Eutrophication

- Policy
- Environment
- Technology

PRESTO

Baltic Sea Region
Programme 2007-2013
Part-financed by the European Union
(European Regional Development Fund
and European Neighbourhood and
Partnership Instrument)

What is Eutrophication?

Eutrophication suffocates the life in lakes and seas. Some of the sea-beds in the Baltic Sea are the largest dead areas in Europe.

EUTROPHICATION

Eutrophication is nutrient enrichment, mainly of nitrogen and phosphorus, in water ecosystems that generates increased production of organic matter. This has many drastically negative consequences, such as reduced water transparency, an overgrowth of filamentous algae and reed beds, intensive algae blooms, and a lack of oxygen in deep waters near the bottom. Many species of microscopic blue-green algae are toxic to animals and humans.

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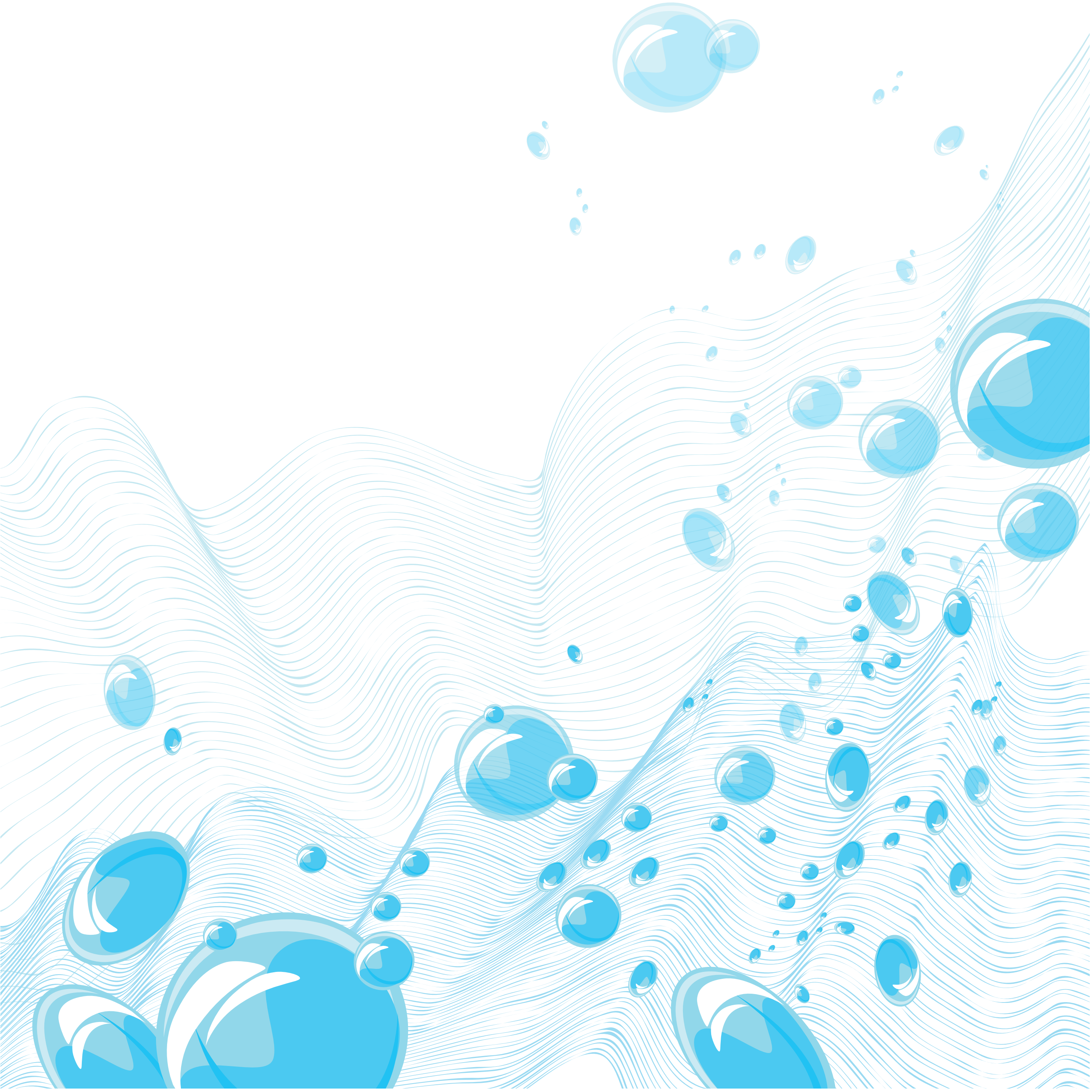


SUSTAINABLE WATER MANAGEMENT POLICIES AND PRACTICES

Pekka Salminen & Hannamaria Yliruusi, Union of the Baltic Cities

Safeguarding the common water resources should be a priority for all nations to ensure that enough high quality water is available to meet the needs of people, the economy and the environment.

