/day	70.5	54.7	23.5	20.5	10.8	63.8	43.8	46.1	g/day	2405	2349	2459
	K	mg/l				2.85	4.33	18.4	16.9	11	2.81	2.52	19.2	g/day	238	385	1409	1294	839	280	251	1911	g/day	144300	148300	192000
	Mg	mg/l				12.3	15.9	9.98	9.24	6.12	6.03	5.95	10.3	g/day	1029	1409	763	707	468	599	591	1026	g/day	78170	81040	107000
	Na	mg/l				4.43	6.82	19.3	17.6	13	10	9.8	25.7	g/day	371	605	1478	1348	996	998	974	2549	g/day	151400	154400	227800
	Si	mg/l				3.72	2.28	1.9	1.7	0.879	9.65	9.65	5.71	g/day	311	202	145	130	67.2	959	959	567	g/day	14880	14900	15370
	Ag	µg/l						0.0000972	0.000087	0.0000438				mg/day			0.00744	0.00665	0.00335				mg/day	0.762	0.762	0.766
	Al	µg/l	56	100		23.6	25.7	258	221	116	499	485	499	mg/day	1980	2281	19740	16870	8886	49540	48220	49600	mg/day	2021000	1934000	2032000
	As	µg/l	0.56	5	100	5.21	0.889	0.194	0.162	0.0882	0.241	0.239	0.396	mg/day	436	78.9	14.8	12.4	6.75	24	23.8	39.4	mg/day	1517	1424	1543
	Ba	µg/l				15.1	15	19	16.2	8.54	35.1	34.9	37	mg/day	1260	1335	1453	1239	653	3486	3469	3673	mg/day	148800	142000	149400
	Cd	µg/l	0.01	0.08	50	0.254	0.29	0.0978	0.0996	0.0775	0.0151	0.013	0.0279	mg/day	21.3	25.8	7.48	7.62	5.93	1.5	1.29	2.78	mg/day	766	873	1356
	Co	µg/l	1.4	4		5.78	11.1	60.4	63	52.8	5.77	2.97	4.38	mg/day	484	987	4623	4818	4038	573	295	435	mg/day	473500	552100	923400
	Cr	µg/l	0.36	1	100	1.17	0.941	0.866	0.714	0.39	1.17	1.11	1.91	mg/day	97.9	83.6	66.2	54.6	29.9	117	110	189	mg/day	6782	6263	6827
	Cu	µg/l	2	5	300	3.61	5.19	349	357	215	200	68.9	125	mg/day	302	460	26720	27320	16410	19910	6846	12420	mg/day	2736000	3131000	3754000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	0.0576	0.0608	0.0864	0.00321	0.00107	0.0184	mg/day	2.87	4.01	4.4	4.65	6.61	0.319	0.106	1.82	mg/day	451	533	1512
	Mn	µg/l	180	700		281	1003	320	315	234	197	195	152	mg/day	23500	89070	24460	24070	17890	19530	19390	15070	mg/day	2505000	2759000	4090000
	Mo	µg/l	0.2	1000		0.489	0.0516	18.4	15	9.19	1.17	0.785	33.2	mg/day	41	4.58	1410	1149	703	116	77.9	3301	mg/day	144400	131700	160700
	Ni	µg/l	4.5	20	500	13.3	9.63	69.2	70.6	50.8	7.31	4.61	10.6	mg/day	1113	855	5293	5402	3888	726	458	1049	mg/day	542000	619100	889200
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.705	0.665	0.38	1.28	1.27	1.07	mg/day	96.3	114	53.9	50.8	29.1	127	127	106	mg/day	5525	5825	6647
	Sb	µg/l	0.02	0.08		0.891	0.873	1.02	0.924	0.645	0.0321	0.0107	1.13	mg/day	74.6	77.5	77.9	70.7	49.3	3.19	1.06	113	mg/day	7979	8097	11270
	Se	µg/l						0.00286	0.00256	0.00129				mg/day			0.219	0.196	0.0984				mg/day	22.4	22.4	22.5
	Sr	µg/l				41.6	84.7	28.7	25.7	13.1	83.2	83.2	49.2	mg/day	3483	7522	2194	1963	1004	8265	8265	4892	mg/day	224700	225000	229500
	Th	µg/l						0.0167	0.015	0.00754				mg/day			1.28	1.15	0.576				mg/day	131	131	132
	Tl	µg/l						0.000548	0.00049	0.000247				mg/day			0.0419	0.0375	0.0189				mg/day	4.29	4.3	4.31
	U	µg/l	0.23	15		1.25	0.176	14.8	14.3	9.28	0.196	0.175	9.17	mg/day	105	15.6	1130	1092	710	19.5	17.4	911	mg/day	115800	125100	162400
	Zn	µg/l	2.2	30	500	8.97	13.7	199	182	99.8	8.09	7.21	9.62	mg/day	751	1217	15210	13950	7632	803	716	956	mg/day	1558000	1599000	1745000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.92	6.9	6.91	7.16	7.11	7.68													
	Alkalinity	mmol/l				0.752	0.343	28.7	27.4	27.4	49	43.5	168	g/day	63	30.5	2193	2095	2095	4866	4320	16660	g/day	224600	240100	479000
	NO3	µg/l	217	20,000		332	1181	3447	2778	1556	5090	1910	8370	mg/day	27790	104900	263700	212500	119000	505600	189700	831400	mg/day	27000000	24350000	27220000
	PO4	µg/l				26.3	27.8	144	121	66.5	271	290	378	mg/day	2204	2472	11040	9228	5086	26900	28780	37560	mg/day	1131000	1058000	1163000
	Chloride	mg/l	2.3	150		1.65	4.44	0.575	0.682	0.347	1.82	1.82	1.08	g/day	138	394	44	52.1	26.5	181	181	107	g/day	4505	5975	6066
	Fluoride	mg/l						0.00861	0.0077	0.00388				g/day			0.658	0.589	0.296				g/day	67.4	67.5	67.8
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day			
	SO4	mg/l	71	154		90.6	131	208	197	123	50.1	47.2	160	g/day	7588	11620	15930	15050	9399	4978	4692	15930	g/day	1632000	1725000	2149000
	Ca	mg/l				29.2	35.9	43.3	42.1	26.4	17.5	17.2	29.4	g/day	2443	3185	3313	3221	2021	1737	1713	2916	g/day	339200	369100	462200
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00376	0.00399	0.00374	0.00167	0.00191	0.000496	g/day	70.5	54.7	0.288	0.305	0.286	0.166	0.19	0.0493	g/day	29.5	35	65.3
	K	mg/l				2.85	4.33	18.4	16.9	11	2.82	2.52	19.2	g/day	238	385	1409	1295	840	280	251	1911	g/day	144200	148400	192200
	Mg	mg/l				12.3	15.9	9.99	9.24	6.12	6.03	5.95	10.3	g/day	1029	1409	764	706	468	599	592	1026	g/day	78250	80960	107100
	Na	mg/l				4.43	6.82	19.3	17.6	13	10	9.79	25.7	g/day	371	605	1479	1347	995	998	973	2558	g/day	151500	154400	227600
	Si	mg/l				3.72	2.28	0.887	0.794	0.41	4.52	4.52	2.67	g/day	311	202	67.8	60.8	31.3	449	449	265	g/day	6948	6963	7167
	Ag*	µg/l						0.0000972	0.0000869	0.0000438				mg/day			0.00743	0.00665	0.00335				mg/day	0.761	0.762	0.766
	Al	µg/l	56	100		23.6	25.7	2.7	2.75	2.7	2.3	2.36	2.28	mg/day	1980	2281	206	211	206	229	234	226	mg/day	21140	24130	47190
	As	µg/l	0.56	5	100	5.21	0.889	0.0444	0.0347	0.0165	0.0488	0.0733	0.0749	mg/day	436	78.9	3.39	2.65	1.26	4.85	7.28	7.44	mg/day	347	304	288
	Ba	µg/l				15.1	15	19	16.2	8.54	35.2	34.9	36.9	mg/day	1260	1335	1450	1239	653	3492	3465	3670	mg/day	148500	142100	149400
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	0.0978	0.0996	0.0776	0.0151	0.0129	0.0277	mg/day	21.3	25.8	7.48	7.62	5.93	1.5	1.28	2.75	mg/day	766	873	1357
	Co	µg/l	1.4	4		5.78	11.1	60.7	63.1	52.8	5.76	2.96	4.34	mg/day	484	987	4643	4823	4039	572	294	431	mg/day	475500	552800	923600
	Cr	µg/l	0.36	1	100	1.17	0.941	0.0193	0.0176	0.0167	0.00313	0.00718	0.0141	mg/day	97.9	83.6	1.48	1.34	1.28	0.311	0.713	1.4	mg/day	151	154	293
	Cu	µg/l	2	5	300	3.61	5.19	40	42	38.1	18.7	20.4	11.7	mg/day	302	460	3062	3213	2911	1862	2026	1161	mg/day	313600	368200	665800
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	0.0576	0.0608	0.0865	0.00321	0.00107	0.0184	mg/day	2.87	4.01	4.4	4.65	6.61	0.319	0.106	1.82	mg/day	451	533	1512
	Mn	µg/l	180	700		281	1003	320	315	234	196	195	151	mg/day	23500	89070	24460	24080	17900	19480	19370	15010	mg/day	2505000	2759000	4093000
	Mo	µg/l	0.2	1000		0.489	0.0516	18.4	15	9.18	1.17	0.784	33.2	mg/day	41	4.58	1409	1145	702	116	77.9	3297	mg/day	144300	131200	160600
	Ni	µg/l	4.5	20	500	13.3	9.63	69.3	70.4	50.8	7.28	4.6	10.3	mg/day	1113	855	5297	5387	3888	723	457	1026	mg/day	542500	617400	889000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.363	0.363	0.253	0.145	0.278	0.255	mg/day	96.3	114	27.7	27.7	19.3	14.4	27.6	25.3	mg/day	2840	3179	4421
	Sb	µg/l	0.02	0.08		0.891	0.873	1.02	0.924	0.644	0.0321	0.0107	1.13	mg/day	74.6	77.5	78	70.7	49.3	3.19	1.06	113	mg/day	7983	8101	11270
	Se*	µg/l						0.00279	0.0025	0.00126				mg/day			0.213	0.191	0.0966				mg/day	21.8	21.9	22.1
	Sr	µg/l				41.6	84.7	28.7	25.7	13.1	83.2	83.2	49.2	mg/day	3483	7522	2191	1964	1005	8260	8260	4892	mg/day	224400	225000	229900
	Th*	µg/l												mg/day									mg/day			
	Tl*	µg/l						0.000548	0.000491	0.000247				mg/day			0.0419	0.0375	0.0189				mg/day	4.29	4.3	4.33
	U	µg/l	0.23	15		1.25	0.176	14.8	14.3	9.28	0.196	0.175	9.16	mg/day	105	15.6	1131	1092	710	19.5	17.4	910	mg/day	115800	125200	162400
	Zn	µg/l	2.2	30	500	8.97	13.7	198	182	99.4	7.91	7.13	8.9	mg/day	751	1217	15160	13910	7605	786	708	884	mg/day	1552000	1594000	1739000

Exceeds water quality action value for the Niesajoki river

Exceeds water quality trigger value for the Niesajoki river

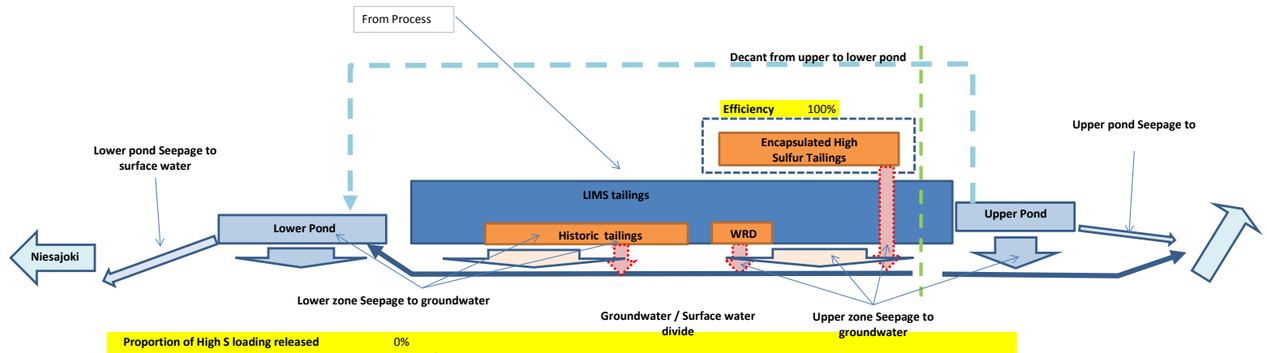
Exceeds IFC effluent water quality guidelines

0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model

* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**

^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Post Closure - Fully Encapsulated 0% High Sulfur Tailings Load Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

Proportion of High S loading released	0%	
LIMS LOM process water seepage	0	m3/day
LIMS divide %	**90%**	**10%**
High S divide %	**0.00%**	**0.00%**

Average

	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	80.00			Runoff	0.00		
	Direct precipitation on lower pond	307.73			Direct precipitation to pond	771.13		
	Decant from upper pond	222.52			Unimpacted groundwater seepage to pond	240.13		
	Treated water from Hannukainen and High S TSF	0.00						
	Unimpacted groundwater seepage to pond	21.52						
	High S Tailings Seepage South	0.00			High S Tailings Seepage North	0.00		
	LIMS tailings Seepage South	397.87	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	44.21	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23			Unimpacted groundwater seepage to LIMS	79.25		
	WRD Seepage to lower pond	**20.99**			Impacted groundwater seepage from OP to LIMS	79.25		
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81** Acid				
	Impacted Groundwater from OP to LIMS	316.99			**Total Inflows**	**1213.97**		
	Impacted groundwater from UG to LIMS	396.24						
	From Upper pond	222.52						
	Total inputs	**2717.07**						
	Total Flow in	**2678.62**						
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**	**290.1477**	Evaporation from upper pond	897.50	**Adjusted (/1.1)**	**815.9052**
	Decant from lower pond to Neisajoki	2311.98	96.3326581		Decant to lower pond	222.52		
	Seepage from lower pond to groundwater	76.49						
	Total Outflows	**2707.63**	31.3383541		Seepage from upper pond to river	93.95		
					Total Outflows	**1213.97**		

June

	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	180.00			Runoff	95.00		
	Direct precipitation on lower pond	247.02			Direct precipitation to pond	619.00		
	Decant from upper pond	222.01			Unimpacted groundwater seepage to pond	385.23		
	Treated water from Hannukainen and High S TSF	0.00						
	Unimpacted groundwater seepage to pond	3.76						
	High S Tailings Seepage South	0.00			High S Tailings Seepage North	0.00		
	LIMS tailings Seepage South	488.74	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	54.30	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	836.00			Unimpacted groundwater seepage to LIMS	92.89		
	WRD Seepage to lower pond	**20.99**			Impacted groundwater seepage from OP to LIMS	92.89		
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81** Acid				
	Impacted Groundwater from OP to LIMS	371.56			**Total Inflows**	**1339.31**		
	Impacted groundwater from UG to LIMS	464.44						
	From Upper pond	222.01						
	Total inputs	**3074.00**						
	Total Flow in	**3035.55**						
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**	**335.2725**	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**	**925.8236**
	Decant from lower pond to Neisajoki	2623.18			Decant to lower pond	222.01		
	Seepage from lower pond to groundwater	77.09						
	Total Outflows	**3069.07**	35.5216867		Seepage from upper pond to river	98.89		
					Total Outflows	**1339.31**		

