Wastewater treatment in Sweden
From Latrine to water closet

By the late 1800s, the larger cities in Sweden began building wastewater systems for the first time. Piping was laid underground to channel wastewater from kitchens and newly installed modern flush toilets (or water closets) to discharge into nearby lakes or coastal waters. In time, this wastewater disposal system replaced the historical latrine management systems where household waste was collected in pits and barrels, and then used as fertiliser on local farms. In areas where using this waste for fertilisation was not possible, the waste was simply buried. By 1880, twelve Swedish cities had underground sewer systems. Water closets were being introduced, primarily to improve sanitary conditions in housing and urban areas generally. Waste-water systems became predominant first in larger cities in the 1920s and later in smaller towns and communities. For more reading on this transformation to water and sewage systems see ‘Use and Misuse of Nature’s resources – A Swedish Environmental History’ Naturvårdsverket (Swedish Environmental Protection Agency, Swedish EPA) Monitor 21.

POLLUTION PROBLEMS
At first, both urban and industrial wastewater was discharged entirely untreated. Lakes, rivers, and coastal areas became increasingly polluted over time. Discharged nutrients and oxygen demanding pollutants caused hypoxia and fish kills, and at times brought waterborne epidemics. Water pollution was seen as a municipal concern into the 1940s, limiting potential for comprehensive action. Development of municipal sewage treatment capacity progressed slowly and by 1940, only 15 municipal wastewater treatment plants were operating countrywide. This number doubled by 1955.

TURNING POINT IN THE 1960S
Eutrophication of Swedish waters gained public attention in the 1960s. Then, many lakes and streams near larger urban areas had been severely degraded by decades of effluent discharge. Lakes became overgrown, and algal blooms drifted onto shores previously considered prime bathing sites. Not only where water bodies eutrophic, but heavy metals

The largest disc filtration plant in Europe. Regional municipal treatment company, Gryaab, manages wastewater treatment for Gothenburg and nearby municipalities. Photo: Ulrika Wahlström
and chemical deposits were found in contaminated sediments – mostly the legacy from historic industrial activities. Environmental alarms were raised regularly, quickly leading to national governmental action against water pollution. The Swedish Environmental Protection Agency (Naturvårdsverket, Swedish EPA) was established in 1967, a year later national funding for wastewater treatment was introduced to decontaminate municipal wastewater and the Environmental Protection Act came into force 1969.

**EXPANSION OF WASTEWATER TREATMENT IN THE 1970S**

From 1971 to 1979 the national government invested over SEK 1.5 billion in expanding municipal wastewater treatment capacity (corresponding to some SEK 5 billion in 2013 value). Several industries also received government grants for environmental improvements. This largely went to improve wastewater treatment. Industrial plants with their own wastewater treatment also invested significantly to reduce effluent discharges since then. Discharges from small properties with private small-scale wastewater systems have not decreased similarly. This extensive investment, mostly in the 1970s, brought significant improvement to Swedish lakes and rivers, which were noticeably cleaner after only a few years. Bathing areas reopened and fisheries recovered.

**AND NOW?**

Essentially all households in urban areas are connected to wastewater treatment plants and over 95% of this sewage goes through biological and chemical processing. Many larger industrial, mining, and airport facilities have their own dedicated treatment plants. And, there are approximately 700,000 households in the country with small-scale wastewater systems. The environmental load from phosphorus and nitrogen released from these small-scale systems is heavy on Swedish lakes, rivers, and coastal waters with limited water exchange.
LOW RATE OF ACTIVITY ON FAULTY SMALL-SCALE TREATMENT FACILITIES

Nearly one million households in Sweden have no access to municipal water treatment facilities, relying instead on small-scale wastewater systems. Some 700,000 of these have flush toilets, where approximately 130,000 have no more than simple sewage sludge separation that fails to meet legal requirements in the Environmental Code. Effluent discharge from these smaller systems primarily impact the local environment. Faulty treatment systems can cause odour nuisance, contaminate groundwater and bathing sites, and make drinking water unusable. The rate of corrective activities for these faulty systems is currently low (1–2%).