90 million people live around the shores of the Baltic Sea, many of them depending on the sea in some way or other for their livelihoods. At the same time, waste and discharges from industry, agriculture and consumer's daily life end up in the sea. The Baltic Sea is one of the most polluted seas in the world. One of the most serious problems is eutrophication that leads to excess growth of algae. Decomposition of this excess organic matter robs the water of oxygen, suffocating other species. That is also common for many inland waters, which are suffering from bad water management, namely excessive discharge of nutrients to the water bodies.

Successful management of natural resources requires accurate knowledge of the resource available, the uses it may be put to and the competing demands for the resource. Moreover, evaluation and priorisation of the significance and value of the competing demands is needed, as well as mechanisms to translate policy decisions into effective actions.

This is particularly difficult in terms of water as a resource, since water sources can cross many state boundaries and the uses of water include many that are difficult to assign financial value to and may also be difficult to manage in conventional terms.

While new opportunities for innovative solutions in water policy and practices must be created to ensure good water quality and sustainable balance in the utilisation of water resources, the implementation of the "Polluter Pays" principle should also be improved through monitoring, water pricing and better economic analysis.

International cooperation and strengthened methods need to be developed to protect common water resources and to make the water management sector more resource efficient. Water policy objectives must be increasingly integrated into other relevant policy areas, such as agriculture, renewable energy and fisheries. River Basin Management agreements between countries are needed for the sustainable management of the Trans Boundary Rivers.

EU's common framework for water management

European Union established the Water Framework Directive (WFD) in year 2000 to bring together in a common framework a diversity of different directives dealing with water issues. It includes all aspects of water use: domestic, industrial, agricultural, leisure and environmental conservation. The purpose of the Directive is to establish a Community framework according to which Member States must ensure the protection of inland surface waters, transitional waters, coastal waters and groundwater within the EU.

The Directive aims for 'good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU. The ecological and chemical status of surface waters is assessed according to the following criteria:

- Biological quality (fish, benthic invertebrates, aquatic flora)
- Hydromorphological quality such as river bank structure, river continuity or substrate of the river bed
- Physical-chemical quality such as temperature, oxygenation and nutrient conditions
- Chemical quality that refers to environmental quality standards for river basin specific pollutants. These standards specify maximum concentrations for specific water pollutants. If even one such concentration is exceeded, the water body will not be classed as having a "good eco logical status"

The WFD adopts a river basin approach and obliges Member States to make appropriate governance arrangements, including transboundary basins. The Directive also requires wide stakeholder participation in water management process as it is recognised that the role of citizens and citizens' groups is crucial in achieving good ecological status of water courses. Also, it addresses adequate water pricing as an incentive for the sustainable use of water resources. Actions structured around the implementation of the Directive offer a shared learning ground within the European Union, but also experience of interest to partners in other parts of the globe.

In the European Commission, macro-regional cooperation is seen as a possible solution to large-scale challenges. In the EU Strategy for the Baltic Sea Region, the European Commission identifies several objectives and priority areas related to improved water management. These include, for example, reducing inputs of nutrients and hazardous substances to water bodies as well as preserving fisheries and exploiting the full potential of the region in research and innovation. Several EU-funding instruments enable establishment of international cooperation projects as one of the means to reach the objectives.

HELCOM – an international policy maker for healthier Baltic Sea

In the Baltic Sea Region, the riparian countries have jointly pooled their efforts in HELCOM, The Baltic Marine Environment Protection Commission, which works as the environmental policy maker for the Baltic Sea area by developing common environmental objectives and actions. The common vision for the future is a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities.

HELCOM's main goal is to protect the marine environment of the Baltic Sea from all sources of pollution, and to restore and safeguard its ecological balance. The Convention, ratified by the member states in 1992, covers the whole of the Baltic Sea area, including inland waters as well as the water of the sea itself and the sea-bed. Measures are also taken in the whole catchment area of the Baltic Sea to reduce land-based pollution.

INFO BOX

According to the HELCOM Baltic Sea Action Plan, the annual phosphorous input to the Baltic Sea needs to be reduced more than 15 000 tons by 2021. The Action Plan includes recommendations for treatment requirements at municipal waste water treatment plants regarding nutrient discharges. The recommendations are partly stricter than those set by the EU directives (see table 1).