Winter

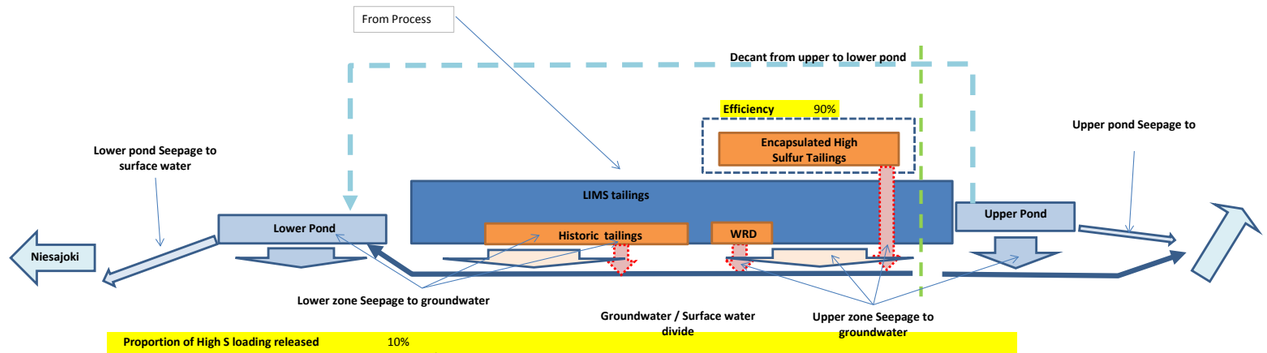
	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	0.00			Runoff	0.00		
	Direct precipitation on lower pond	0.00			Direct precipitation to pond	0.00		
	Decant from upper pond	193.74			Unimpacted groundwater seepage to pond	151.12		
	Unimpacted groundwater seepage to pond	28.50						
	Treated water from Hannukainen and High S TSF	0.00						
	High S Tailings Seepage South	0.00			High S Tailings Seepage North	0.00		
	LIMS tailings Seepage South	380.68	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	42.30	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	709.61			Unimpacted groundwater seepage to LIMS	78.85		
	WRD Seepage to lower pond	**20.99**			Impacted groundwater seepage from OP to LIMS	78.85		
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81** Acid				
	Impacted Groundwater from OP to LIMS	315.38			**Total Inflows**	**351.11**		
	Impacted groundwater from UG to LIMS	394.23						
	From Upper pond	193.74						
	Total inputs	**2254.33**						
	Total Flow in	**2215.88**						
Outflows	Evaporation from Lower pond	2.63	**Adjusted (/1.1)**	**2.390943**	Evaporation from upper pond	58.03	**Adjusted (/1.1)**	**52.75839**
	Decant from lower pond to Neisajoki	2153.32			Decant to lower pond	193.74		
	Seepage from lower pond to groundwater	60.17						
	Total Outflows	**2216.12**	25.6495055		Seepage from upper pond to river	99.34		
					Total Outflows	**351.11**		

Post Closure - Fully Encapsulated 0% High Sulfur Tailings Load
Time Data Summary Predicted Water Quality

			Guidelines			Concentration in pond								Loading to local river systems based on groundwater seepage from pond								Loading to Niesajoki River based on decant volumes				Total Loading to Niesajoki (Seepage + Decant)			
			Niasjoki		IFC	Current Mean		South Pond			North Pond			Current Mean		South Pond (To Niesajoki)			North Pond (to Kylmäoja Stream)				South Pond (To Niesajoki)				South Pond (To Niesajoki)		
			AV	TV	Guidelines	South Pond	North Pond	June	Average	Winter	June	Average	Winter	South Pond	North Pond	June	Average	Winter	June	Average	Winter		June	Average	Winter		June	Average	Winter
		m3/day												83.73	88.80	77.09	76.49	60.17	98.89	93.95	99.34		2623.18	2311.98	2153.32				
Mass Balance Data	pH	S.U.				7.15	6.89	5.23	5.24	5.29	5.43	5.4	7.11																
	Alkalinity	mmol/l				0.752	0.343	0.667	0.558	0.527	1.6	1.19	1.02	g/day	63	30.5	51.4	42.7	31.7	158	112	101	g/day	1751	1290	1135	g/day	1802	1333	1166
	NO3	µg/l	217	20,000		332	1181	165	138	130	369	260	203	mg/day	27790	104900	12690	10530	7823	36510	24400	20210	mg/day	431800	318400	279900	mg/day	444500	329000	287800
	PO4	µg/l				26.3	27.8	2258	2247	2227	1512	1466	1441	mg/day	2204	2472	174100	171900	134000	149500	137800	143100	mg/day	5924000	5195000	4796000	mg/day	6098000	5366000	4930000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.81	8.79	1.17	g/day	138	394	273	246	113	871	826	116	g/day	9279	7450	4044	g/day	9551	7696	4157
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.72				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66	3.13	2.62	2.49	6.41	4.57	3.65	g/day	520	325	241	200	150	633	429	363	g/day	8214	6060	5361	g/day	8455	6261	5511
	SO4	mg/l	71	154		90.6	131	491	478	474	282	274	271	g/day	7588	11620	37840	36550	28510	27850	25760	26920	g/day	1288000	1105000	1020000	g/day	1326000	1141000	1049000
	Ca	mg/l				29.2	35.9	344	340	337	214	210	209	g/day	2443	3185	26520	26010	20290	21190	19760	20710	g/day	902500	786200	726300	g/day	929100	812200	746600
	Fe	mg/l	0.78	2.6	2	0.842	0.616	4.17	4.13	4.09	2.57	2.42	2.33	g/day	70.5	54.7	321	316	246	254	227	232	g/day	10940	9537	8807	g/day	11260	9852	9053
	K	mg/l				2.85	4.33	140	139	138	89.1	88.5	87.6	g/day	238	385	10780	10660	8318	8808	8311	8698	g/day	366700	322400	297700	g/day	377500	333000	306000
	Mg	mg/l				12.3	15.9	42.9	41.8	41.3	27.4	26.1	25	g/day	1029	1409	3311	3195	2485	2707	2450	2483	g/day	112700	96590	88940	g/day	116000	99780	91430
	Na	mg/l				4.43	6.82	30.7	29.7	28.6	29.8	26.6	21	g/day	371	605	2368	2269	1719	2948	2500	2082	g/day	80560	68580	61510	g/day	82930	70850	63220
	Si	mg/l				3.72	2.28	7.61	6.43	6.18	11.7	8.09	6.21	g/day	311	202	587	492	372	1153	760	617	g/day	19970	14870	13320	g/day	20560	15370	13690
	Ag	µg/l						0.000322	0.000322	0.000322				mg/day			0.0248	0.0246	0.0194				mg/day	0.845	0.744	0.693	mg/day	0.869	0.769	0.713
	Al	µg/l	56	100		23.6	25.7	1578	1525	1504	1291	1079	960	mg/day	1980	2281	121600	116700	90470	127700	101400	95340	mg/day	4139000	3526000	3238000	mg/day	4260000	3643000	3328000
	As	µg/l	0.56	5	100	5.21	0.889	5.65	5.63	5.58	3.74	3.65	3.59	mg/day	436	78.9	436	431	336	370	343	357	mg/day	14830	13020	12030	mg/day	15260	13450	12360
	Ba	µg/l				15.1	15	534	528	524	347	337	333	mg/day	1260	1335	41150	40400	31520	34300	31680	33060	mg/day	1400000	1221000	1128000	mg/day	1441000	1262000	1160000
	Cd	µg/l	0.01	0.08	50	0.254	0.29	1.12	1.12	1.11	0.703	0.698	0.696	mg/day	21.3	25.8	86.6	85.7	66.9	69.5	65.6	69.1	mg/day	2947	2590	2394	mg/day	3033	2676	2460
	Co	µg/l	1.4	4		5.78	11.1	27.9	26.5	26.3	7.21	6.74	6.51	mg/day	484	987	2154	2024	1584	713	633	647	mg/day	73300	61170	56680	mg/day	75460	63200	58260
	Cr	µg/l	0.36	1	100	1.17	0.941	4.05	3.95	3.9	3.47	3.01	2.76	mg/day	97.9	83.6	312	302	235	343	283	274	mg/day	10630	9142	8395	mg/day	10940	9444	8629
	Cu	µg/l	2	5	300	3.61	5.19	60.3	58.6	58.3	15.8	14.5	13.7	mg/day	302	460	4649	4482	3509	1559	1359	1365	mg/day	158200	135500	125600	mg/day	162800	139900	129100
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	1.1	1.1	1.09	0.688	0.688	0.688	mg/day	2.87	4.01	84.6	83.9	65.5	68.1	64.7	68.4	mg/day	2878	2537	2345	mg/day	2963	2621	2411
	Mn	µg/l	180	700		281	1003	877	837	829	487	430	403	mg/day	23500	89070	67630	64020	49890	48170	40410	40050	mg/day	2301000	1935000	1785000	mg/day	2369000	1999000	1835000
	Mo	µg/l	0.2	1000		0.489	0.0516	64	63.9	63.4	40.7	40.4	40.3	mg/day	41	4.58	4934	4891	3818	4021	3798	4003	mg/day	167900	147800	136600	mg/day	172800	152700	140400
	Ni	µg/l	4.5	20	500	13.3	9.63	50	46.6	46.3	15.5	14.4	13.8	mg/day	1113	855	3854	3562	2783	1530	1350	1371	mg/day	131200	107700	99600	mg/day	135000	111200	102400
	Pb	µg/l	0.06	7.2	200	1.15	1.28	1.95	1.81	1.77	2.38	1.82	1.51	mg/day	96.3	114	150	138	106	235	171	150	mg/day	5109	4186	3802	mg/day	5259	4324	3908
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0966	#NUM!	#NUM!	#NUM!	mg/day	4.21	3.71	3.46	mg/day	4.34	3.83	3.55
	Se	µg/l						0.00946	0.00946	0.00946				mg/day			0.73	0.724	0.569				mg/day	24.8	21.9	20.4	mg/day	25.6	22.6	20.9
	Sr	µg/l				41.6	84.7	1054	1038	1029	672	652	645	mg/day	3483	7522	81230	79370	61910	66420	61300	64050	mg/day	2764000	2399000	2215000	mg/day	2845000	2478000	2277000
	Th	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	150	132	123
	Tl	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.2	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	965	965	958	606	606	606	mg/day	105	15.6	74420	73850	57660	59920	56920	60180	mg/day	2532000	2232000	2063000	mg/day	2607000	2306000	2121000
	Zn	µg/l	2.2	30	500	8.97	13.7	574	573	572	22	19.5	18.1	mg/day	751	1217	44240	43800	34440	2177	1829	1800	mg/day	1506000	1324000	1232000	mg/day	1550000	1368000	1267000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.59	6.38	6.35	7.4	7.18	7.11																
	Alkalinity	mmol/l				0.752	0.343	12.6	9.19	9.12	76.9	54.3	47.3	g/day	63	30.5	972	703	549	7604	5098	4700	g/day	33060	21240	19650	g/day	34030	21940	20200
	NO3	µg/l	217	20,000		332	1181	165	138	130	369	260	203	mg/day	27790	104900	12690	10530	7821	36500	24390	20210	mg/day	431700	318400	279900	mg/day	444400	328900	287700
	PO4	µg/l				26.3	27.8	836	1000	1038	5.67	96.3	255	mg/day	2204	2472	64460	76460	62450	561	9048	25300	mg/day	2194000	2311000	2235000	mg/day	2258000	2388000	2297000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.23	1.88	8.82	8.8	1.17	g/day	138	394	273	247	113	872	827	117	g/day	9289	7458	4049	g/day	9562	7705	4162
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.72				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day				g/day			
	SO4	mg/l	71	154		90.6	131	490	475	469	281	274	271	g/day	7588	11620	37770	36330	28250	27790	25700	26880	g/day	1285000	1098000	1011000	g/day	1323000	1134000	1039000
	Ca	mg/l				29.2	35.9	340	336	334	211	207	206	g/day	2443	3185	26220	25730	20080	20870	19480	20440	g/day	892300	777700	718600	g/day	918500	803500	738600
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00137	0.00752	0.0113	0.000225	0.00122	0.00218	g/day	70.5	54.7	0.106	0.575	0.68	0.0223	0.115	0.216	g/day	3.6	17.4	24.3	g/day	3.71	18	25
	K	mg/l				2.85	4.33	140	139	137	89	88.4	87.6	g/day	238	385	10770	10630	8273	8805	8309	8698	g/day	366600	321300	296100	g/day	377400	332000	304300
	Mg	mg/l				12.3	15.9	42.9	41.8	41.3	27.3	26.1	25	g/day	1029	1409	3310	3195	2485	2705	2449	2483	g/day	112600	96570	88930	g/day	115900	99770	91410
	Na	mg/l				4.43	6.82	30.7	29.7	28.6	29.8	26.6	21	g/day	371	605	2367	2269	1718	2947	2500	2082	g/day	80550	68570	61500	g/day	82920	70840	63220
	Si	mg/l				3.72	2.28	3.56	3	2.89	5.45	3.78	2.9	g/day	311	202	274	230	174	539	355	288	g/day	9329	6947	6220	g/day	9604	7177	6393
	Ag*	µg/l						0.000322	0.000322	0.000322				mg/day			0.0248	0.0246	0.0194				mg/day	0.844	0.744	0.693	mg/day	0.869	0.769	0.712
	Al	µg/l	56	100		23.6	25.7	0.784	3.71	5.05	1.72	1.63	2.42	mg/day	1980	2281	60.5	284	304	170	154	240	mg/day	2057	8585	10870	mg/day	2118	8869	11170
	As	µg/l	0.56	5	100	5.21	0.889	0.303	1.38	1.61	0.0121	0.0246	0.0335	mg/day	436	78.9	23.4	105	97	1.2	2.31	3.32	mg/day	795	3181	3473	mg/day	818	3286	3570
	Ba	µg/l				15.1	15	11.8	7.94	7.1	15.8	10.6	9.42	mg/day	1260	1335	907	608	427	1565	996	935	mg/day	30860	18370	15290	mg/day	31760	18970	15720
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	1.12	1.12	1.11	0.666	0.674	0.675	mg/day	21.3	25.8	86.1	85.4	66.7	65.8	63.3	67	mg/day	2929	2581	2386	mg/day	3015	2666	2452
	Co	µg/l	1.4	4		5.78	11.1	27.9	26.4	26.3	7.06	6.66	6.45	mg/day	484	987	2150	2022	1582	698	625	641	mg/day	73140	61110	56620	mg/day	75290	63130	58200
	Cr	µg/l	0.36	1	100	1.17	0.941	0.00828	0.00295	0.00228	0.00377	0.000469	0.000282	mg/day	97.9	83.6	0.638	0.225	0.137	0.373	0.0441	0.028	mg/day	21.7	6.82	4.92	mg/day	22.4	7.04	5.06
	Cu	µg/l	2	5	300	3.61	5.19	7.16	12.7	13.5	0.787	0.642	0.64	mg/day	302	460	552	970	812	77.8	60.3	63.6	mg/day	18790	29320	29060	mg/day	19340	30290	29870
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	1.04	1.09	1.08	0.688	0.688	0.688	mg/day	2.87	4.01	80.3	83.3	65.2	68	64.7	68.4	mg/day	2731	2519	2335	mg/day	2812	2603	2400
	Mn	µg/l	180	700		281	1003	876	836	829	482	427	401	mg/day	23500	89070	67550	63970	49860	47690	40150	39840	mg/day	2299000	1934000	1784000	mg/day	2366000	1998000	1834000
	Mo	µg/l	0.2	1000		0.489	0.0516	63.1	63.4	62.9	40.2	39.9	39.8	mg/day	41	4.58	4867	4849	3787	3974	3753	3958	mg/day	165600	146600	135500	mg/day	170500	151400	139300
	Ni	µg/l	4.5	20	500	13.3	9.63	49.6	46.4	46.1	14.3	13.7	13.2	mg/day	1113	855	3820	3546	2772	1413	1284	1316	mg/day	130000	107200	99190	mg/day	133800	110700	102000
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.0442	0.0626	0.0648	0.0165	0.0107	0.00897	mg/day	96.3	114	3.41	4.79	3.9	1.63	1.01	0.891	mg/day	116	145	139	mg/day	119	150	143
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0966				mg/day	4.21	3.71	3.46	mg/day	4.33	3.83	3.55
	Se*	µg/l						0.00717	0.00829	0.00839				mg/day			0.553	0.634	0.505				mg/day	18.8	19.2	18.1	mg/day	19.4	19.8	18.6
	Sr	µg/l				41.6	84.7	1054	1037	1029	671	652	645	mg/day	3483	7522	81220	79350	61900	66400	61280	64040	mg/day	2764000	2399000	2215000	mg/day	2845000	2478000	2277000
	Th*	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	149	132	122
	Tl*	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.19	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	965	965	958	606	606	606	mg/day	105	15.6	74400	73830	57640	59890	56900	60170	mg/day	2532000	2232000	2063000	mg/day	2606000	2305000	2120000
	Zn	µg/l	2.2	30	500	8.97	13.7	557	564	564	17	16.4	15.7	mg/day	751	1217	42930	43130	33950	1683	1545	1563	mg/day	1461000	1304000	1215000	mg/day	1504000	1347000	1249000