Property owners are obligated to ensure that their systems function properly and to address faults, but they often lack understanding and motivation to do so. The Swedish Agency for Marine and Water Management (SwAM, Havs- och vattenmyndigheten) has determined this rate should increase to at least 5%. We see a significant need for added investment to accelerate efforts to correct non-compliant small-scale wastewater systems.

Legally, Swedish municipalities are both examining and supervisory authority for wastewater volumes up to 2,000 person equivalents (pe). As of 1 July 2011, SwAM is the supervisory guidance authority for small-scale systems up to 200 pe. Swedish EPA General Recommendations for Small Scale Wastewater Treatment Systems (NFS 2006:7) provide guidance for municipal authorities regarding enforcement of environmental and health safety safeguard requirements for these small-scale systems. Though municipalities do conduct extensive supervisory activities and demand corrective measures, currently many wastewater discharge systems provide inadequate treatment.

Understanding of these small-scale wastewater systems must improve in Sweden. A 2009 survey of municipalities across the country found many municipalities had not identified all of these small-scale systems. Infiltration and drainfield systems are the most common types of small wastewater systems. Technical solutions, such as domestic wastewater plants and enhanced biological phosphorus reduction, are increasing in number, as is liquid/solid separation where urine or flush water can be processed for agricultural reuse.

Small-scale wastewater systems, and municipal wastewater treatment plants, are the largest point sources of phosphorus release and are a significant factor in causing eutrophication in our waters. In 2009, the total phosphorus and nitrogen release from all of Sweden’s small-scale wastewater systems was estimated at 290 and 2,900 tons, respectively.
Wastewater sewage systems

Wastewater treatment plants with sewage systems and pumping stations have been built to treat wastewater from urban and built-up areas throughout Sweden. The Swedish EPA conducted a study of the design of the sewage systems in every Swedish municipality in 2010. The study found that in over 3,300 urban and built-up areas, a total population of approximately 7,800,000 had access to municipal wastewater treatment. This situation changes continuously where new housing developments are connected and smaller plants are replaced with pumping stations that transfer sewage to larger wastewater treatment plants. Over time, this reduces the total number of plants. Detailed statistics for quality of wastewater treatment can provide a basis for combining wastewater solutions between certain areas. Another possibility these statistical details can be used for is the replacement of older treatment plants with pumping stations with more modern wastewater treatment plants or expanding the sewage system to nearby larger urbanized areas.

Maps showing schematic connections between built-up areas and treatment plants based on the statistical details contained in the wastewater treatment plants environmental reports for 2008. Updated maps from 2010 for all Swedish municipalities are published at http://www.gis.scb.se/test/avlopp2010/. Source: Swedish EPA (Naturvårdsverket)
Releases from Municipal Wastewater Treatment Plants

Measured releases of nutrients from wastewater treatment plants increased dramatically from the 1960s as more communities switched to wastewater treatment plants. While this may seem paradoxical, it was not due to similar increases in total effluents from urban areas. Rather, this mostly shows that untreated wastewater was previously discharged with no measure or control and we therefore have no reliable data. A system of modern wastewater treatment plants was built through the 1960s and 70s to remove phosphorus and organic matter. Releases of these substances thereby decreased significantly. From the mid-1980s new purification methods have been added to reduce nitrogen levels also. The degree of purification for phosphorus and biochemically degradable organic matter (BOD) has held constant near 95% for the last decade. The degree of purification for nitrogen is much lower, but has improved over the same period in larger wastewater treatment plants that discharge into nitrogen sensitive recipients. The average purification degree for the country as a whole in 2012 was approximately 60% for nitrogen, showing no change from 2010.

The maps and diagrams on page 7 show the most recent release statistics (2012) for nitrogen, phosphorus and organic matter from wastewater treatment plants into larger marine basins. Nitrogen and phosphorus releases into the Baltic Proper were greatest, while organic matter release is equal when comparing Kattegatt to the Baltic Proper. Discharge to Skagerrak is very small. Source: MI22SM1401, Statistics Sweden (Statistiska centralbyrån, SCB).
Nitrogen (Tot-N):
- Bothnian Bay: 1,273 t/year
- Bothnian Sea: 3,464 t/year
- Baltic Proper: 7,246 t/year
- Skagerrak: 4,085 t/year
- Öresund: 756 t/year
- Kattegat: 296 t/year