Table 1. Treatment requirements for total phosphorous and total nitrogen in the WWTPs discharging to the Baltic Sea catchment area.

	Reduction requirement tot P		Reduction requirement tot N	
for WWTPs > 100 000 PE	min % of reduction	max concentration in outflow	min % of reduction	max concentration in outflow
HELCOM Baltic Sea Action Plan	90	0,5 mg/l	70 – 80	10 mg/l
EU Urban Wastewater Directive	80	1 mg/l	70 - 80	10 mg/l

Necessity to comply with the recommendations of HELCOM has been recognised at the highest political level in the Baltic Sea region. However, countries see the validity of these recommendations differently. Some countries of the region like Estonia have transferred the stricter HELCOM treatment requirement to their national legislation. On the other hand for example in Finland, regardless of the lower requirements of the national legislation, in environmental permits for wastewater treatment plants the treatment requirements for phosphorus are usually stipulated to the HELCOM level. Some countries rely on voluntary actions of water utilities and municipalities. In Rostock, Germany, for instance, the waste water treatment plant voluntarily exceeds the treatment requirement set in the environmental permit and complies with the HELCOM recommendation.

The Belarusian water policies

One of the objectives of the Belarusian Water Strategy 2020 is to bring Belarusian water laws in line with the EU regulations. The goals of the EU Water Framework Directive and the Belarusian strategy are similar and they both strive to achieve good environmental status of surface waters.

Belarus has acceded to the Helsinki Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE Water Convention) and to the Protocol on Water and Health annexed to the Convention. The Protocol aims at sustainable protection of human health and wellbeing by improving water management, including the protection of water ecosystems. A major focus of the Convention is on transboundary water cooperation. Belarus has signed and is currently implementing four intergovernmental and nine interagency bilateral environmental agreements. The agreements set out general environmental cooperation approaches, including the protection of transboundary watercourses and lakes, and lay basis for joint actions to achieve the set targets.

The alarming state of the Baltic Sea is recognized also in Belarus and eutrophication is seen as an important environmental problem. However, currently advanced biological and chemical treatment methods to remove nutrients from wastewaters are not widely used in Belarus. The situation is expected to improve since the new standards for the design of wastewater treatment facilities are developed. In Belarus currently, 92% of urban population and 32% of rural population are connected to centralized sewage systems and local sewage systems (septic tanks). Despite the adequate level of centralized sewage development, Belarus is facing challenges that are familiar around the Baltic Sea Region. Wastewater treatment facilities were built decades ago and need comprehensive rehabilitation and upgrading.

Picture: Joint actions are needed for cleaner waters in the Baltic Sea Region.

Phase III of the Belarusian National Program “Clean Water” 2011-2015 and various international investment projects are underway in Belarus to address the challenges to maintain healthy living environment. Reconstruction projects are being implemented with the loans from the International Bank for Reconstruction and Development (IBRD), the European Bank for Reconstruction and Development (EBRD) and the Nordic Investment Bank (NIB). In addition to loans, the Northern Dimension Environmental Partnership (NDEP), the Swedish International Development Cooperation Agency (SIDA), the Polish National Fund for Environmental Protection and Water Management and the Finnish Ministry for Foreign Affairs have provided grants for reconstruction projects. To be able to accumulate more investments and to make the water and sewage sector more attractive for investors both environmentally and economically, there are plans to make the establishment of public-private-partnerships in the Belarusian water sector legally possible in the near future.

Getting the prices right

The need to conserve adequate supplies of a resource for which demand is continuously increasing is also one of the drivers behind what is arguably one of the EU's common Water Framework Directives's most important points - the introduction of pricing. Adequate water pricing acts as an incentive for the sustainable use of water resources and thus helps to achieve the environmental objectives under the Directive.

The EU Member States will be required to ensure that the price charged to water consumers - such as for the abstraction and distribution of fresh water and the collection and treatment of waste water - reflects the true costs. Whereas this principle has a long tradition in some countries, this is currently not the case in others. However, derogations will be possible, e.g. in less-favoured areas or to provide basic services at an affordable price.

To improve the economic sustainability of water utilities in Belarus, the Belarusian National Program "Clean Water" 2011–2015 provides for a phased increase in water utilities' cost recovery based on income growth of the population. The objective is that in 2016, 100% water and sanitation cost recovery will be achieved.