Exceeds water quality action value for the Niesajoki river
Exceeds water quality trigger value for the Niesajoki river
Exceeds IFC effluent water quality guidelines
0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model
* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**
^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Post Closure - 10% High Sulfur Tailings Load
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

Proportion of High S loading released	10%	
LIMS LOM process water seepage	0	m3/day
LIMS divide %	**90%**	**10%**
High S divide %	**9.00%**	**1.00%**

Average

	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	80.00			Runoff	0.00		
	Direct precipitation on lower pond	307.73			Direct precipitation to pond	771.13		
	Decant from upper pond	222.52			Unimpacted groundwater seepage to pond	240.13		
	Treated water from Hannukainen and High S TSF	0.00						
	Unimpacted groundwater seepage to pond	21.52						
	High S Tailings Seepage South	11.01			High S Tailings Seepage North	1.22		
	LIMS tailings Seepage South	397.87	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	44.21	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23			Unimpacted groundwater seepage to LIMS	79.25		
	WRD Seepage to lower pond	20.99			Impacted groundwater seepage from OP to LIMS	79.25		
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81 Acid				
	Impacted Groundwater from OP to LIMS	316.99			**Total Inflows**	**1213.97**		
	Impacted groundwater from UG to LIMS	396.24						
	From Upper pond	222.52						
	Total inputs	**2728.07**						
	Total Flow in	**2678.62**						
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**	**290.1477**	Evaporation from upper pond	897.50	**Adjusted (/1.1)**	**815.9052**
	Decant from lower pond to Neisajoki	2311.98	96.3326581		Decant to lower pond	222.52		
	Seepage from lower pond to groundwater	76.49			Seepage from upper pond to river	93.95		
	Total Outflows	**2707.63**	31.3383541		**Total Outflows**	**1213.97**		

June

	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	180.00			Runoff	95.00		
	Direct precipitation on lower pond	247.02			Direct precipitation to pond	619.00		
	Decant from upper pond	222.01			Unimpacted groundwater seepage to pond	385.23		
	Treated water from Hannukainen and High S TSF	0.00						
	Unimpacted groundwater seepage to pond	3.76						
	High S Tailings Seepage South	11.01			High S Tailings Seepage North	1.22		
	LIMS tailings Seepage South	488.74	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	54.30	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	836.00			Unimpacted groundwater seepage to LIMS	92.89		
	WRD Seepage to lower pond	20.99			Impacted groundwater seepage from OP to LIMS	92.89		
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81 Acid				
	Impacted Groundwater from OP to LIMS	371.56			**Total Inflows**	**1339.31**		
	Impacted groundwater from UG to LIMS	464.44						
	From Upper pond	222.01						
	Total inputs	**3085.00**						
	Total Flow in	**3035.55**						
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**	**335.2725**	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**	**925.8236**
	Decant from lower pond to Neisajoki	2623.18			Decant to lower pond	222.01		
	Seepage from lower pond to groundwater	77.09			Seepage from upper pond to river	98.89		
	Total Outflows	**3069.07**	35.5216867		**Total Outflows**	**1339.31**		

Winter

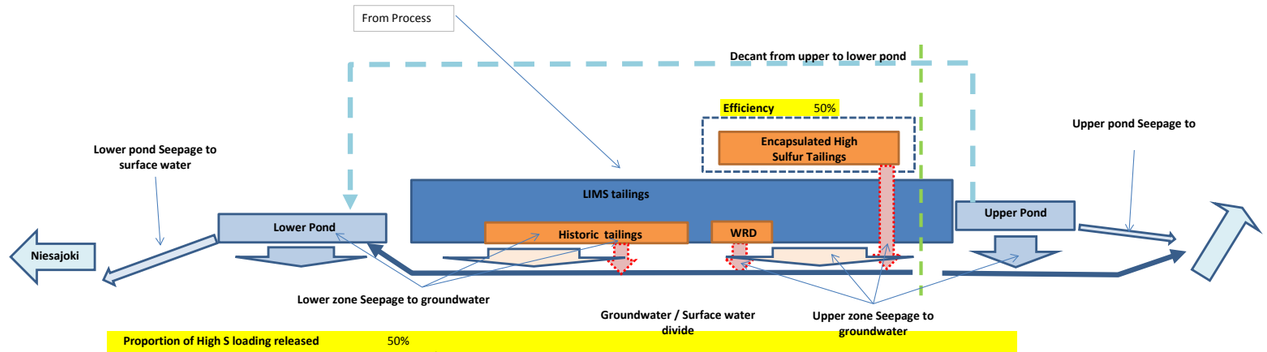
	Lower (Tailings) Pond				Upper Pond			
Inflows	Runoff	0.00			Runoff	0.00		
	Direct precipitation on lower pond	0.00			Direct precipitation to pond	0.00		
	Decant from upper pond	193.74			Unimpacted groundwater seepage to pond	151.12		
	Unimpacted groundwater seepage to pond	28.50						
	Treated water from Hannukainen and High S TSF	0.00						
	High S Tailings Seepage South	11.01			High S Tailings Seepage North	1.22		
	LIMS tailings Seepage South	380.68	**PPT source**	0 **Entrained water**	LIMS tailings Seepage North	42.30	**PPT source**	0 **Entrained water**
	Unimpacted groundwater seepage to LIMS	709.61			Unimpacted groundwater seepage to LIMS	78.85		
	WRD Seepage to lower pond	20.99			Impacted groundwater seepage from OP to LIMS	78.85		
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81 Acid				
	Impacted Groundwater from OP to LIMS	315.38			**Total Inflows**	**351.11**		
	Impacted groundwater from UG to LIMS	394.23						
	From Upper pond	193.74						
	Total inputs	**2265.33**						
	Total Flow in	**2215.88**						
Outflows	Evaporation from Lower pond	2.63	**Adjusted (/1.1)**	**2.390943**	Evaporation from upper pond	58.03	**Adjusted (/1.1)**	**52.75839**
	Decant from lower pond to Neisajoki	2153.32			Decant to lower pond	193.74		
	Seepage from lower pond to groundwater	60.17			Seepage from upper pond to river	99.34		
	Total Outflows	**2216.12**	25.6495055		**Total Outflows**	**351.11**		

Post Closure - 10% high Sulfur Tailings Load
Time Data Summary Predicted Water Quality

			Guidelines			Concentration in pond								Loading to local river systems based on groundwater seepage from pond								Loading to Niesajoki River based on decant volumes				Total Loading to Niesajoki (Seepage + Decant)			
			Niasjoki		IFC	Current Mean		South Pond			North Pond			Current Mean		South Pond (To Niesajoki)			North Pond (to Kylmäoja Stream)			South Pond (To Niesajoki)				South Pond (To Niesajoki)		
			AV	TV	Guidelines	South Pond	North Pond	June	Average	Winter	June	Average	Winter	South Pond	North Pond	June	Average	Winter	June	Average	Winter	June	Average	Winter		June	Average	Winter
		m3/day												83.73	88.80	77.09	76.49	60.17	98.89	93.95	99.34	2623.18	2311.98	2153.32				
Mass Balance Data	pH	S.U.				7.15	6.89	4.95	4.95	4.98	5.15	5.13	5.46																
	Alkalinity	mmol/l				0.752	0.343	0.667	0.558	0.527	1.6	1.19	1.02	g/day	63	30.5	51.4	42.7	31.7	158	112	101	g/day	1751	1290	1135	g/day	1802	1333	1166
	NO3	µg/l	217	20,000		332	1181	165	138	130	369	260	203	mg/day	27790	104900	12690	10530	7823	36510	24400	20210	mg/day	431800	318400	279900	mg/day	444500	329000	287800
	PO4	µg/l				26.3	27.8	2259	2247	2228	1512	1467	1441	mg/day	2204	2472	174100	171900	134000	149600	137800	143200	mg/day	5925000	5196000	4797000	mg/day	6099000	5367000	4931000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.81	8.79	1.17	g/day	138	394	273	246	113	871	826	116	g/day	9279	7450	4044	g/day	9551	7696	4157
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.72				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66	3.13	2.62	2.49	6.41	4.57	3.65	g/day	520	325	241	200	150	633	429	363	g/day	8214	6060	5361	g/day	8455	6261	5511
	SO4	mg/l	71	154		90.6	131	494	480	476	283	276	273	g/day	7588	11620	38050	36750	28670	28010	25910	27090	g/day	1295000	1111000	1026000	g/day	1333000	1148000	1055000
	Ca	mg/l				29.2	35.9	344	340	337	214	210	209	g/day	2443	3185	26530	26010	20300	21190	19760	20720	g/day	902600	786300	726300	g/day	929100	812300	746600
	Fe	mg/l	0.78	2.6	2	0.842	0.616	4.93	4.88	4.84	3.04	2.89	2.81	g/day	70.5	54.7	380	374	291	301	272	279	g/day	12930	11290	10430	g/day	13310	11670	10720
	K	mg/l				2.85	4.33	140	139	138	89.1	88.5	87.6	g/day	238	385	10780	10660	8318	8808	8311	8698	g/day	366700	322400	297700	g/day	377500	333000	306000
	Mg	mg/l				12.3	15.9	43	41.8	41.3	27.4	26.1	25	g/day	1029	1409	3313	3198	2487	2709	2452	2485	g/day	112700	96660	89010	g/day	116100	99860	91500
	Na	mg/l				4.43	6.82	30.7	29.7	28.6	29.8	26.6	21	g/day	371	605	2368	2269	1719	2948	2500	2082	g/day	80570	68590	61520	g/day	82940	70860	63230
	Si	mg/l				3.72	2.28	7.61	6.43	6.18	11.7	8.09	6.21	g/day	311	202	587	492	372	1153	760	617	g/day	19970	14870	13320	g/day	20560	15370	13690
	Ag	µg/l						0.000322	0.000322	0.000322				mg/day			0.0248	0.0246	0.0194				mg/day	0.845	0.744	0.693	mg/day	0.869	0.769	0.713
	Al	µg/l	56	100		23.6	25.7	1619	1567	1545	1317	1105	986	mg/day	1980	2281	124800	119800	92960	130300	103800	97930	mg/day	4248000	3622000	3327000	mg/day	4373000	3742000	3419000
	As	µg/l	0.56	5	100	5.21	0.889	5.76	5.74	5.69	3.81	3.71	3.66	mg/day	436	78.9	444	439	343	377	349	364	mg/day	15120	13280	12260	mg/day	15560	13710	12600
	Ba	µg/l				15.1	15	534	528	524	347	337	333	mg/day	1260	1335	41150	40410	31520	34310	31680	33060	mg/day	1400000	1221000	1128000	mg/day	1441000	1262000	1160000
	Cd	µg/l	0.01	0.08	50	0.254	0.29	1.23	1.23	1.22	0.772	0.767	0.765	mg/day	21.3	25.8	95	94.1	73.4	76.3	72.1	76	mg/day	3234	2843	2628	mg/day	3329	2937	2701
	Co	µg/l	1.4	4		5.78	11.1	38.5	37	36.8	13.8	13.3	13.1	mg/day	484	987	2966	2829	2212	1366	1254	1303	mg/day	100900	85510	79170	mg/day	103900	88340	81390
	Cr	µg/l	0.36	1	100	1.17	0.941	4.16	4.06	4.01	3.54	3.08	2.83	mg/day	97.9	83.6	321	311	241	350	289	281	mg/day	10920	9395	8629	mg/day	11240	9706	8870
	Cu	µg/l	2	5	300	3.61	5.19	559	557	553	329	328	327	mg/day	302	460	43100	42640	33300	32530	30780	32470	mg/day	1467000	1289000	1192000	mg/day	1510000	1332000	1225000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	1.21	1.21	1.2	0.757	0.757	0.757	mg/day	2.87	4.01	93	92.3	72.1	74.9	71.1	75.2	mg/day	3166	2791	2579	mg/day	3259	2883	2652
	Mn	µg/l	180	700		281	1003	879	839	831	488	431	404	mg/day	23500	89070	67780	64170	50000	48300	40520	40170	mg/day	2306000	1940000	1789000	mg/day	2374000	2004000	1839000
	Mo	µg/l	0.2	1000		0.489	0.0516	64.1	64.1	63.6	40.7	40.5	40.4	mg/day	41	4.58	4942	4899	3824	4028	3805	4010	mg/day	168200	148100	136900	mg/day	173100	153000	140700
	Ni	µg/l	4.5	20	500	13.3	9.63	59.8	56.3	55.9	21.6	20.5	19.9	mg/day	1113	855	4607	4308	3366	2136	1925	1979	mg/day	156700	130200	120500	mg/day	161400	134500	123800
	Pb	µg/l	0.06	7.2	200	1.15	1.28	1.95	1.81	1.77	2.38	1.82	1.51	mg/day	96.3	114	150	139	106	236	171	150	mg/day	5112	4188	3804	mg/day	5262	4327	3911
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0966				mg/day	4.21	3.71	3.46	mg/day	4.34	3.83	3.55
	Se	µg/l						0.00946	0.00946	0.00946				mg/day			0.73	0.724	0.569				mg/day	24.8	21.9	20.4	mg/day	25.6	22.6	20.9
	Sr	µg/l				41.6	84.7	1054	1038	1029	672	652	645	mg/day	3483	7522	81240	79370	61910	66430	61300	64050	mg/day	2764000	2399000	2216000	mg/day	2846000	2479000	2278000
	Th	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	150	132	123
	Tl	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.2	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	965	966	958	606	606	606	mg/day	105	15.6	74430	73860	57660	59920	56920	60180	mg/day	2533000	2232000	2064000	mg/day	2607000	2306000	2121000
	Zn	µg/l	2.2	30	500	8.97	13.7	577	576	575	23.9	21.4	20	mg/day	751	1217	44480	44040	34620	2367	2010	1992	mg/day	1514000	1331000	1239000	mg/day	1558000	1375000	1274000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.5	6.34	6.26	7.39	7.17	7.07																
	Alkalinity	mmol/l				0.752	0.343	10.4	8.54	7.38	75	52.6	43.4	g/day	63	30.5	804	653	444	7420	4946	4314	g/day	27360	19740	15890	g/day	28170	20400	16340
	NO3	µg/l	217	20,000		332	1181	164	138	130	369	260	203	mg/day	27790	104900	12670	10530	7834	36480	24410	20200	mg/day	431000	318200	280400	mg/day	443700	328700	288200
	PO4	µg/l				26.3	27.8	874	1036	1207	6.04	113	327	mg/day	2204	2472	67380	79200	72600	598	10620	32460	mg/day	2293000	2394000	2598000	mg/day	2360000	2473000	2671000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.23	1.88	8.8	8.8	1.18	g/day	138	394	273	247	113	871	827	117	g/day	9284	7461	4051	g/day	9557	7707	4165
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.71				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day				g/day			
	SO4	mg/l	71	154		90.6	131	492	476	472	282	276	272	g/day	7588	11620	37970	36420	28420	27910	25890	26990	g/day	1292000	1101000	1017000	g/day	1330000	1137000	1045000
	Ca	mg/l				29.2	35.9	340	336	334	211	207	206	g/day	2443	3185	26250	25730	20100	20860	19480	20430	g/day	893100	777800	719300	g/day	919300	803600	739400
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00169	0.00815	0.0147	0.00023	0.00127	0.00243	g/day	70.5	54.7	0.13	0.624	0.884	0.0228	0.119	0.242	g/day	4.42	18.9	31.6	g/day	4.55	19.5	32.5
	K	mg/l				2.85	4.33	140	139	138	89.1	88.4	87.6	g/day	238	385	10760	10620	8281	8816	8302	8700	g/day	366100	320900	296300	g/day	376900	331500	304600
	Mg	mg/l				12.3	15.9	43	41.8	41.3	27.5	26	25	g/day	1029	1409	3316	3198	2486	2716	2443	2487	g/day	112800	96650	88970	g/day	116200	99850	91460
	Na	mg/l				4.43	6.82	30.8	29.7	28.5	29.9	26.7	21	g/day	371	605	2375	2268	1715	2956	2506	2083	g/day	80810	68570	61390	g/day	83190	70840	63100
	Si	mg/l				3.72	2.28	3.56	3	2.89	5.45	3.79	2.89	g/day	311	202	275	230	174	538	356	287	g/day	9351	6944	6225	g/day	9625	7173	6399
	Ag*	µg/l						0.000321	0.000321	0.000321				mg/day			0.0248	0.0246	0.0193				mg/day	0.843	0.743	0.692	mg/day	0.868	0.768	0.712
	Al	µg/l	56	100		23.6	25.7	0.828	3.67	4.91	1.69	1.64	2.47	mg/day	1980	2281	63.9	281	295	167	154	245	mg/day	2173	8484	10570	mg/day	2237	8765	10870
	As	µg/l	0.56	5	100	5.21	0.889	0.255	0.996	1.96	0.0031	0.00794	0.0127	mg/day	436	78.9	19.7	76.2	118	0.307	0.746	1.26	mg/day	670	2304	4227	mg/day	690	2380	4345
	Ba	µg/l				15.1	15	11.7	7.94	7.07	15.8	10.5	9.37	mg/day	1260	1335	902	607	426	1562	990	930	mg/day	30690	18350	15230	mg/day	31590	18960	15650
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	1.24	1.23	1.21	0.76	0.76	0.759	mg/day	21.3	25.8	95.3	93.7	73.1	75.1	71.4	75.4	mg/day	3244	2833	2614	mg/day	3339	2927	2687
	Co	µg/l	1.4	4		5.78	11.1	38.4	37	36.8	13.7	13.3	13.1	mg/day	484	987	2962	2826	2213	1358	1246	1300	mg/day	100800	85430	79190	mg/day	103800	88260	81400
	Cr	µg/l	0.36	1	100	1.17	0.941	0.0516	0.0183	0.0159	0.0215	0.00302	0.00209	mg/day	97.9	83.6	3.98	1.4	0.957	2.13	0.283	0.208	mg/day	135	42.3	34.3	mg/day	139	43.7	35.2
	Cu	µg/l	2	5	300	3.61	5.19	159	212	247	34.3	25.4	27	mg/day	302	460	12250	16190	14870	3387	2382	2683	mg/day	416700	489200	532300	mg/day	429000	505400	547200
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	1.18	1.2	1.2	0.756	0.756	0.756	mg/day	2.87	4.01	91.2	91.9	71.9	74.8	71.1	75.1	mg/day	3104	2778	2574	mg/day	3196	2870	2646
	Mn	µg/l	180	700		281	1003	879	841	830	487	430	404	mg/day	23500	89070	67760	64290	49920	48140	40420	40110	mg/day	2306000	1943000	1786000	mg/day	2374000	2008000	1836000
	Mo	µg/l	0.2	1000		0.489	0.0516	63.1	63.4	63	39.7	39.6	39.5	mg/day	41	4.58	4867	4851	3793	3928	3723	3926	mg/day	165600	146600	135700	mg/day	170500	151500	139500
	Ni	µg/l	4.5	20	500	13.3	9.63	59.9	56.2	55.9	21	20.1	19.7	mg/day	1113	855	4615	4301	3362	2078	1891	1953	mg/day	157000	130000	120300	mg/day	161700	134300	123700
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.242	0.303	0.344	0.0821	0.0597	0.0566	mg/day	96.3	114	18.7	23.1	20.7	8.11	5.61	5.62	mg/day	636	699	741	mg/day	655	723	761
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0967				mg/day	4.22	3.72	3.46	mg/day	4.34	3.84	3.56
	Se*	µg/l						0.00734	0.00821	0.00861				mg/day			0.566	0.628	0.518				mg/day	19.3	19	18.5	mg/day	19.8	19.6	19.1
	Sr	µg/l				41.6	84.7	1051	1034	1025	671	652	645	mg/day	3483	7522	81060	79080	61690	66370	61250	64060	mg/day	2758000	2390000	2207000	mg/day	2839000	2469000	2269000
	Th*	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	149	132	122
	Tl*	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.2	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	964	964	957	605	605	605	mg/day	105	15.6	74320	73740	57580	59790	56800	60060	mg/day	2529000	2229000	2060000	mg/day	2603000	2303000	2118000
	Zn	µg/l	2.2	30	500	8.97	13.7	572	573	573	21.9	20.2	19.2	mg/day	751	1217	44120	43830	34480	2167	1899	1910	mg/day	1501000	1325000	1234000	mg/day	1545000	1369000	1268000