Phosphorus (Tot-P):
- Bothnian Bay: 1,536 t/year
- Bothnian Sea: 2,274 t/year
- Baltic Proper: 2,578 t/year
- Skagerrak: 2,878 t/year
- Öresund: 159 t/year
- Kattegat: 5 t/year

Organic compounds (BOD$_7$):
- Bothnian Bay: 465 t/year
- Bothnian Sea: 1,274 t/year
- Baltic Proper: 639 t/year
- Skagerrak: 1,459 t/year
- Öresund: 159 t/year
- Kattegat: 5 t/year
The degree of purification in Swedish wastewater treatment plants currently is good, and is still gradually improving. But effluent discharge from these wastewater systems remains a significant source of eutrophying substances (phosphorus and nitrogen) and organic matter in our waters. The wastewater treatment plants primarily process wastewater from urban areas, while rural permanent and holiday homes most often have private systems. Wastewater treatment standards in rural areas vary widely, and general estimates are that only some 80% of small-scale wastewater systems comply with Environmental Code standards. To address these releases, the Swedish EPA has issued general recommendations for small-scale wastewater treatment systems. The SwAM is supervisory authority for small-scale systems (up to 200 pe) since 2011. And many municipalities currently have systematic programmes to implement improvements and develop corrective strategies.

**METALS AND OTHER POLLUTANTS**

Many of the chemicals widely used today enter wastewater and contaminate sewage sludge and effluent. Almost all metals in wastewater settle in the sludge, so levels in effluents are relatively low. The total cadmium and mercury discharge through wastewater treatment plants effluent remains essentially unchanged from 2010. Lead releases from wastewater treatment plants have decreased from approximately 686 kg annually in 2010 to nearly 383 kg for 2012. Chrome discharge was 1,386 kg annually in 2010, decreasing to 946 kg for 2012. These totals are based on data from wastewater treatment plants with larger capacity than 20,000 pe. These plants process nearly 80% of Sweden’s total wastewater. More details can be found in the Statistics Sweden (SCB) Article MI22SM1401.

The wastewater treatment plants also receive small volumes of solvents and persistent organic pollutants such as nonylphenols, brominated flame retardants, polynuclear aromatic hydrocarbons (PAHs), PCB, hexachlorobenzenes (HCB) and dioxins. Many of these pollutants are used industrially or contained in household products. For example, nonylphenols are banned for use within the EU but are still come to us in imported textiles.
Drugs and drug residues flushed into wastewater cause several types of problems. Many drugs are persistent and despite their low levels, impact aquatic organisms. This issue is discussed in the Swedish EPA rapport 5794 (Avloppsreningsverkens förmåga att ta hand om läkemedelsrester och andra farliga ämnen; English translation, ‘wastewater treatment plants’ capacity to treat drug residues and other hazardous substances’). The Swedish medicine information portal, Fass (at www.fass.se), includes an attempt at environmental classification of drugs, which is available to patients, practitioners and the public who are interested in environmental issues.

Discharge of eutrophying substances has significantly decreased in recent decades. The pie charts illustrate the various anthropogenic sources of nitrogen and phosphorus discharge for 2009. Agriculture is the largest single source, and WWTPs are the source of 20% of nitrogen and 15% of phosphorus in Sweden. Small-scale wastewater systems contribute as much phosphorus as the significantly larger wastewater treatment plants (15%). Total phosphorus discharge was 1 930 tons, and for nitrogen this was 83,500 tons. Source: SMED (Swedish Environmental Emissions Data) report nr 56, 2011 (Swedish only). New data will be published in 2015 with a detailed assessment of the environmental objective for ‘No Eutrophication’.
**Total WWTPs, Effluent volumes and Concentrations**

Number of plants, effluent volumes (tons) and concentration levels (mg/l) of phosphor, nitrogen, and organic pollutants from wastewater treatment plants larger than 2,000 pe annually for 2012. Discharge reported per treatment method, total population connected to the plant and the recipient marine basin. Source: SCB and Swedish EPA, MI22SM1401.