Exceeds water quality action value for the Niesajoki river
Exceeds water quality trigger value for the Niesajoki river
Exceeds IFC effluent water quality guidelines
0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model
* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**
^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Post Closure - 50% High Sulfur Tailings Load
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

80

Proportion of High S loading released	50%	
LIMS LOM process water seepage	0	m3/day
LIMS divide %	**90%**	**10%**
High S divide %	**45.00%**	**5.00%**

Average

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	80.00				Inflowa	Runoff	0.00			
	Direct precipitation on lower pond	307.73					Direct precipitation to pond	771.13			
	Decant from upper pond	222.52					Unimpacted groundwater seepage to pond	240.13			
	Treated water from Hannukainen and High S TSF	0.00									
	Unimpacted groundwater seepage to pond	21.52									
	High S Tailings Seepage South	55.03					High S Tailings Seepage North	6.11			
	LIMS tailings Seepage South	397.87	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	44.21	**PPT source**	0	**Entrained water**
	Unimpacted groundwater seepage to LIMS	713.23					Unimpacted groundwater seepage to LIMS	79.25			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	79.25			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	316.99					**Total Inflows**	**1213.97**			
	Impacted groundwater from UG to LIMS	396.24									
	From Upper pond	222.52									
	Total inputs	**2772.10**									
	Total Flow in	**2678.62**									
Outflows	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**		**290.1477**	Outflows	Evaporation from upper pond	897.50	**Adjusted (/1.1)**		**815.9052**
	Decant from lower pond to Neisajoki	2311.98	96.3326581				Decant to lower pond	222.52			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	93.95			
	Total Outflows	**2707.63**	31.3383541				**Total Outflows**	**1213.97**			

June

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	180.00				Inflowa	Runoff	95.00			
	Direct precipitation on lower pond	247.02					Direct precipitation to pond	619.00			
	Decant from upper pond	222.01					Unimpacted groundwater seepage to pond	385.23			
	Treated water from Hannukainen and High S TSF	0.00									
	Unimpacted groundwater seepage to pond	3.76									
	High S Tailings Seepage South	55.03					High S Tailings Seepage North	6.11			
	LIMS tailings Seepage South	488.74	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	54.30	**PPT source**	0	**Entrained water**
	Unimpacted groundwater seepage to LIMS	836.00					Unimpacted groundwater seepage to LIMS	92.89			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	92.89			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	371.56					**Total Inflows**	**1339.31**			
	Impacted groundwater from UG to LIMS	464.44									
	From Upper pond	222.01									
	Total inputs	**3129.03**									
	Total Flow in	**3035.55**									
Outflows	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**		**335.2725**	Outflows	Evaporation from upper pond	1018.41	**Adjusted (/1.1)**		**925.8236**
	Decant from lower pond to Neisajoki	2623.18					Decant to lower pond	222.01			
	Seepage from lower pond to groundwater	77.09					Seepage from upper pond to river	98.89			
	Total Outflows	**3069.07**	35.5216867				**Total Outflows**	**1339.31**			

Winter

Lower (Tailings) Pond						Upper Pond					
Inflows	Runoff	0.00				Inflowa	Runoff	0.00			
	Direct precipitation on lower pond	0.00					Direct precipitation to pond	0.00			
	Decant from upper pond	193.74					Unimpacted groundwater seepage to pond	151.12			
	Unimpacted groundwater seepage to pond	28.50									
	Treated water from Hannukainen and High S TSF	0.00									
	High S Tailings Seepage South	55.03					High S Tailings Seepage North	6.11			
	LIMS tailings Seepage South	380.68	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	42.30	**PPT source**	0	**Entrained water**
	Unimpacted groundwater seepage to LIMS	709.61					Unimpacted groundwater seepage to LIMS	78.85			
	WRD Seepage to lower pond	20.99					Impacted groundwater seepage from OP to LIMS	78.85			
	Historic Tailings seepage to lower pond	1.65	Neutral	15.81	Acid						
	Impacted Groundwater from OP to LIMS	315.38					**Total Inflows**	**351.11**			
	Impacted groundwater from UG to LIMS	394.23									
	From Upper pond	193.74									
	Total inputs	**2309.36**									
	Total Flow in	**2215.88**									
Outflows	Evaporation from Lower pond	2.63	**Adjusted (/1.1)**		**2.390943**	Outflows	Evaporation from upper pond	58.03	**Adjusted (/1.1)**		**52.75839**
	Decant from lower pond to Neisajoki	2153.32					Decant to lower pond	193.74			
	Seepage from lower pond to groundwater	60.17					Seepage from upper pond to river	99.34			
	Total Outflows	**2216.12**	25.6495055				**Total Outflows**	**351.11**			

Post Closure - 50% High Sulfur Tailings Load
Time Data Summary Predicted Water Quality

			Guidelines			Concentration in pond								Loading to local river systems based on groundwater seepage from pond								Loading to Niesajoki River based on decant volumes				Total Loading to Niesajoki (Seepage + Decant)			
			Niasjoki		IFC	Current Mean		South Pond			North Pond			Current Mean		South Pond (To Niesajoki)			North Pond (to Kylmäoja Stream)				South Pond (To Niesajoki)				South Pond (To Niesajoki)		
			AV	TV	Guidelines	South Pond	North Pond	June	Average	Winter	June	Average	Winter	South Pond	North Pond	June	Average	Winter	June	Average	Winter		June	Average	Winter		June	Average	Winter
		m3/day												83.73	88.80	77.09	76.49	60.17	98.89	93.95	99.34		2623.18	2311.98	2153.32				
Mass Balance Data	pH	S.U.				7.15	6.89	4.49	4.49	4.5	4.69	4.68	4.77																	
	Alkalinity	mmol/l				0.752	0.343	0.667	0.558	0.527	1.6	1.19	1.02	g/day	63	30.5	51.4	42.7	31.7	158	112	101	g/day	1751	1290	1135	g/day	1802	1333	1166
	NO3	µg/l	217	20,000		332	1181	165	138	130	369	260	203	mg/day	27790	104900	12690	10530	7823	36510	24400	20210	mg/day	431800	318400	279900	mg/day	444500	329000	287800
	PO4	µg/l				26.3	27.8	2261	2249	2229	1513	1468	1442	mg/day	2204	2472	174300	172000	134200	149700	137900	143300	mg/day	5930000	5200000	4801000	mg/day	6104000	5372000	4935000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.81	8.79	1.17	g/day	138	394	273	246	113	871	826	116	g/day	9279	7450	4044	g/day	9551	7696	4157
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.72				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66	3.13	2.62	2.49	6.41	4.57	3.65	g/day	520	325	241	200	150	633	429	363	g/day	8214	6060	5361	g/day	8455	6261	5511
	SO4	mg/l	71	154		90.6	131	504	491	487	290	282	279	g/day	7588	11620	38860	37550	29300	28660	26530	27750	g/day	1322000	1135000	1048000	g/day	1361000	1173000	1078000
	Ca	mg/l				29.2	35.9	344	340	337	214	210	209	g/day	2443	3185	26540	26020	20310	21200	19770	20730	g/day	903000	786600	726600	g/day	929500	812600	746900
	Fe	mg/l	0.78	2.6	2	0.842	0.616	7.97	7.92	7.86	4.95	4.8	4.72	g/day	70.5	54.7	614	606	473	490	451	469	g/day	20900	18320	16930	g/day	21520	18930	17400
	K	mg/l				2.85	4.33	140	139	138	89.1	88.5	87.6	g/day	238	385	10780	10670	8318	8808	8311	8699	g/day	366700	322400	297700	g/day	377500	333000	306000
	Mg	mg/l				12.3	15.9	43.1	41.9	41.5	27.5	26.2	25.1	g/day	1029	1409	3323	3207	2495	2716	2460	2493	g/day	113100	96950	89270	g/day	116400	100200	91770
	Na	mg/l				4.43	6.82	30.7	29.7	28.6	29.8	26.6	21	g/day	371	605	2369	2270	1720	2949	2501	2083	g/day	80620	68630	61550	g/day	82980	70900	63270
	Si	mg/l				3.72	2.28	7.61	6.43	6.18	11.7	8.09	6.21	g/day	311	202	587	492	372	1153	760	617	g/day	19970	14870	13320	g/day	20560	15370	13690
	Ag	µg/l						0.000322	0.000322	0.000322				mg/day			0.0248	0.0246	0.0194				mg/day	0.845	0.744	0.693	mg/day	0.869	0.769	0.713
	Al	µg/l	56	100		23.6	25.7	1786	1733	1710	1422	1210	1090	mg/day	1980	2281	137600	132600	102900	140600	113700	108300	mg/day	4684000	4007000	3682000	mg/day	4821000	4139000	3785000
	As	µg/l	0.56	5	100	5.21	0.889	6.2	6.18	6.13	4.08	3.99	3.94	mg/day	436	78.9	478	473	369	404	375	391	mg/day	16270	14290	13200	mg/day	16740	14760	13570
	Ba	µg/l				15.1	15	534	528	524	347	337	333	mg/day	1260	1335	41160	40410	31530	34310	31690	33070	mg/day	1401000	1222000	1128000	mg/day	1442000	1262000	1160000
	Cd	µg/l	0.01	0.08	50	0.254	0.29	1.67	1.67	1.66	1.05	1.04	1.04	mg/day	21.3	25.8	129	128	99.6	104	97.9	103	mg/day	4384	3857	3565	mg/day	4513	3985	3665
	Co	µg/l	1.4	4		5.78	11.1	80.6	79.1	78.6	40.2	39.8	39.5	mg/day	484	987	6211	6049	4727	3980	3737	3929	mg/day	211300	182900	169200	mg/day	217600	188900	173900
	Cr	µg/l	0.36	1	100	1.17	0.941	4.6	4.5	4.44	3.81	3.36	3.1	mg/day	97.9	83.6	355	344	267	377	315	308	mg/day	12070	10410	9566	mg/day	12420	10750	9834
	Cu	µg/l	2	5	300	3.61	5.19	2554	2553	2534	1582	1580	1580	mg/day	302	460	196900	195300	152500	156400	148500	156900	mg/day	6701000	5903000	5456000	mg/day	6898000	6098000	5609000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	1.65	1.65	1.63	1.03	1.03	1.03	mg/day	2.87	4.01	127	126	98.3	102	97	103	mg/day	4316	3805	3517	mg/day	4443	3930	3615
	Mn	µg/l	180	700		281	1003	887	847	839	493	436	409	mg/day	23500	89070	68390	64770	50480	48790	40990	40660	mg/day	2327000	1958000	1806000	mg/day	2396000	2023000	1857000
	Mo	µg/l	0.2	1000		0.489	0.0516	64.5	64.5	64	41	40.8	40.6	mg/day	41	4.58	4976	4933	3851	4055	3831	4037	mg/day	169300	149100	137800	mg/day	174300	154000	141600
	Ni	µg/l	4.5	20	500	13.3	9.63	98.8	95.4	94.7	46.1	45	44.4	mg/day	1113	855	7615	7294	5697	4559	4227	4413	mg/day	259100	220500	203900	mg/day	266700	227800	209600
	Pb	µg/l	0.06	7.2	200	1.15	1.28	1.95	1.82	1.77	2.38	1.82	1.51	mg/day	96.3	114	151	139	107	236	171	150	mg/day	5124	4199	3814	mg/day	5274	4337	3920
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0966				mg/day	4.21	3.71	3.46	mg/day	4.34	3.83	3.55
	Se	µg/l						0.00946	0.00946	0.00946				mg/day			0.73	0.724	0.569				mg/day	24.8	21.9	20.4	mg/day	25.6	22.6	20.9
	Sr	µg/l				41.6	84.7	1054	1038	1029	672	653	645	mg/day	3483	7522	81280	79410	61940	66450	61330	64080	mg/day	2766000	2400000	2217000	mg/day	2847000	2480000	2279000
	Th	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	150	132	123
	Tl	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.2	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	966	966	959	606	606	606	mg/day	105	15.6	74460	73890	57690	59950	56950	60210	mg/day	2534000	2233000	2064000	mg/day	2608000	2307000	2122000
	Zn	µg/l	2.2	30	500	8.97	13.7	589	588	588	31.6	29.1	27.8	mg/day	751	1217	45430	44980	35350	3130	2735	2757	mg/day	1546000	1360000	1265000	mg/day	1591000	1405000	1301000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	6.2	5.98	5.93	7.35	7.11	6.99																	
	Alkalinity	mmol/l				0.752	0.343	5.54	4.11	3.82	68.3	45.8	36.5	g/day	63	30.5	427	314	230	6756	4298	3630	g/day	14550	9491	8236	g/day	14970	9805	8466
	NO3	µg/l	217	20,000		332	1181	164	138	130	369	259	203	mg/day	27790	104900	12670	10530	7797	36480	24350	20200	mg/day	431000	318200	279000	mg/day	443700	328700	286800
	PO4	µg/l				26.3	27.8	1197	2347	3040	8.29	216	436	mg/day	2204	2472	92280	179500	182900	820	20260	43320	mg/day	3140000	5425000	6546000	mg/day	3232000	5605000	6729000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.8	8.8	1.17	g/day	138	394	273	247	113	871	827	116	g/day	9284	7452	4044	g/day	9557	7699	4157
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.71				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day				g/day			
	SO4	mg/l	71	154		90.6	131	501	486	482	289	281	278	g/day	7588	11620	38630	37150	29000	28580	26430	27660	g/day	1315000	1123000	1038000	g/day	1353000	1160000	1067000
	Ca	mg/l				29.2	35.9	341	338	336	211	207	206	g/day	2443	3185	26280	25860	20200	20860	19480	20470	g/day	894100	781500	722700	g/day	920400	807400	742900
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00348	0.023	0.0417	0.000254	0.0015	0.00309	g/day	70.5	54.7	0.268	1.76	2.51	0.0251	0.141	0.307	g/day	9.13	53.1	89.7	g/day	9.39	54.8	92.2
	K	mg/l				2.85	4.33	139	138	137	89.1	88.4	87.6	g/day	238	385	10730	10590	8258	8816	8302	8700	g/day	365100	320000	295500	g/day	375800	330600	303800
	Mg	mg/l				12.3	15.9	43	41.8	41.3	27.5	26.2	25	g/day	1029	1409	3316	3198	2486	2716	2466	2487	g/day	112800	96650	88970	g/day	116200	99850	91460
	Na	mg/l				4.43	6.82	30.8	29.7	28.5	29.9	26.7	20.9	g/day	371	605	2375	2268	1715	2956	2506	2080	g/day	80810	68570	61390	g/day	83190	70840	63100
	Si	mg/l				3.72	2.28	3.56	3	2.89	5.45	3.79	2.89	g/day	311	202	275	230	174	538	356	287	g/day	9351	6944	6225	g/day	9625	7173	6399
	Ag*	µg/l						0.000321	0.000321	0.000321				mg/day			0.0248	0.0246	0.0193				mg/day	0.843	0.743	0.692	mg/day	0.868	0.768	0.712
	Al	µg/l	56	100		23.6	25.7	1.29	3.94	5.69	1.56	1.66	2.59	mg/day	1980	2281	99.4	301	343	154	156	257	mg/day	3383	9108	12260	mg/day	3483	9409	12600
	As	µg/l	0.56	5	100	5.21	0.889	1.13	4.45	5	0.00223	0.00629	0.011	mg/day	436	78.9	87.2	340	301	0.22	0.591	1.09	mg/day	2968	10290	10780	mg/day	3055	10630	11080
	Ba	µg/l				15.1	15	11.5	7.8	6.95	15.4	10.3	9.15	mg/day	1260	1335	888	597	418	1521	968	909	mg/day	30220	18030	14960	mg/day	31110	18630	15380
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	1.67	1.66	1.65	1.02	1.03	1.03	mg/day	21.3	25.8	129	127	99.4	101	96.6	102	mg/day	4394	3846	3558	mg/day	4523	3974	3658
	Co	µg/l	1.4	4		5.78	11.1	80.7	79	78.4	39.8	39.5	39.4	mg/day	484	987	6224	6040	4716	3934	3710	3911	mg/day	211800	182600	168800	mg/day	218000	188600	173500
	Cr	µg/l	0.36	1	100	1.17	0.941	0.248	0.0931	0.0749	0.014	0.00213	0.00159	mg/day	97.9	83.6	19.1	7.12	4.51	1.38	0.2	0.158	mg/day	649	215	161	mg/day	668	222	166
	Cu	µg/l	2	5	300	3.61	5.19	1697	1906	1957	36.2	29.4	33.6	mg/day	302	460	130800	145800	117800	3582	2758	3339	mg/day	4451000	4408000	4215000	mg/day	4581000	4553000	4332000
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	1.64	1.64	1.63	1.03	1.03	1.03	mg/day	2.87	4.01	126	126	98.1	102	96.9	102	mg/day	4294	3798	3512	mg/day	4420	3924	3610
	Mn	µg/l	180	700		281	1003	885	846	841	491	435	408	mg/day	23500	89070	68190	64710	50580	48520	40830	40550	mg/day	2320000	1956000	1810000	mg/day	2388000	2021000	1861000
	Mo	µg/l	0.2	1000		0.489	0.0516	63.8	64.1	63.7	39.3	39.3	39.3	mg/day	41	4.58	4918	4902	3833	3890	3696	3907	mg/day	167400	148200	137200	mg/day	172300	153100	141000
	Ni	µg/l	4.5	20	500	13.3	9.63	98.6	95.1	94.5	44.4	44	43.7	mg/day	1113	855	7601	7273	5686	4388	4130	4338	mg/day	258700	219800	203500	mg/day	266300	227100	209200
	Pb	µg/l	0.06	7.2	200	1.15	1.28	0.864	0.893	0.897	0.0503	0.0396	0.04	mg/day	96.3	114	66.6	68.3	54	4.98	3.72	3.97	mg/day	2266	2065	1932	mg/day	2333	2133	1986
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0967				mg/day	4.22	3.72	3.46	mg/day	4.34	3.84	3.56
	Se*	µg/l						0.00845	0.00908	0.00916				mg/day			0.651	0.695	0.551				mg/day	22.2	21	19.7	mg/day	22.8	21.7	20.3
	Sr	µg/l				41.6	84.7	1051	1034	1025	671	652	645	mg/day	3483	7522	81060	79080	61690	66370	61250	64060	mg/day	2758000	2390000	2207000	mg/day	2839000	2469000	2269000
	Th*	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	149	132	122
	Tl*	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.19	3.9	mg/day	4.9	4.33	4.01
	U	µg/l	0.23	15		1.25	0.176	964	964	957	605	605	605	mg/day	105	15.6	74320	73740	57580	59790	56800	60060	mg/day	2529000	2229000	2060000	mg/day	2603000	2303000	2118000
	Zn	µg/l	2.2	30	500	8.97	13.7	588	587	587	28	26.9	26.3	mg/day	751	1217	45330	44930	35300	2769	2532	2612	mg/day	1543000	1358000	1263000	mg/day	1588000	1403000	1299000

Exceeds water quality action value for the Niesajoki river

Exceeds water quality trigger value for the Niesajoki river

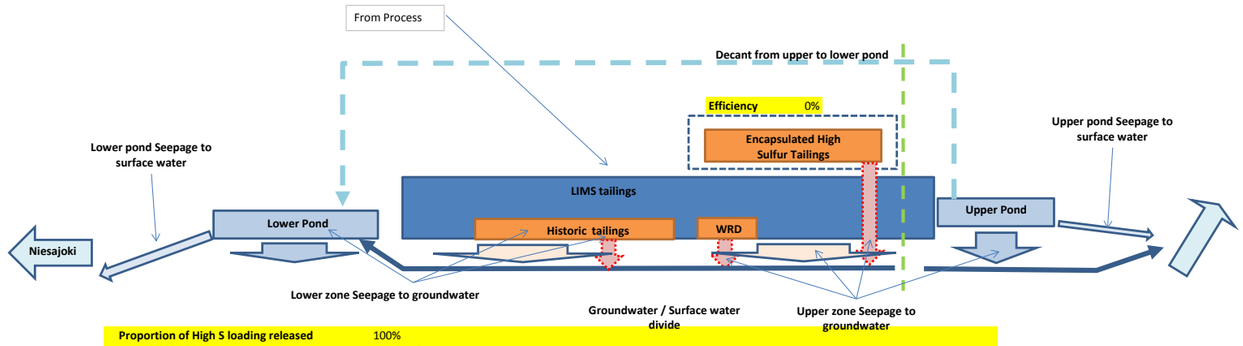
Exceeds IFC effluent water quality guidelines

0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model

* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**

^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

Post Closure - 100% High Sulfur Tailings Load
Water Balance



Source	Chemistry data used
Historic WRD	Average TP water quality
Historic Tailings To Neisajoki	Average TP water quality
Precipitation	From Hannukainen models
Clean groundwater	Average from all BH (deep and shallow) outside of TSF area
Historic Tailings to Upper pond and North GW	Average TSF seepage

Flow data used
Assume recharge in WRD area
Assume recharge in tailings area
Values from Hydro model
Values from hydro model
From Recharge in area

Proportion of High S loading released	100%	
LIMS LOM process water seepage	0	m3/day
LIMS divide %	**90%**	**10%**
High S divide %	**90.00%**	**10.00%**

80

Average

Lower (Tailings) Pond						Upper Pond					
	Runoff	80.00					Runoff	0.00			
	Direct precipitation on lower pond	307.73					Direct precipitation to pond	771.13			
	Decant from upper pond	222.52					Unimpacted groundwater seepage to pond	240.13			
	Treated water from Hannukainen and High S TSF	0.00									
	Unimpacted groundwater seepage to pond	21.52									
	High S Tailings Seepage South	110.07					High S Tailings Seepage North	12.23			
	LIMS tailings Seepage South	397.87	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	44.21	**PPT source**	0	**Entrained water**
Inflows	Unimpacted groundwater seepage to LIMS	713.23				**Inflowa**	Unimpacted groundwater seepage to LIMS	79.25			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	79.25			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	316.99					**Total Inflows**	**1213.97**			
	Impacted groundwater from UG to LIMS	396.24									
	From Upper pond	222.52									
	Total inputs	**2827.14**									
	Total Flow in	**2678.62**									
	Evaporation from Lower pond	319.16	**Adjusted (/1.1)**	**290.1477**			Evaporation from upper pond	897.50	**Adjusted (/1.1)**	**815.9052**	
Outflows	Decant from lower pond to Neisajoki	2311.98	96.3326581			**Outflows**	Decant to lower pond	222.52			
	Seepage from lower pond to groundwater	76.49					Seepage from upper pond to river	93.95			
	Total Outflows	**2707.63**	31.3383541				**Total Outflows**	**1213.97**			

June

Lower (Tailings) Pond						Upper Pond					
	Runoff	180.00					Runoff	95.00			
	Direct precipitation on lower pond	247.02					Direct precipitation to pond	619.00			
	Decant from upper pond	222.01					Unimpacted groundwater seepage to pond	385.23			
	Treated water from Hannukainen and High S TSF	0.00									
	Unimpacted groundwater seepage to pond	3.76									
	High S Tailings Seepage South	110.07					High S Tailings Seepage North	12.23			
	LIMS tailings Seepage South	488.74	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	54.30	**PPT source**	0	**Entrained water**
Inflows	Unimpacted groundwater seepage to LIMS	836.00				**Inflowa**	Unimpacted groundwater seepage to LIMS	92.89			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	92.89			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	371.56					**Total Inflows**	**1339.31**			
	Impacted groundwater from UG to LIMS	464.44									
	From Upper pond	222.01									
	Total inputs	**3184.06**									
	Total Flow in	**3035.55**									
	Evaporation from Lower pond	368.80	**Adjusted (/1.1)**	**335.2725**			Evaporation from upper pond	1018.41	**Adjusted (/1.1)**	**925.8236**	
Outflows	Decant from lower pond to Neisajoki	2623.18				**Outflows**	Decant to lower pond	222.01			
	Seepage from lower pond to groundwater	77.09					Seepage from upper pond to river	98.89			
	Total Outflows	**3069.07**	35.5216867				**Total Outflows**	**1339.31**			

Winter

Lower (Tailings) Pond						Upper Pond					
	Runoff	0.00					Runoff	0.00			
	Direct precipitation on lower pond	0.00					Direct precipitation to pond	0.00			
	Decant from upper pond	193.74					Unimpacted groundwater seepage to pond	151.12			
	Unimpacted groundwater seepage to pond	28.50									
	Treated water from Hannukainen and High S TSF	0.00									
	High S Tailings Seepage South	110.07					High S Tailings Seepage North	12.23			
	LIMS tailings Seepage South	380.68	**PPT source**	0	**Entrained water**		LIMS tailings Seepage North	42.30	**PPT source**	0	**Entrained water**
Inflows	Unimpacted groundwater seepage to LIMS	709.61				**Inflowa**	Unimpacted groundwater seepage to LIMS	78.85			
	WRD Seepage to lower pond	**20.99**					Impacted groundwater seepage from OP to LIMS	78.85			
	Historic Tailings seepage to lower pond	**1.65**	Neutral	**15.81**	Acid						
	Impacted Groundwater from OP to LIMS	315.38					**Total Inflows**	**351.11**			
	Impacted groundwater from UG to LIMS	394.23									
	From Upper pond	193.74									
	Total inputs	**2364.40**									
	Total Flow in	**2215.88**									
	Evaporation from Lower pond	2.63	**Adjusted (/1.1)**	**2.390943**			Evaporation from upper pond	58.03	**Adjusted (/1.1)**	**52.75839**	
Outflows	Decant from lower pond to Neisajoki	2153.32				**Outflows**	Decant to lower pond	193.74			
	Seepage from lower pond to groundwater	60.17					Seepage from upper pond to river	99.34			
	Total Outflows	**2216.12**	25.6495055				**Total Outflows**	**351.11**			

Post Closure 100% High Sulfur Tailings Load
Time Data Summary Predicted Water Quality