<table>
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<tr>
<th>Treatment method</th>
<th>Total treatment plants</th>
<th>Water volume 1,000 m³</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
<th>BOD₇</th>
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<table>
<thead>
<tr>
<th>Size in pe</th>
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<th></th>
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<td>100,001–</td>
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<td>614,726</td>
<td>0.22</td>
<td>10.3</td>
<td>5.9</td>
</tr>
</tbody>
</table>

| Inland                         | 281                    | 534,246               | 0.19       | 16.0     | 6.2  |

| Coastal                        | 130                    | 734,885               | 0.24       | 11.6     | 6.3  |
| Bothnian Bay                   | 11                     | 30,983                | 0.32       | 28.6     | 11.3 |
| Bothnian Sea                   | 31                     | 74,785                | 0.28       | 24.3     | 8.3  |
| Baltic Proper                  | 46                     | 351,101               | 0.24       | 9.8      | 4.8  |
| Öresund                        | 6                      | 68,173                | 0.25       | 7.8      | 5.5  |
| Kattegatt                      | 15                     | 187,114               | 0.21       | 8.4      | 7.9  |
| Skagerrak                      | 21                     | 22,728                | 0.23       | 12.4     | 6.5  |

<p>| Total 2012                     | 411                    | 1,269,131             | 0.22       | 13.5     | 6.3  |
| Total 2010                     | 467                    | 1,186,767             | 0.22       | 14.7     | 6.7  |
| Total 2008                     | 467                    | 1,258,539             | 0.25       | 14.6     | 5.9  |
| Total 2006                     | 475                    | 1,239,805             | 0.29       | 14.8     | 6.9  |
| Total 2000                     | 478                    | 1,362,917             | 0.31       | 13.9     | 7.2  |</p>
<table>
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<tr>
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<th>Release (t/year)</th>
<th>Removal efficiency (%)</th>
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<tr>
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<td>Phosphorus</td>
<td>Nitrogen</td>
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<tr>
<td><strong>Size in pe</strong></td>
<td></td>
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<tr>
<td>2,001–10,000</td>
<td>28</td>
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<tr>
<td>100,001–</td>
<td>136</td>
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<tr>
<td><strong>Inland</strong></td>
<td>99</td>
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</tr>
<tr>
<td><strong>Coastal</strong></td>
<td>176</td>
<td>8,550</td>
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<tr>
<td>Bothnian Bay</td>
<td>10</td>
<td>885</td>
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<tr>
<td>Bothnian Sea</td>
<td>21</td>
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<tr>
<td>Baltic Proper</td>
<td>83</td>
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<tr>
<td>Öresund</td>
<td>17</td>
<td>532</td>
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<tr>
<td>Kattegatt</td>
<td>40</td>
<td>1,578</td>
</tr>
<tr>
<td>Skagerrak</td>
<td>5</td>
<td>282</td>
</tr>
<tr>
<td><strong>Total 2012</strong></td>
<td>275</td>
<td>17,120</td>
</tr>
<tr>
<td>Total 2010</td>
<td>267</td>
<td>17,419</td>
</tr>
<tr>
<td>Total 2008</td>
<td>313</td>
<td>18,433</td>
</tr>
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<td>Total 2006</td>
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<td>18,343</td>
</tr>
<tr>
<td>Total 2000</td>
<td>424</td>
<td>18,977</td>
</tr>
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</table>
Impact on sensitive areas

Wastewater treatment plants discharge for plants with load capacity greater than 10,000 pe. The EU directive on Urban Wastewater Treatment (91/271/EEC) set the upper limit for nitrogen concentration in effluents at 10 mg/l for wastewater treatment plants with load capacity greater than 100,000 pe; and at 15 mg/l for plants with load capacity between 10,000 and 100,000 pe. Alternatively, the directive requires a degree of purification no less than 70% of the influent nitrogen levels (including natural retention).
Wastewater treatment plants compliant with Directive requirements treatment in 2012.


Releases from wastewater treatment plants do not impact marine areas that are sensitive to nitrogen. This applies to plants that discharge to the Bothnian Sea or its northern arm, the Bothnian Bay.

Release of nitrogen (t/year) 2012

- 100
- 500
- 1,000

The map illustrates coastal areas in Sweden that are sensitive to phosphorus and nitrogen. All inland waters are sensitive to phosphorus.
Eutrophication – A critical issue

Eutrophication is caused by excess amounts of nitrogen and phosphorus in relation to natural conditions. The primary reason eutrophication occurs in lakes and rivers is phosphorus leaching from farmland, with contributions from discharge from wastewater treatment plants and industrial activities. Surface runoff and rural small-scale wastewater disposal also contribute a significant share of phosphorus release. Marine environments can be impacted by both phosphorus and nitrogen, depending on which substance is lacking for algae growth.

SENSITIVE ENVIRONMENTS
Under the urban wastewater treatment directive, Sweden has identified eutrophic areas or those at risk of eutrophication if no corrective action is taken. All waters in the country, including coastal areas, are identified as sensitive to phosphorus discharge. Coastal areas from the Norwegian border on the west-coast to the eastern coast of Norrtälje Municipality – Skagerrak, Kattegatt, Öresund and the Baltic Proper – are identified as sensitive to nitrogen release. Strict requirements are in place for treating phosphorus in wastewater treatment plants throughout the country. Additional nitrogen purification is required in southern Sweden in plants larger than 10,000 pe with coastal marine recipients. Stricter requirements for smaller treatment plants or those with other recipients may be issued under Chap 2. § 3 of the Swedish Environmental Code.

MARINE ENVIRONMENTS
The marine environment in areas surrounding Sweden has received significant attention in recent years. Eutrophication is perhaps the single largest problem in the Baltic Sea. Levels of nitrogen and phosphorus in marine waters are raised compared to 50 to 60 years ago. Moreover, the problems with anoxic bottoms in the Baltic have not decreased, but rather seem to have increased despite significant measures. In November 2007, the environmental ministers of all coastal countries around the Baltic Sea decided within the Helsinki Commission (HELCOM) on a joint action plan for the Baltic Sea including Öresund and Kattegatt (the BSAP, Baltic Sea Action Plan). The agreement’s objective is to restore a healthy ecological status for the marine environment.
by 2021. The largest challenge in this is to reduce total nutrient loads, so the plan therefore includes reduction targets for the signatory countries. For Sweden, the reduction target for 2013 includes reducing annual nitrogen discharge by 9,200 tons and phosphorous by 530 tons – as compared with the period from 1997 to 2003. Sweden has developed and implemented various measures to reduce nutrient releases to oceans and lakes, as detailed in Swedish EPA reports 5830, 5984 and 5985. To reduce phosphorus loads, the government introduced a ban on phosphates in laundry detergents and in 2011, a ban on phosphates in dishwasher detergents (Government letter 2009/10:213, Åtgärder för levande hav, English translation: ‘Measures for a living Sea). Sweden also implemented the EU Marine Strategy Framework Directive (2008/56/EC) through the Swedish Marine Environmental Ordinance (2010:1341), which, combined with the BSAP, will be controlling for future measures designed to improve marine ecology. As of 2012, the SwAM has formally determined the characteristics of a healthy ecological status, and is now preparing Sweden’s Action Plan programme.

**REDUCED DISCHARGES**

Scientific understanding of the effects from reducing phosphorus and nitrogen discharge has changed. Some researchers have questioned the usefulness of nitrogen purification in WWTPs along the Baltic coastline due to the significant natural fixation of nitrogen from the air. This nitrogen fixation is done by cyanobacteria (blue green algae), which are benefited from conditions with higher phosphorus levels in the water, high temperatures, and limited water exchange. When nitrogen levels are low at the same time, these bacteria have a further competitive advantage over non-nitrogen fixing algae. Therefore, reducing nitrogen discharge in relation to phosphorus would thereby further benefit the cyanobacteria, since in the worst case, their nitrogen fixation would counteract the effects of cutting anthropogenic nitrogen release. The relationship between algae blooms and nutrient discharge is complicated and is analysed in the Swedish EPA Monitor 19, Förändringar under ytan (English translation: ‘Changes under the surface’). The publication Havet (www.havet.nu, English translation ‘The Sea’) reports the latest findings from national and regional environmental monitoring conducted in all of Sweden’s coastal areas.
Monitoring Environmental Status

Discharges from wastewater treatment plants and industrial facilities impact the environment to differing degrees, from the local streams to the entire Baltic Sea or North Sea. Establishing where an impact originates requires that every effluent discharge affecting a specific aquatic environment – the recipient – can be quantified. In smaller lakes and marine bays, pollution most often can be linked to specific sources. But naturally, the larger the recipient, the greater difficulty in doing so. Marine environments are subject to winds, currents, and precipitation from the atmosphere, all of which can significantly influence how various pollutants spread.