			Guidelines			Concentration in pond								Loading to local river systems based on groundwater seepage from pond								Loading to Niesajoki River based on decant volumes				Total Loading to Niesajoki (Seepage + Decant)			
			Niasjoki		IFC	Current Mean		South Pond			North Pond			Current Mean		South Pond (To Niesajoki)			North Pond (to Kylmäoja Stream)				South Pond (To Niesajoki)				South Pond (To Niesajoki)		
			AV	TV	Guidelines	South Pond	North Pond	June	Average	Winter	June	Average	Winter	South Pond	North Pond	June	Average	Winter	June	Average	Winter		June	Average	Winter		June	Average	Winter
		m3/day												83.73	88.80	77.09	76.49	60.17	98.89	93.95	99.34		2623.18	2311.98	2153.32				
Mass Balance Data	pH	S.U.				7.15	6.89	4.22	4.23	4.23	4.43	4.42	4.47																	
	Alkalinity	mmol/l				0.752	0.343	0.667	0.558	0.527	1.6	1.19	1.02	g/day	63	30.5	51.4	42.7	31.7	158	112	101	g/day	1751	1290	1135	g/day	1802	1333	1166
	NO3	µg/l	217	20,000		332	1181	165	138	130	369	260	203	mg/day	27790	104900	12690	10530	7823	36510	24400	20210	mg/day	431800	318400	279900	mg/day	444500	329000	287800
	PO4	µg/l				26.3	27.8	2263	2251	2232	1515	1469	1444	mg/day	2204	2472	174400	172200	134300	149800	138000	143400	mg/day	5936000	5205000	4805000	mg/day	6110000	5377000	4940000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.81	8.79	1.17	g/day	138	394	273	246	113	871	826	116	g/day	9279	7450	4044	g/day	9551	7696	4157
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.2	2.18	1.72				g/day	74.8	65.9	61.4	g/day	77	68.1	63.1
	TOC	mg/l	9	21		6.21	3.66	3.13	2.62	2.49	6.41	4.57	3.65	g/day	520	325	241	200	150	633	429	363	g/day	8214	6060	5361	g/day	8455	6261	5511
	SO4	mg/l	71	154		90.6	131	517	504	500	298	291	288	g/day	7588	11620	39870	38560	30080	29480	27310	28570	g/day	1357000	1166000	1077000	g/day	1397000	1204000	1107000
	Ca	mg/l				29.2	35.9	344	340	338	214	210	209	g/day	2443	3185	26550	26040	20320	21210	19780	20740	g/day	903400	787000	727000	g/day	930000	813000	747300
	Fe	mg/l	0.78	2.6	2	0.842	0.616	11.8	11.7	11.6	7.33	7.19	7.1	g/day	70.5	54.7	907	897	700	725	675	705	g/day	30870	27100	25050	g/day	31770	28000	25750
	K	mg/l				2.85	4.33	140	139	138	89.1	88.5	87.6	g/day	238	385	10780	10670	8319	8809	8312	8699	g/day	366700	322400	297700	g/day	377500	333100	306000
	Mg	mg/l				12.3	15.9	43.3	42.1	41.6	27.6	26.3	25.2	g/day	1029	1409	3335	3219	2504	2726	2469	2503	g/day	113500	97310	89610	g/day	116800	100500	92110
	Na	mg/l				4.43	6.82	30.8	29.7	28.6	29.8	26.6	21	g/day	371	605	2371	2272	1721	2950	2503	2084	g/day	80670	68680	61600	g/day	83040	70950	63320
	Si	mg/l				3.72	2.28	7.61	6.43	6.18	11.7	8.09	6.21	g/day	311	202	587	492	372	1153	760	617	g/day	19970	14870	13320	g/day	20560	15370	13690
	Ag	µg/l						0.000322	0.000322	0.000322				mg/day			0.0248	0.0246	0.0194				mg/day	0.845	0.744	0.693	mg/day	0.869	0.769	0.713
	Al	µg/l	56	100		23.6	25.7	1993	1941	1916	1552	1340	1221	mg/day	1980	2281	153700	148500	115300	153500	125900	121200	mg/day	5229000	4487000	4126000	mg/day	5382000	4636000	4241000
	As	µg/l	0.56	5	100	5.21	0.889	6.75	6.73	6.67	4.43	4.33	4.28	mg/day	436	78.9	520	515	402	438	407	425	mg/day	17700	15560	14370	mg/day	18220	16070	14770
	Ba	µg/l				15.1	15	534	528	524	347	337	333	mg/day	1260	1335	41170	40420	31530	34320	31700	33070	mg/day	1401000	1222000	1129000	mg/day	1442000	1262000	1160000
	Cd	µg/l	0.01	0.08	50	0.254	0.29	2.22	2.22	2.2	1.39	1.39	1.38	mg/day	21.3	25.8	171	170	132	138	130	137	mg/day	5822	5125	4737	mg/day	5994	5295	4869
	Co	µg/l	1.4	4		5.78	11.1	133	132	131	73.3	72.8	72.6	mg/day	484	987	10270	10080	7870	7247	6841	7210	mg/day	349400	304500	281600	mg/day	359700	314600	289500
	Cr	µg/l	0.36	1	100	1.17	0.941	5.15	5.05	4.99	4.16	3.7	3.45	mg/day	97.9	83.6	397	386	300	411	348	342	mg/day	13500	11680	10740	mg/day	13900	12060	11040
	Cu	µg/l	2	5	300	3.61	5.19	5049	5048	5010	3147	3146	3145	mg/day	302	460	389200	386100	301400	311300	295600	312400	mg/day	13240000	11670000	10790000	mg/day	13630000	12060000	11090000
	Hg	µg/l	0.002	0.05	2	0.0342	0.0451	2.19	2.19	2.18	1.38	1.38	1.38	mg/day	2.87	4.01	169	168	131	136	129	137	mg/day	5754	5072	4688	mg/day	5923	5240	4819
	Mn	µg/l	180	700		281	1003	897	857	849	500	442	416	mg/day	23500	89070	69150	65530	51060	49400	41570	41280	mg/day	2353000	1981000	1827000	mg/day	2422000	2046000	1878000
	Mo	µg/l	0.2	1000		0.489	0.0516	65.1	65	64.5	41.3	41.1	41	mg/day	41	4.58	5018	4975	3883	4089	3863	4072	mg/day	170800	150400	139000	mg/day	175800	155300	142800
	Ni	µg/l	4.5	20	500	13.3	9.63	148	144	143	76.7	75.6	75.1	mg/day	1113	855	11380	11030	8611	7588	7105	7456	mg/day	387100	333300	308100	mg/day	398500	344300	316800
	Pb	µg/l	0.06	7.2	200	1.15	1.28	1.96	1.82	1.78	2.39	1.83	1.51	mg/day	96.3	114	151	139	107	236	172	150	mg/day	5138	4211	3825	mg/day	5289	4351	3932
	Sb	µg/l	0.02	0.08		0.891	0.873	0.00161	0.00161	0.00161				mg/day	74.6	77.5	0.124	0.123	0.0966				mg/day	4.21	3.71	3.46	mg/day	4.34	3.83	3.55
	Se	µg/l						0.00946	0.00946	0.00946				mg/day			0.73	0.724	0.569				mg/day	24.8	21.9	20.4	mg/day	25.6	22.6	20.9
	Sr	µg/l				41.6	84.7	1055	1039	1030	672	653	645	mg/day	3483	7522	81320	79450	61970	66490	61360	64110	mg/day	2767000	2402000	2218000	mg/day	2848000	2481000	2280000
	Th	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	150	132	123
	Tl	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.76	4.2	3.91	mg/day	4.9	4.33	4.02
	U	µg/l	0.23	15		1.25	0.176	966	967	959	607	606	606	mg/day	105	15.6	74510	73930	57720	59980	56980	60240	mg/day	2535000	2235000	2066000	mg/day	2610000	2309000	2123000
	Zn	µg/l	2.2	30	500	8.97	13.7	605	603	603	41.3	38.7	37.4	mg/day	751	1217	46610	46150	36270	4083	3640	3714	mg/day	1586000	1395000	1298000	mg/day	1633000	1441000	1334000
Thermodynamic equilibrated data	pH	S.U.				7.15	6.89	5.88	5.46	5.36	7.29	7.02	6.88																	
	Alkalinity	mmol/l				0.752	0.343	2.99	1.41	1.13	59.2	37.3	28.2	g/day	63	30.5	231	108	68	5857	3509	2798	g/day	7851	3270	2434	g/day	8081	3378	2502
	NO3	µg/l	217	20,000		332	1181	164	137	130	368	259	203	mg/day	27790	104900	12670	10520	7809	36420	24340	20180	mg/day	431100	317900	279500	mg/day	443700	328400	287300
	PO4	µg/l				26.3	27.8	2889	4439	4460	14.5	378	510	mg/day	2204	2472	222700	339600	268400	1429	35540	50620	mg/day	7579000	10260000	9604000	mg/day	7802000	10600000	9872000
	Chloride	mg/l	2.3	150		1.65	4.44	3.54	3.22	1.88	8.8	8.78	1.17	g/day	138	394	273	246	113	870	825	116	g/day	9274	7446	4043	g/day	9547	7693	4156
	Fluoride	mg/l						0.0285	0.0285	0.0285				g/day			2.19	2.18	1.71				g/day	74.7	65.8	61.3	g/day	76.9	68	63
	TOC	mg/l	9	21		6.21	3.66							g/day	520	325							g/day				g/day			
	SO4	mg/l	71	154		90.6	131	511	498	494	297	289	286	g/day	7588	11620	39380	38080	29710	29330	27180	28450	g/day	1340000	1151000	1063000	g/day	1379000	1189000	1093000
	Ca	mg/l				29.2	35.9	343	340	337	211	208	206	g/day	2443	3185	26420	26010	20290	20860	19500	20470	g/day	898900	786200	726300	g/day	925300	812200	746600
	Fe	mg/l	0.78	2.6	2	0.842	0.616	0.00855	0.251	0.772	0.00029	0.00195	0.00465	g/day	70.5	54.7	0.659	19.2	46.4	0.0287	0.183	0.462	g/day	22.4	580	1662	g/day	23.1	599	1708
	K	mg/l				2.85	4.33	139	138	137	88.9	88.3	87.4	g/day	238	385	10690	10580	8251	8788	8294	8685	g/day	363600	319700	295300	g/day	374300	330300	303500
	Mg	mg/l				12.3	15.9	43.2	42	41.5	27.5	26.2	25.2	g/day	1029	1409	3330	3214	2500	2719	2463	2498	g/day	113300	97150	89470	g/day	116600	100400	91970
	Na	mg/l				4.43	6.82	30.7	29.7	28.6	29.8	26.6	20.9	g/day	371	605	2367	2268	1718	2944	2497	2081	g/day	80540	68560	61500	g/day	82900	70830	63220
	Si	mg/l				3.72	2.28	3.55	3	2.88	5.44	3.77	2.9	g/day	311	202	274	229	174	538	354	288	g/day	9315	6937	6210	g/day	9589	7166	6384
	Ag*	µg/l						0.000321	0.000321	0.000321				mg/day			0.0248	0.0246	0.0193				mg/day	0.843	0.743	0.692	mg/day	0.868	0.768	0.712
	Al	µg/l	56	100		23.6	25.7	1.63	12.5	22	1.4	1.73	2.84	mg/day	1980	2281	125	952	1326	138	162	282	mg/day	4265	28790	47470	mg/day	4390	29740	48790
	As	µg/l	0.56	5	100	5.21	0.889	5.21	5.86	5.82	0.00189	0.0065	0.0141	mg/day	436	78.9	401	448	350	0.187	0.61	1.41	mg/day	13660	13540	12530	mg/day	14060	13980	12880
	Ba	µg/l				15.1	15	11.4	7.65	6.82	15	10	8.89	mg/day	1260	1335	875	585	410	1480	941	883	mg/day	29790	17680	14680	mg/day	30660	18270	15090
	Cd^	µg/l	0.01	0.08	50	0.254	0.29	2.22	2.21	2.2	1.35	1.37	1.37	mg/day	21.3	25.8	171	169	132	134	128	136	mg/day	5812	5116	4729	mg/day	5983	5286	4861
	Co	µg/l	1.4	4		5.78	11.1	133	132	131	72.3	72.2	72.2	mg/day	484	987	10250	10060	7857	7145	6784	7170	mg/day	348800	304000	281200	mg/day	359000	314100	289000
	Cr	µg/l	0.36	1	100	1.17	0.941	0.366	0.183	0.168	0.0112	0.00197	0.00168	mg/day	97.9	83.6	28.2	14	10.1	1.1	0.185	0.167	mg/day	961	422	361	mg/day	989	436	371
	Cu	µg/l	2	5	300	3.61	5.19	4052	4648	4726	39.7	37.4	49.2	mg/day	302	460	312400	355500	284400	3929	3515	4890	mg/day	10630000	10750000	10180000	mg/day	10940000	11100000	10460000
	Hg^	µg/l	0.002	0.05	2	0.0342	0.0451	2.19	2.19	2.17	1.37	1.37	1.37	mg/day	2.87	4.01	169	167	131	136	129	137	mg/day	5734	5063	4680	mg/day	5902	5230	4811
	Mn	µg/l	180	700		281	1003	896	855	847	496	440	414	mg/day	23500	89070	69040	65420	50980	49040	41380	41140	mg/day	2349000	1977000	1824000	mg/day	2418000	2043000	1875000
	Mo	µg/l	0.2	1000		0.489	0.0516	64.6	64.5	63.9	38.8	39.1	39.3	mg/day	41	4.58	4983	4932	3846	3842	3671	3904	mg/day	169500	149100	137600	mg/day	174500	154000	141500
	Ni	µg/l	4.5	20	500	13.3	9.63	147	144	143	73.3	73.7	73.8	mg/day	1113	855	11360	11010	8597	7246	6922	7331	mg/day	386400	332700	307600	mg/day	397800	343700	316200
	Pb	µg/l	0.06	7.2	200	1.15	1.28	1.1	1.15	1.16	0.037	0.0336	0.0385	mg/day	96.3	114	85	87.9	70	3.66	3.15	3.83	mg/day	2891	2658	2507	mg/day	2976	2746	2577
	Sb	µg/l	0.02	0.08		0.891	0.873	0.0016	0.0016	0.0016				mg/day	74.6	77.5	0.124	0.123	0.0965				mg/day	4.2	3.71	3.45	mg/day	4.33	3.83	3.55
	Se*	µg/l						0.00914	0.00928	0.00929				mg/day			0.705	0.71	0.559				mg/day	24	21.5	20	mg/day	24.7	22.2	20.6
	Sr	µg/l				41.6	84.7	1053	1037	1028	671	652	644	mg/day	3483	7522	81190	79320	61870	66330	61230	64010	mg/day	2763000	2398000	2214000	mg/day	2844000	2477000	2276000
	Th*	µg/l						0.0554	0.0554	0.0554				mg/day			4.27	4.24	3.34				mg/day	145	128	119	mg/day	149	132	122
	Tl*	µg/l						0.00181	0.00181	0.00181				mg/day			0.14	0.139	0.109				mg/day	4.75	4.19	3.9	mg/day	4.89	4.33	4.01
	U	µg/l	0.23	15		1.25	0.176	965	965	957	605	605	605	mg/day	105	15.6	74360	73790	57610	59810	56850	60130	mg/day	2530000	2230000	2062000	mg/day	2605000	2304000	2119000
	Zn	µg/l	2.2	30	500	8.97	13.7	603	602	602	35.7	35.7	35.5	mg/day	751	1217	46510	46070	36210	3531	3355	3525	mg/day	1583000	1393000	1296000	mg/day	1629000	1439000	1332000

Exceeds water quality action value for the Niesajoki river
Exceeds water quality trigger value for the Niesajoki river
Exceeds IFC effluent water quality guidelines
0.001 Equilibrated value equivalent to unequilibrated value as not included in the equilibrated model
* **Ag, Se, Th, Tl concentrations based on limited loadings from historic trial pits only**
^ **Cd and Hg concentrations elevation partially due to detection limits in groundwater constituent**