MONITORING RECIPIENTS
All operations requiring permits under the Environmental Code, including wastewater treatment plants conduct self-monitoring. This normally includes monitoring the function of the facilities, managing chemicals and waste, water effluents and atmospheric emissions and, in certain cases, also measurements in the recipient. This is all reported in annual environmental reports. The Swedish EPA collects and publishes this data in the Swedish Pollutant Release and Transfer Register (http://utslappisiffror.naturvardsverket.se), providing insight into the releases from larger facilities subject to permit. Monitoring of larger rivers, lakes, and coastal areas is most often conducted by various water conservation associations. Members in these associations normally include municipalities, local industries, and sector organisations. A good example is the Lake Vänern’s Society for Water Conversation which functions as an SRK (Coordinated Recipient Monitoring) (SRK), see www.vanern.se.

ENVIRONMENTAL MONITORING
Environmental monitoring is used to document changes to the environment. The Swedish EPA manages the national environmental monitoring programme that has ten programme fields and, with the SwAM, coordinates national and regional environmental monitoring efforts. Sewage sludge and outgoing water from nine Swedish wastewater treatment plants are analysed on an annual basis with regard to many environmental pollutants within the Toxic Substances Coordination Programme at the Swedish EPA. The SwAM is mandated the responsibility for water-related fields as of 1 July 2011, except for environmental pollutants, which are still managed by the Swedish EPA. County councils are tasked with coordinating regional and local environmental monitoring. On the municipal level, environmental monitoring is conducted to ensure their needs for environmental information. National regulations and ordinances require municipalities to gather data concerning bathing sites in urban areas, and similar. The environmental code mandates municipalities
to require local businesses to conduct self-monitoring. These data can provide important environmental information and is used for international reporting.

THE SWEDISH EPA’S SCREENING PROGRAMME
Many chemical substances used in modern society are released into wastewater and enter the treatments plants. Of these, heavy metals are monitored regularly under a mandatory screening programme required in Swedish EPA’s Regulation SNFS 1990:14. However, most organic pollutants are not regularly analysed due the difficulty and expense involved. Moreover, new chemical substances are developed continually. The Swedish EPA therefore established a specific screening programme with occasional sampling surveys and analyses focused on newly identified environmental toxins and drug residues. This enables monitoring of to what extent these pollutants are spread in the environment. The sources of these pollutants can also be determined and the likelihood for human exposure. Often this involves sampling sludge, sediment, and water effluent from industrial and municipal treatment plants, as these collect the pollutants from a variety of sources.

BATHING WATERS
Discharges can also impact bathing water quality. This concerns treatment plants in regard to overflows when untreated wastewater is released due to heavy inflows. The EU Bathing Water Directive (76/160/EEC) obligates Sweden to monitor all larger bathing sites in the country. The SwAM has overall responsibility for this monitoring. Detailed information regarding bathing water quality is published at the national portal http://badplatsen.smittskyddsinstitutet.se.
Swedish wastewater treatment plants commonly combine mechanical, biological and chemical treatment in various ways. Invariably, water treatment begins with mechanical solids removal.

The most common treatment combinations include:
- Biological treatment
- Chemical treatment
- Biological-chemical treatment (conventional three stage treatment)
- Biological-chemical treatment with separate de-nitrification processing
- Biological-chemical treatment with supplemental treatment (as with filtration)

**MECHANICAL TREATMENT**
This treatment stage separates larger debris like stones, sand, grit, wood pieces, paper, hair, textiles, and plastics. This is done with a grit chamber and primary sedimentation.
- Inlet screens separate rags and larger objects that would otherwise clog the pumps or foul treatment further in the process.
- The grit chamber is a basin section with a well for collecting sand, gravel, and other heavier particles that settle to the bottom. The separated sand is removed through pumps. Most of the material removed in the grit chamber is processed for landfill.
- Primary sedimentation separates remaining particles which may also foul later biological-chemical treatment. Heavier particles settle to the bottom where squeegees scrape them to a collection well from where the sludge is pumped for separate treatment.