ATTACHMENT B – EXAMPLE PHREEQC INPUT SCRIPT FOR LIFE OF MINE TAILINGS UNDER CURRENT CONDITIONS

```
KNOBS
    -iterations            10000
    -convergence_tolerance 1e-008
    -tolerance             1e-015
    -step_size             100
    -pe_step_size          5


SELECTED_OUTPUT
    -file                  Equilibration output_LOM_V2.out
    -selected_out          true
    -high_precision        true
    -simulation            true
    -state                 true
    -solution              true
    -distance              false
    -time                  false
    -step                  false
    -ph                    true
    -pe                    true
    -alkalinity            true
    -ionic_strength        true
    -water                 true
    -charge_balance        true
    -totals                C(4)      N     P     Cl    F     S(6)  Ca    Fe
      K     Mg    Na    Si    Ag    Al    As    Ba    Cd    Co    Cr    Cu
      Hg    Mn    Mo    Ni    Pb    Sb    Se    Sr    Tl    U     Zn
END
PHASES
Fix_pe
    e- = e-
    log_k     0
End
SOLUTION_SPREAD
          pH       Temperature                 pe           Alkalinity
N(5)             P                Cl                 F                S(6)
                Ca                Fe                 K                Mg
                Na                Si                Ag                Al
                As                Ba                Cd                Co
                Cr                Cu            Hg(0)                 Mn
                Mo                Ni                Pb                Sb
                Se                Sr                Tl                 U
                Zn
                                                  mg/kgw as HCO3    mg/kgw
as NO3       mg/kgw as P            mg/kgw            mg/kgw       mg/kgw
as SO4            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw            mg/kgw            mg/kgw
mg/kgw            mg/kgw
  5.80562963                 7        6.19437037          23.76843902
1.926590673  0.032310557       0.530337522       0.004813932
245.1327329   37.0496228       0.231852556       28.65386424
10.40831018  26.63883908       1.073547095       5.43507E-08
0.145080715  0.001046939       0.010621711       0.001267703
0.041851028  0.013183542       0.235838383       0.000342498
0.201343114  0.014715026       0.061342348       0.000669779
0.001693484  1.59775E-06       0.016070117       3.06314E-07
0.018303901  0.119080304
```

```
 5.972695422                  7       6.027304578          23.36714845
1.279576554   0.02217271        0.389921866       0.003539364
426.7160684  34.21125167        0.237028939       38.60449111
12.11507145  35.97281953        0.789307693       3.99605E-08
0.102030584  0.001761735        0.007443957       0.004299656
0.036532607  0.019610537         0.19944225       0.000555636
0.164298188  0.016060465        0.084017869       0.001180056
0.002614989  1.17472E-06        0.011815287       2.25212E-07
0.020927047  0.092493367
 6.074284255                  7       5.925715745           24.0731026
0.915498829  0.015285403        0.272461643       0.002295197
292.6536038  25.83239646        0.157923727       26.81113968
8.857341611  26.15451964        0.529902322       2.59135E-08
0.069201876  0.001149374        0.005046512       0.002805855
0.037226512  0.012750997        0.153511124       0.000395264
0.154917932   0.01137691         0.06451206       0.000796282
0.001808408  7.61777E-07        0.007798442       1.46045E-07
0.014952685  0.065221089
 5.064454837                  7       6.935545163          42.16193489
3.747142152  0.109688785        9.886098973                0
39.76757584  14.59967362        0.559255576       3.041597365
5.580757906  13.62522363        9.103517387                0
0.495242552  0.000232613        0.03034619          1.358E-05
0.00442851   0.001135355        0.145813915       2.32276E-06
0.172512496   0.00098933        0.005922777       0.001279064
2.32276E-05            0         0.06882552                0
0.000175518  0.007369962
 5.064454837                  7       6.935545163          42.16193489
1.44378487   0.109022928        9.886098973                0
37.66579019  14.42571461         0.41341741       2.830969765
5.521171448  13.45154335        9.103517387                0
0.485626338  0.000231065        0.030222309       1.20315E-05
0.002399969    0.0010889        0.050673791       7.74252E-07
0.171505968  0.000710599        0.003971661       0.001275967
7.74252E-06            0         0.06882552                0
0.000160033  0.006735076
 5.239260696                  7       6.760739304          134.6355632
6.829230547  0.129922812        6.571823106                0
132.9647631  25.17186183        0.439592828       16.29996134
9.201713713  25.07933185        6.051598925                0
0.495149606  0.000360505        0.033343596       2.44679E-05
0.003726194  0.001737784        0.102164742       1.49259E-05
0.143377321  0.027102293        0.009006859       0.001103489
0.00092129             0        0.045752034                0
0.007476704  0.008826275
end

EQUILIBRIUM_PHASES 1
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 1
Save Solution 11
Save Equilibrium Phase 11
end
SURFACE 11
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
```

```
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 11 ## uses ferrihydrite precipited as reactive
surface
USE Surface 11
USE Solution 11
SAVE Solution 21  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 1
    H2O        -1
    0 moles

USE solution 21
End
EQUILIBRIUM_PHASES 2
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 2
Save Solution 12
Save Equilibrium Phase 12
end
SURFACE 12
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 12 ## uses ferrihydrite precipited as reactive
surface
USE Surface 12
USE Solution 12
SAVE Solution 22  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 2
    H2O        -1
    0 moles

USE solution 22
End
EQUILIBRIUM_PHASES 3
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 3
Save Solution 13
Save Equilibrium Phase 13
end
SURFACE 13
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 13 ## uses ferrihydrite precipited as reactive
surface
USE Surface 13
USE Solution 13
```

```
SAVE Solution 23  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 3
    H2O        -1
    0 moles

USE solution 23
End
EQUILIBRIUM_PHASES 4
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 4
Save Solution 14
Save Equilibrium Phase 14
end
SURFACE 14
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 14 ## uses ferrihydrite precipited as reactive
surface
USE Surface 14
USE Solution 14
SAVE Solution 24  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 4
    H2O        -1
    0 moles

USE solution 24
End
EQUILIBRIUM_PHASES 5
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 5
Save Solution 15
Save Equilibrium Phase 15
end
SURFACE 15
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 15 ## uses ferrihydrite precipited as reactive
surface
USE Surface 15
USE Solution 15
SAVE Solution 25  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 5
    H2O        -1
```

```
    0 moles

USE solution 25
End
EQUILIBRIUM_PHASES 6
    Fix_pe    -5 O2(g) 10
    CO2(g)    -2.61 10
    Alunite 0 0
    Gibbsite 0 0
    Ferrihydrite 0 0
    Malachite 0 0
Use Solution 6
Save Solution 16
Save Equilibrium Phase 16
end
SURFACE 16
    Hfo_sOH Ferrihydrite         equilibrium_phase 0.005 64200
    Hfo_wOH Ferrihydrite         equilibrium_phase 0.2
    -donnan 1e-008
USE EQUILIBRIUM_PHASES 16 ## uses ferrihydrite precipited as reactive
surface
USE Surface 16
USE Solution 16
SAVE Solution 26  #Waste rock leachate after Mineral Precipitation and
Sorption Loss
END
REACTION 6
    H2O        -1
    0 moles

USE solution 26
End
```

APPENDIX K

K ARTIFICIAL PIT FLOODING

Technical Memo

Kaya Consulting Limited

DATE: January, 2013

TO: Sarah Lyle, Andy Barnes, SRK Consultants

FROM: Michael Stewart

CC:

SUBJECT: Pit Lake Water Balance Calculations for Hannukainen and Kuervitikko pit lakes

---

1. Introduction and Purpose of Assessment

At the end of operations at Hannukainen the two open pits (Hannukainen and Kuervitikko) will be allowed to fill with water to form pit lakes. Infilling will be through natural surface water and groundwater inflows to the pits, with the potential for the infilling to be augmented by pumping from nearby watercourses and main water management ponds. The formation of pit lakes is a common closure option for open pits at mine sites. The submerging of pit walls prevents oxidation of the wall rock, with the aim of limiting the generation of poor quality water.

A water balance model was set-up for each pit lake in order to provide predictions of the time required to fill each pit lake, to assess the relative contributions of different sources of inputs and to allow analysis of the sensitivity of the model to changes in key model inputs.

A water balance model was set-up using the GoldSim modelling software, with the model being run using a monthly time step and assuming the pits are empty of water at the end of operations.

2.1. Key Physical Data

Key physical data for each pit lake is shown in Table 1. Storage/elevation and area/elevation curves for the pit lakes are shown in Figure 1.

2.2 Water Balance Inputs and Outflows

Key inputs and outflows to the water balance are;

- Surface water runoff over pit walls;
- Precipitation and Evaporation on pit lake surface;
- Runoff from catchment areas surrounding pits (including runoff from waste dumps);
- Groundwater Inflows and Outflows;
- Pumping from nearby watercourses; and
- Overspill from pits.

2.2.1 Surface water runoff over pit walls

Annual flow rates for natural runoff from pit wall areas are modelled as:

Total Annual Flow (m^3/year) = Total Annual Rainfall (m/year) x Runoff Coefficient x 2-D Pit Wall Surface Area (m^2)

These are partitioned into average monthly flow rates based on the equation;

Average Monthly Inflow (m^3/mon) = Total Annual Flow Volume (m^3) x Percentage of Annual Flow Occurring in Month (/mon).

Annual average precipitation and return period annual totals were calculated based on available data from the Kaunisvaara weather station, with average annual precipitation at the site estimated to be 528 mm. Pöyry (2012) presented return period precipitation estimates as shown in Table 2. Monthly average precipitation totals were also calculated, giving a monthly precipitation distribution shown in Table 3. In Table 3 'Effective precipitation' is defined to calculate the timing of inputs from precipitation to water bodies, taking into account that precipitation during winter months within the study area will fall as snow and will not contribute to the lake water balance until it melts in spring. Hence, in defining Effective Precipitation it is assumed that all precipitation falling in the winter months is assumed to be snow, and that this snow melts during May and June. Hence, in Table 3 the winter monthly percentages for effective precipitation equal zero (i.e., precipitation is stored as snow) and the high monthly percentages in May and June reflect snowmelt.

Hence, the pit wall runoff varies depending on annual rainfall totals and the seasonal distribution of rainfall in the study area.

Runoff coefficients considered in the assessment are provided in Table 4. It is possible that rainfall falling on overburden exposed in the upper benches within each pit would produce significantly less runoff than rainfall falling on exposed rock within the pit walls. However, depth to overburden at the Hannukainen and Kuervitikko is considered small and as a result a single runoff coefficient was used for the whole pit wall area.

The pit wall area exposed above the pit lake water level varies over time as the pit lake fills. Pit wall areas are calculated as the difference between the total pit area and the pit lake area. Over time the pit wall area will become steadily smaller as the pit lake expands and submerges the pit walls. The change in area varies based on the relationships outlined in Figure 2.

2.2.2 Precipitation on, and Evaporation from, pit lake surface

Annual net inflows due to precipitation on, and evaporation from, the surface of a pit lake are based on:

Annual Net Flow to Lake Surface (m^3/year) = (Total Annual Precipitation (m/year) – Total Annual Evaporation (m/year)) x Lake Area (m^2).

The pit lakes load balance models run on a monthly time step with monthly precipitation and evaporation totals modelled as:

Average Monthly Inflow/Outflow (m^3/mon) = ((Total Annual Precipitation (m) x Percentage of Precipitation Occurring in Month (/mon)) – (Total Annual Evaporation (m) x Percentage Evaporation Occurring in Month (/mon)) x Lake Area (m^2).

Return period annual precipitation totals are provided in Table 2.

Estimated annual average lake evaporation is 286.6 mm predicted by the Finnish Environment Institute SYKE model, for lakes in the Hannukainen area, from data presented in Pöyry (2012a). No information was available (i.e., annual evaporation measurements obtained for multiple years) to allow development of return period evaporation estimates, so the model is run with average evaporation in every year. The monthly distribution of the annual precipitation and evaporation totals is provided in Table 3.

The model predicts the change in pit lake area over time as it fills, based on relationships relating lake area with pit lake volume, Figure 2. Over time the pit lake area will increase as the pit fills and submerges the pit walls.

2.2.3 Runoff from catchments surrounding pit lakes

During operations waste rock will be stacked on land surrounding the two pit lakes. At closure runoff from the waste dumps will be directed towards the pit lakes. There will be six waste dump areas at closure and annual runoff totals from the waste dumps have been calculated by Pöyry (K-M Haanpaa pers. comm.). These annual runoff totals and the pits into which runoff flows are provided in Table 5.

Within the model these annual totals are divided into monthly totals based on the monthly distribution for Effective Precipitation in Table 3. It is assumed that during winter months the waste dumps will be frozen so the monthly runoff for the dumps will be described better by the Effective Precipitation monthly distribution rather than that for natural watersheds, shown in Table 3.

2.2.3 Groundwater Inflows and Outflows

Groundwater inflows to Hannukainen and Kuervitikko pits have been predicted by groundwater modelling. The pits will be net sinks for groundwater and groundwater inflow rates to the pit lakes will decrease as they fill. The change in groundwater inflow rate with water level in the pit lakes is summarised in Table 6.

2.2.4 Pumping of water from nearby watercourses

It is advantageous if the pit lakes could be filled as quickly as possible as this would limit the time of exposure for acid generating pit wall rock. There are a number of possible sources of water at the Hannukainen site that could be pumped into the pits to speed up the infilling process.

One source of water could be the Clarification Pond at Hannukainen. This pond has a full capacity of 1.8 Mm^3 with a minimum volume of 0.5 Mm^3. It is assumed in the Base Case that at the beginning of closure 1.3 Mm^3 (difference between maximum and minimum) volume can be pumped from the pond to Hannukainen pit at a rate of 550 L/s. This is an assumed pumping rate, based on pumping capacity available at the mine site for pumping of water from the Hannukainen site to the Rautuvaara TMF (2000 m^3/hour). Pumping from the Clarification Pond to Hannukainen pit is assumed to take place all year round.

Once the Clarification Pond has been emptied, it is assumed that additional water can be obtained from Äkäsjoki River. The Äkäsjoki is a relatively large river with average monthly flows outlined in Table 7. There is a high seasonality in flow rates in the river, with higher flows in spring due to snow melt, moderate flows in summer and low flows in winter. For practical and environmental reasons the Base Case assumes that there is no pumping during winter (November to April). The pumping rate during open water months (May to October) is set at 550 L/s.

It is noted that the volume of water available from the Clarification Pond (1.3 Mm^3) is significantly smaller than the annual pumping rate from the Äkäsjoki (8.7 Mm^3).

The Base Case assumes that water is pumped to Hannukainen pit lake first, with water pumped to Kuervitikko pit lake only once Hannukainen pit is full. However, sensitivity runs are undertaken that consider pumping to Kuervitikko before Hannukainen and sensitivity runs also consider the impact of varying the pumping rate to both pit lakes.

A detailed assessment of the impact of pumping from Akasjoki has not been undertaken for this assessment. However, the proposed pumped flow rate (0.55 m^3/s) is around 3% of May flows in the river and 10% of mid-summer flows. Pumping rates would need to be agreed with regulators.

2.2.4 Overspill from pit lakes

Hannukainen pit lake will overspill towards Äkäsjoki River once the pit lake water level has reached 185.5 m asl.

Kuervitikko pit lake will overspill towards Kuerjoki River once the pit lake water level has reached 234.3 m asl.

2.3 Summary of Model Inputs and Sensitivity

Base Case model inputs and values considered in sensitivity analyses are summarised in Table 8.

2. Model Results

Model results are presented for the Base Case, as outlined in Table 8 and for a series of sensitivity runs that consider the impact of changing key parameters on the time to fill the two pit lakes.

3.1 Base Case

The predicted evolution of water levels in the pit lakes is shown in Figure 2 for the Base Case scenario. Under Base Case conditions Hannukainen pit lake is predicted to fill within 14 years.

Kuervitikko pit lake is predicted to fill within 17 years. It is noted that in the Base Case pumping of water to Kuervitikko only occurs once Hannukainen is full. At Kuervitikko the pit lake is substantially filled in years 1 to 15 by groundwater and surface water inflows only, with two additional years of pumped inflows (years 16 to 17) once Hannukainen pit lake is full and the pumps are moved to Kuervitikko.

Annual inflows and outflows for Hannukainen and Kuervitikko pit lakes are shown in Table 9. It is clear from the table that the dominant inflow to the pit lake is the pumped inflow from either the Water

Collection Pond or from Äkäsjoki. Pumped inflows account for around 80% of the total inflow to Hannukainen pit lake.

3.2 Sensitivity Runs

Seven model scenarios are considered varying key model inputs. Details of the sensitivity run and predicted times to fill for each run are provided in Tables 10a and b. It is clear from the results that the time to fill is most sensitive to the pumped inflow rate from the Water Collection Pond or from Äkäsjoki. Without pumped inflows the time to fill Hannukainen pit is predicted to be 81 years for average runoff and precipitation conditions, compared to 14 years with the pumped inflows as outlined in the Base Case run.

Without pumped inflows the time to fill Kuervitikko pit is predicted to be 18 years for average runoff and precipitation conditions, compared to 17 years with the pumped inflows as outlined in the Base Case run. If the Kuervitikko pit lake were to be filled with pumped water before Hannukainen pit lake, the model predicts the pit could be filled in4 years only.

3. Summary and Conclusions

This report has presented initial water balance calculations for the infilling of two pit lakes at the proposed Hannukainen mine site. The model results, in terms of the time for the pit lakes to fill, are sensitive to the pumped inflow rate from the Water Collection Pond or from Äkäsjoki.

Without pumped inflows the time to fill Hannukainen pit is predicted to be 81 years for average runoff and precipitation conditions. However, the time to fill can be reduced to 14 years with pumped inflows at 550 L/s during summer months.