**CHEMICAL TREATMENT**
The chemical treatment stage primarily removes phosphorus from the wastewater, through chemical precipitation based on aluminium or iron floculants that bind the dissolved phosphorus. After flocculation, the resulting sludge is separated through sedimentation, removing up to 90% of the phosphorus.
**BIOLOGICAL TREATMENT**

This stage uses microorganisms, mostly bacteria, which consume the organic matter remaining in the wastewater after the mechanical and chemical treatment. Most of the organic matter at this stage is dissolved in the waste water and 90% of it is removed, while nearly 20% of the nitrogen is used by the microorganisms. The microorganisms flocculate into larger clumps (called flocs), that are also separated in sedimentation basins (activated sludge method).

**NITROGEN REMOVAL**

Certain wastewater treatment plants in Sweden also have nitrogen removal processes included in the biological treatment. Nitrogen removal is a fairly complicated process so it is therefore more common at larger wastewater treatment plants or where the recipient is particularly sensitive. In transferring the wastewater between oxygenated and some anoxic basins, favourable environments are created for various types of microorganisms. Nitrifying bacteria oxidises ammonia to nitrates in the presence of oxygen. Then, denitrifying bacteria (requiring anoxic conditions) convert the nitrates into NOx gases. Normally, the nitrogen removal process captures approximately 50 to 75% of influent nitrogen.

**FILTRATION**

Filtration is the final stage in treatment added to increase purification levels in effluents in plants with particularly strict requirements. This removes floating sludge and other particles that have not previously settled in the sedimentation basins.
Regulatory Frameworks in Sweden and the EU

Sweden first regulated wastewater discharge by the Swedish Water Act in the early 1940s, which also covered issuing permits for certain industrial activities. In 1956, a specific law was enacted for inspection of lakes and other wetlands and involved creating a new agency, the National Water Inspectorate.

The Swedish Environmental Protection Act that was passed in 1969 followed by the Environmental Code in 1999 created a single regulatory framework covering all forms of impact on our physical environment. Sweden’s ascension to the EU in 1995, also brought the gradual incorporation of all EU legislation into national laws, including those affecting the environment and water quality. The EU already had several directives in place for various types of water regulation and water use areas. The Water Framework Directive was passed in 2000 to replace and incorporate many of the previous water-related directives. A corresponding directive was passed 2008 regarding marine environments.

The more important EU directives for water quality issues include:

THE URBAN WASTEWATER DIRECTIVE
The objective of the EU Urban Wastewater Directive (91/271/EEC) is to protect the environment from adverse impact from urban waste water discharges and from certain industrial processes. This includes the following requirements:
- All urban areas (where appropriate considering size and location) shall have a collection system for wastewater before 1998, 2000 or 2005.
- The water piped in a collection system shall be processed through no less than secondary treatment. This generally involves biological treatment or a similar process so the water complies with set quality standards.
• The treated water must meet specific minimum requirements in regard to water quality.
• When the wastewater is released to sensitive environments (sensitive to added nutrients) significantly stricter requirements are set for effective treatment.

Sweden has incorporated the urban wastewater directive into law through our Environmental Code and through Swedish EPA regulations for treatment of wastewater from urban or built-up areas. These regulations provide specifically for broad ranging limit values for levels of nitrogen and oxygen demanding pollutants in effluents, and for monitoring and sampling. The limit values for the oxygen demanding pollutants apply to the entire country, while limits for nitrogen release apply only to releases into coastal or marine environments from the western coastal Norwegian border to Norrtälje Municipality on the east coast. Supplemental regulations are provided in Swedish EPA regulations for monitoring discharges to water and land recipients from plants for treatment of urban wastewater.

DEDICATED INDUSTRIAL TREATMENT FACILITIES
Releases from industrial operations with dedicated treatment facilities are regulated in the terms of their operating permits issued under the Environmental Code. EU-wide requirements in the Industrial Emissions Directive provide for a comprehensive permitting process that considers the impact of atmospheric emissions and water discharges from specified industrial activities, waste management, and agriculture. The directive standards are less stringent than Swedish law, and are therefore not controlling. The Swedish EPA has separate regulations (SNFS 1995:7) regarding release of certain highly hazardous substances.
Wastewater sludge at the Ryaverket plant. Ryaverket is certified under the Swedish REVAQ system, which means the sludge is quality assured. Photo: Ulrika Wahlström

The diagrams illustrate heavy metal presence in sludge from wastewater treatment plants 1987–2012. Mean values for WWTPs designed for 20,000 to 100,000 pe. Source: Swedish EPA and SCB, MI22SM1401.
Nutrients in wastewater must be returned to the soil

Long-term sustainability demands that society reuse the nutrients contained in its wastewater. Today’s agriculture is not self-sufficient in regard to plant nutrients, which leads to a significant annual demand for rock phosphates for artificial fertilizers. If the plant nutrients contained in society’s wastewater can be reused for agricultural use, these would become part of a cycle which could bring significant environmental and financial benefits. When these nutrients in the wrong place, they can cause severe eutrophication. For more information, see the Swedish EPA report 6580 *Hållbar återföring av fosfor* (Sustainable recovery of Phosphorus).

Phosphorus is primarily found in sewage sludge, which can be used as fertilizer on farm fields and other land. For the sludge to be usable as fertilizer, it must not contain too much of any unwanted substances such as heavy metals and organic environmental pollutants. The Swedish Water & Wastewater Association, representing the water industry, has established a quality assurance certification system, REVAQ, which enables wastewater treatment plants to obtain certification of their sludge. Nearly half of all wastewater in Sweden is now treated in REVAQ certified wastewater treatment plants. Our treatment plants are designed to remove plant nutrients from the water and bind these in the sludge, but current treatment methods are not in place to remove environmental pollutants. The latter pass through the systems eventually reaching inland waters and marine environments where they impact local bottom fauna and fish. Occasionally, these pollutants also kill the organisms used in the treatment processes and basins, causing significant processing problems. Certain substances can also remain in the sludge where they are spread to the fields and environment. Unwanted pollutants can also enter wastewater through surface runoff. Therefore there are active programmes designed to separate surface runoff from wastewater or to treat the runoff water prior to connection with the wastewater treatment plants.

Despite significant investment and effort intending to reduce the inflow of environmental pollutants, the sludge they produce still contains many of these unwanted substances. This raises concerns regarding the consequences arising from these more or less unknown substances. An example of these artificial substances is perflourinated compounds, PFAS (perflouraoalkyl and polyfluoroalkyl compounds). These belong to a group of biologically persistent substances.

The diagrams (above) illustrate that the quality of sewage sludge has improved over recent decades. Still, there is much to do to produce better and cleaner sludge. Silver and triclosan are examples of substances that are used as antibacterial and antifungal agents that can settle in excessive concentrations in sludge due to their chemical properties. Along with continuing to improve sludge quality, recycling nutrients can also be done by separating urine from wastewater at the source, and extracting nutrients and separating pollutants from the sludge. Pathogens may also enter wastewater in various ways, creating a need to sanitise the sludge before reuse.
Development over the last 200 years has taken Swedish society from dugout latrines, to underground sewers flowing into lakes or coastal waters, to advanced wastewater treatment plants. Wastewater issues have changed from resolving local sanitary problems to a global environmental issue. This paper 'Wastewater Treatment in Sweden' is published by the Swedish Environmental Agency (Swedish EPA) to provide an historical overview of development of urban wastewater treatment from 1900s to the present. The paper is published biannually and includes the most recent statistical data from 2012 for releases and sludge from wastewater treatment plants. This information is published in accordance with Article 16 of the Urban Wastewater Treatment Directive (91/271/EEC). The Directive applies to all wastewater collected in sewage systems, but quantitative requirements apply only to treatment plants serving more than 2,000 persons. For Sweden, this corresponds to over 400 plants. The original EU member states (EU15) were obligated to meet all requirements within the Directive framework by 2005. The 12 new EU members have varying transitional rules.