Without pumped inflows the time to fill Kuervitikko pit is predicted to be 18 years for average runoff and precipitation conditions. The time to fill can be reduced to 17 years with pumped inflows at 550 L/s during summer months, if the pit lake is filled after Hannukainen or 4 years if Kuervitikko pit lake is filled before Hannukainen pit lake.

These model results are based on information available at the time of the analysis and are based on the assumptions outlined in the text above. It would be noted that the calculations consider the pit lake water balance only and do not consider water quality predictions. Pumped inflow options are based on the available (2,000 m^3/hour) capacity for pumps taking water from Hannukainen to Rautuvaara during operations. If additional pumping capacity were available at closure infilling times could be reduced. In contrast, if this pumping capacity was not available infilling would take longer.

A detailed assessment of the impact of pumping from Äkäsjoki has not been undertaken for this assessment. However, the proposed pumped flow rate (0.55 m^3/s) is around 3% of May flows in the river and 10% of mid-summer flows. Pumping rates would need to be agreed with regulators. However, the main purpose of this assessment was to identify sensitivities and likely infilling rates of the pit lakes under a range of infilling conditions.

4. References

Pöyry, 2012. Site Water Balance Water Management Plan, Hannukainen DFS.

Table 1: Key Physical Data for Each Pit Lake

Open Pit	Total Depth (m)	Max Open Pit Surface Area (m^2)	Total Pit Volume (m^3)	Full Pit Lake Spill Elevation (masl)
Hannukainen pit	[a]205.5	[a]1,720,000	[a]148,500,000	185.5
Kuervitikko pit	[a]134.3	[a]472,000	[a]29,540,000	234.3

a Calculated from bottom of open pit to 185.5 masl level

b Calculated from bottom of open pit to 234.3 masl level

Table 2: Return Period Precipitation Estimates

Return Period	[a]Annual Precipitation (mm)
1 in 50 dry year	274
1 in 20 dry year	317
Average year	528
1 in 20 wet year	740
1 in 50 wet year	793

[a] *Return period analysis was undertaken by Pöyry (2012)*

Table 3: Estimates of Monthly Precipitation and Evaporation

Parameter	Percentage by Month (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation	6.5	5.1	5.4	5.9	6.4	9.8	14.0	13.4	9.6	8.9	8.6	6.3
[a]Effective Precipitation	0.0	0.0	0.0	0.0	44.2	9.8	14.0	13.4	9.6	8.9	0.0	0.0
Lake Evaporation	0.0	0.0	0.0	0.3	11.0	23.7	27.6	22.9	10.4	3.8	0.4	0.0
Catchment Runoff	2.7	2.0	2.0	4.1	32.6	15.0	7.7	7.3	7.5	8.7	6.5	3.9

[a] See text for definition

Table 4: Runoff coefficients

Area	Runoff Coefficient
Pit Walls – exposed bedrock	[a]0.9
Catchment surrounding pit lake	[a]0.5
Waste rock dump	[a]0.5

[a] *Estimated based on experience of similar studies at other mine sites*

[b] *Based on observed runoff and precipitation data for northern Finland*

Table 5: Runoff from waste rock dumps surrounding pit lakes

Waste Rock Dump	Normal year (Mm^3/yr)	Dry year (Mm^3/yr)	Wet year (Mm^3/yr)	Pit lake to which runoff flows
West Overburden Dump	0.21	0.11	0.30	Hannukainen pit lake
West Dump Inert	0.29	0.15	0.41	Hannukainen pit lake
West Dump PAF	0.10	0.05	0.14	Hannukainen pit lake
East Dump Overburden	0.32	0.16	0.45	66% to Hannukainen pit lake and 33% to Kuerjoki River
East Dump Inert	0.29	0.14	0.40	Hannukainen pit lake
East Dump PAF	0.47	0.23	0.66	Hannukainen pit lake

Table 6: Groundwater flow rates with water level

Hannukainen pit		Kuervitikko pit	
Water Level (masl)	Groundwater flow rate (m^3/day)	Water Level (masl)	Groundwater flow rate (m^3/day)
-20	7343	100	7363
-10	7052	110	7031
0	6761	120	6700
10	6470	130	6369
20	6179	140	6037
30	5887	150	5706
40	5596	160	5375
50	5305	170	5043
60	5014	180	4712
70	4723	190	4381
80	4432	200	4049
90	4141	210	3718
100	3850	220	3387
110	3559	230	3056
120	3268	240	2724
130	2977		
140	2686		
150	2395		
160	2104		
170	1813		
180	1522		
190	1231		
200	940		
210	649		
220	358		

Table 7: Average monthly flows in Äkäsjoki River

Average Monthly Flow (m^3/s)											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1.7	1.3	1.2	2.6	20.4	9.4	4.8	4.6	4.7	5.5	4.1	2.4

Table 8: Summary of Base Case model parameters

Parameter	**Base Case Value**	**Source**
Pit areas/volumes and storage curves	Figure 2.	Provided by SRK
Upstream catchment area to pit lakes	Runoff from waste rock dumps flows to pit lakes as per Table 5	Pöyry pers comm.
Groundwater flow rate	Flow rate varies with pit lake water level as per Table 6	Groundwater model results
Pit lake surface spill levels	Hannukainen pit overspills to Äkäsjoki at 185.5 masl Kuervitikko pit lake overspills to Kuerjoki at 234.3 masl	
Variation of pit lake area over time	Predicted by model.	-
Annual precipitation total	Average annual precipitation of 528 mm. Runs assume same annual precipitation total in every year.	Statistical analysis of rainfall data provided by Pöyry (2012)
Annual Evaporation total	Average annual lake evaporation of 286.6 mm. Runs assume same annual evaporation total in every year.	From SYKE model predictions for study area
Monthly distribution of precipitation	Table 3.	Statistical analysis of precipitation data from Pöyry (2012)
Monthly distribution of evaporation	Table 3, lake evaporation values.	From SYKE model predictions for study area
Runoff coefficients	Table 4.	Estimated based on observed runoff and precipitation data and experience of other pit lake infilling studies.
Additional infilling	Initial input of 1.3 Mm^3 from Water Collection Pond at 550 L/s to Hannukainen pit lake. On-going pumped inflow from Äkäsjoki River during summer months at 550 L/s to Hannukainen pit lake. No pumped inflows to Kuervitikko pit lake.	Estimated

Table 9: Summary of Annual Inflows and Outflow for Base Case

Hannukainen pit lake

Time (yr)	Flows (m^3/year)						
	Precipitation on Pit Lake	Precipitation on Pit Walls	Groundwater Inflow	Pumped Inflows	All Inflows	Evaporation	Overflow from Pit Lake
1	122,340	867,500	2,091,300	9,978,300	13,190,000	72,754	0
2	241,550	760,210	1,727,500	8,678,300	11,538,000	135,580	0
3	342,010	669,800	1,522,100	8,678,300	11,343,000	189,910	0
4	420,040	599,570	1,366,100	8,678,300	11,195,000	231,140	0
5	481,950	543,850	1,235,400	8,678,300	11,070,000	265,180	0
6	546,490	485,770	1,123,100	8,678,300	10,964,000	300,020	0
7	617,340	422,010	1,025,700	8,678,300	10,874,000	339,260	0
8	680,710	364,970	938,750	8,678,300	10,793,000	372,490	0
9	729,470	321,080	858,970	8,678,300	10,718,000	399,220	0
10	782,980	272,930	785,590	8,678,300	10,650,000	428,530	0
11	826,990	233,320	716,630	8,678,300	10,586,000	451,750	0
12	863,730	200,250	651,100	8,678,300	10,524,000	471,480	0
13	890,580	176,090	588,850	8,678,300	10,464,000	485,790	0
14	906,060	162,160	525,850	8,678,300	10,403,000	493,070	0
15	906,060	162,160	496,950	0	1,695,700	493,070	1,202,600

Kuervitikko pit lake

Time (yr)	Flows (m^3/year)						
	Precipitation on Pit Lake	Precipitation on Pit Walls	Groundwater Inflow	Pumped Inflows	All Inflows	Evaporation	Overflow from Pit Lake
1	24,131	242,230	1,185,100	0	1,451,461	14,367	0
2	53,704	217,930	1,069,900	0	1,341,534	30,005	0
3	77,033	196,330	1,012,800	0	1,286,163	42,291	0
4	92,725	180,500	970,980	0	1,244,205	50,897	0
5	104,370	172,330	934,250	0	1,210,950	56,900	0
6	116,990	160,370	902,570	0	1,179,930	63,811	0
7	130,080	146,870	877,840	0	1,154,790	71,357	0
8	143,400	137,210	853,700	0	1,134,310	78,001	0
9	151,770	129,060	831,460	0	1,112,290	82,493	0
10	159,240	120,640	812,360	0	1,092,240	87,105	0
11	168,520	114,590	793,410	0	1,076,520	91,573	0
12	175,140	108,030	775,360	0	1,058,530	95,104	0
13	180,820	101,210	760,050	0	1,042,080	98,832	0
14	189,130	96,046	743,930	0	1,029,106	102,730	0
15	196,520	88,790	728,810	0	1,014,120	106,730	0
16	224,500	61,904	668,400	8,669,700	9,624,504	125,920	0
17	250,760	40,582	558,980	8,695,700	9,546,022	135,940	0
18	250,180	40,490	530,700	0	821,370	135,560	685,810

Table 10a: Summary of sensitivity results for Hannukainen pit

Model Run	Comment	Years to fill pit lake	Result compared to Base Case
Base Case	Parameters as per Table 8	14	
Sensitivity1	1 in 20 wet year rainfall in every year. Wet year runoff from waste dump.	14	Higher rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by pumped inflows.
Sensitivity 2	1 in 20 dry year rainfall in every year. Dry year runoff from waste dump.	15	Lower rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by pumped inflows.
Sensitivity 3	Zero Pumped Inflow	81	As pumped inflows dominate the Base Case water balance for Hannukainen pit, if there are no pumped inflows to the pit lake the time to fill will increase to 82 years.
Sensitivity 4	Pumped Inflow Halved	24	Halving pumped inflows increases the time to fill to 25 years.
Sensitivity 5	Groundwater Inflow Halved	15	Groundwater inflows are a small component of the Base Case water balance so that halving inflows does not have a significant impact on time to fill.
Sensitivity 6	Groundwater Inflow Doubled	13	Groundwater inflows are a small component of the Base Case water balance so that doubling inflows does not have a significant impact on time to fill.
Sensitivity 7	Kuervitikko pit filled before Hannukainen pit	18	Infilling Kuervitikko pit lake prior to filling Hannukainen is predicted to delay infilling of Hannukainen by around 4 years from the Base Case.

Table 10b: Summary of sensitivity results for Kuervitikko pit

Model Run	Comment	Years to fill pit lake	Result compared to Base Case
Base Case	Parameters as per Table 8	17	
Sensitivity1	1 in 20 wet year rainfall in every year. Wet year runoff from waste dump.	16	Higher rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by groundwater inflows during initial period when there are no pumped inflows to Kuervitikko.
Sensitivity 2	1 in 20 dry year rainfall in every year. Dry year runoff from waste dump.	17	Lower rainfall and runoff rates have no significant impact on time to fill, as water balance is dominated by groundwater inflows during initial period when there are no pumped inflows to Kuervitikko.
Sensitivity 3	Zero Pumped Inflow	18	Pumped inflows have limited impact on infilling rate as pit lake is substantially filled before pumping commences (i.e., after Hannukainen has been filled). Kuervitikko is able to fill in 19 years from groundwater inflows alone.
Sensitivity 4	Pumped Inflow Halved	18	Halving pumped inflows has limited impact on time to fill for reasons outlined above.
Sensitivity 5	Groundwater Inflow Halved	18	The impact of reducing groundwater inflows is compensated by pumped inflows filling the pit in years 16 to 19.
Sensitivity 6	Groundwater Inflow Doubled	10	Groundwater inflows are a key inflow to Kuervitikko pit lake and increasing groundwater flows reduces the time for the pit lake to fill.
Sensitivity 7	Kuervitikko pit filled before Hannukainen pit	4	If Kuervitikko is filled before Hannukainen the pit could be filled in substantially less time than under Base Case conditions.

Figure 1: Volume of pit lakes plotted against water level

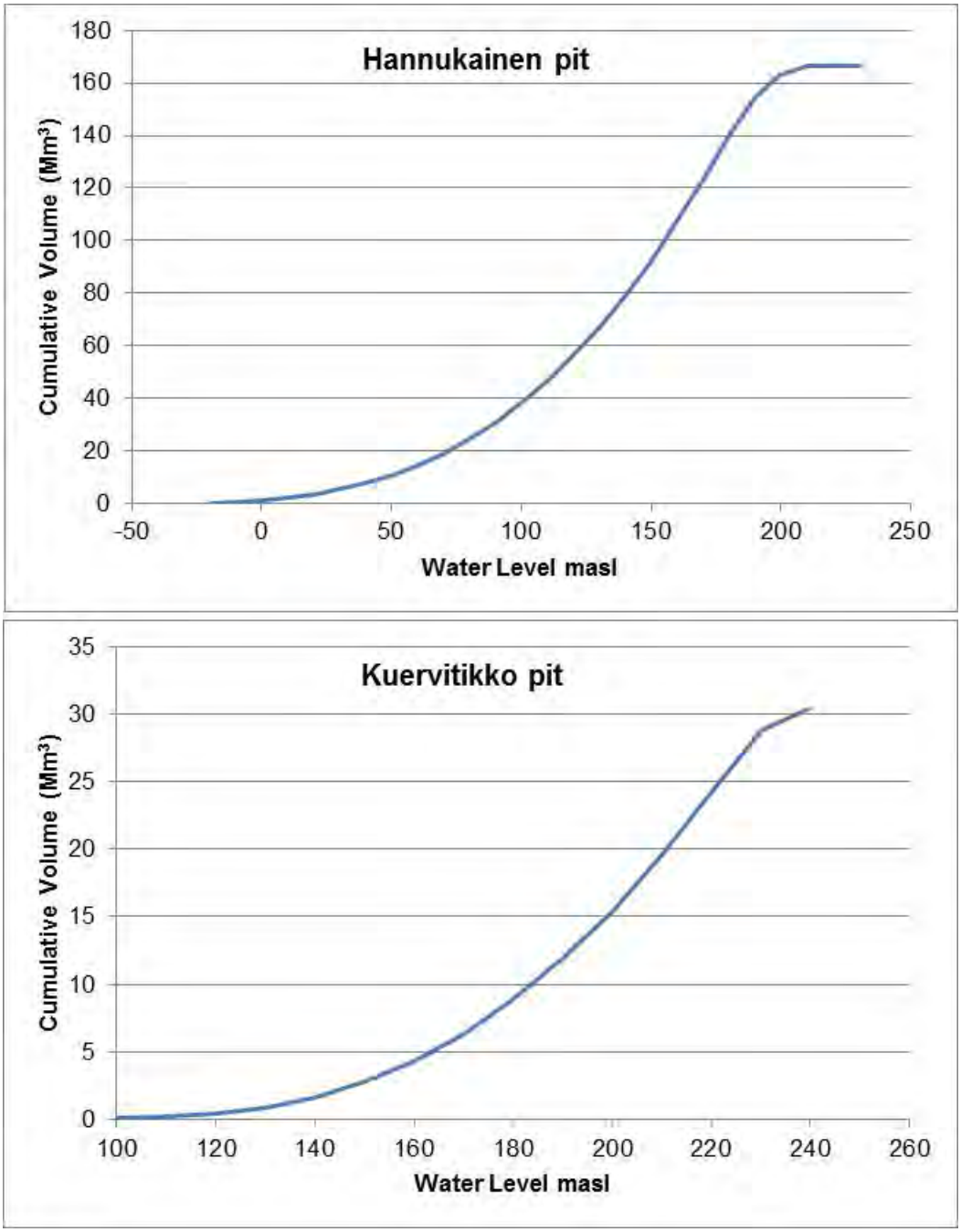


Figure 2: Predicted Evolution of Hannukainen and Kuervitikko pit lake water levels for Base Case