Many challenges remain

As the common threats are recognised and visions are set, the international cooperation should focus its full attention on actions and policies that ensure long-term sustainable management of water resources. As a supportive initiative, the United Nations has declared years 2005-2015 to be a Decade of Water for Life. The primary goal of the Decade is to promote efforts to fulfil international commitments made on water and water-related issues.

Unfortunately, several challenges still exist in the way of fulfilling the commitments and turning the visions into actions. These vary from lack of commitment to implement the common decisions and differing views on country-wide nutrient reduction requirements to conflicting interests of different policy sectors (e.g. environment and agriculture) as well as low awareness on costs and benefits of reaching the common objectives that are set, for example, in the Baltic Sea Action Plan (HELCOM).

Overcoming the challenge requires sustained commitment, cooperation, higher priorisation of water protection and investment on the part of all stakeholders. Involvement of all stakeholders is crucial for finding new opportunities and implementing integrated solutions for more sustainable water management policies and practices in the future.

LINKS:

HELCOM Baltic Sea Action Plan 2007-2021: http://www.helcom.fi/BSAP/en_GB/intro/

EU Water Framework Directive: http://ec.europa.eu/environment/water/water-framework/

EU Strategy for the Baltic Sea Region: http://www.balticsea-region-strategy.eu/

Belarusian Water Strategy 2020: http://www.minpriroda.gov.by/ru/legistation/new_url_1649710582

Belarusian National Program "Clean Water" 2011–2015: http://pravo.by/main.aspx?guid=3871&p0=C21101234&p2={NRPA}

NUTRIENT DISCHARGES AND THE ENVIRONMENT

Tuuli Ojala, John Nurminen Foundation

More efficient treatment of urban wastewaters improves the state of the watercourses

Eutrophication means enrichment of water bodies with nutrients (nitrogen and phosphorus) and the negative consequences of this process. Eutrophication disturbs the ecological balance of the watercourses, harms fishing and affects negatively the use of water in drinking, household and recreational purposes.

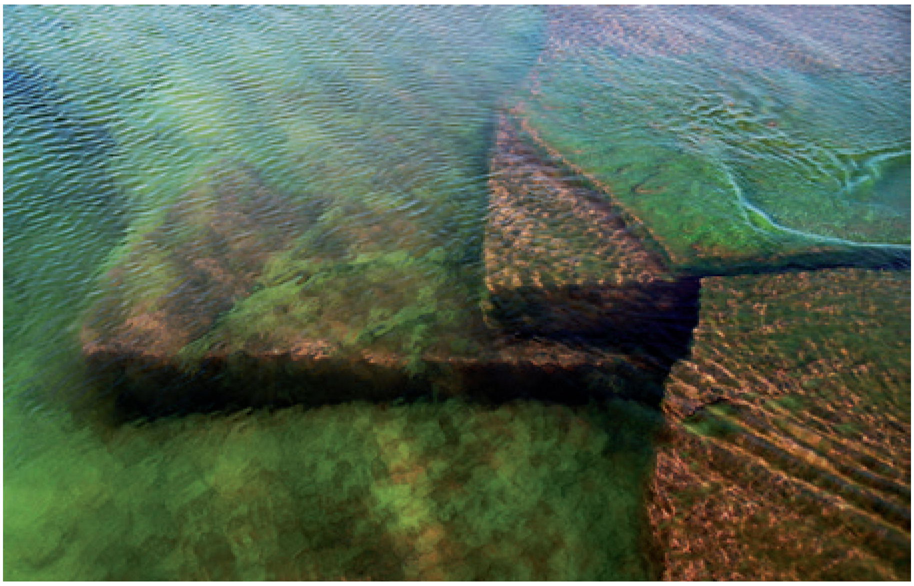
The pollution of waters with an excess amount of nutrients stimulates primary production: algae blooms are common in eutrophicated water bodies. The abundance of microscopic planktonic algae decreases the transparency of water. Typical to highly eutrophic watercourses are blooms of blue-green algae, many species of which are toxic.

The symptoms of eutrophication include overgrowth of the shoreline by macrophytes (aquatic plants) as well as increased growth of epiphytes (plants growing upon other plants) and harmful macroscopic algae. Eutrophication has also on negative effect on the living conditions of many fish species with a high commercial value.

Due to increased primary production, more oxygen is consumed to decompose the organic matter. This leads to reduced oxygen content in the water, especially in the near-bottom layers and/or in wintertime. The lack of oxygen and formation of hydrogen sulfide (H_2S) kills water organisms. Oxygen depletion in the near-bottom layers of water leads to an active release of phosphorus from the bottom sediments to the water and intensifies the eutrophication process.

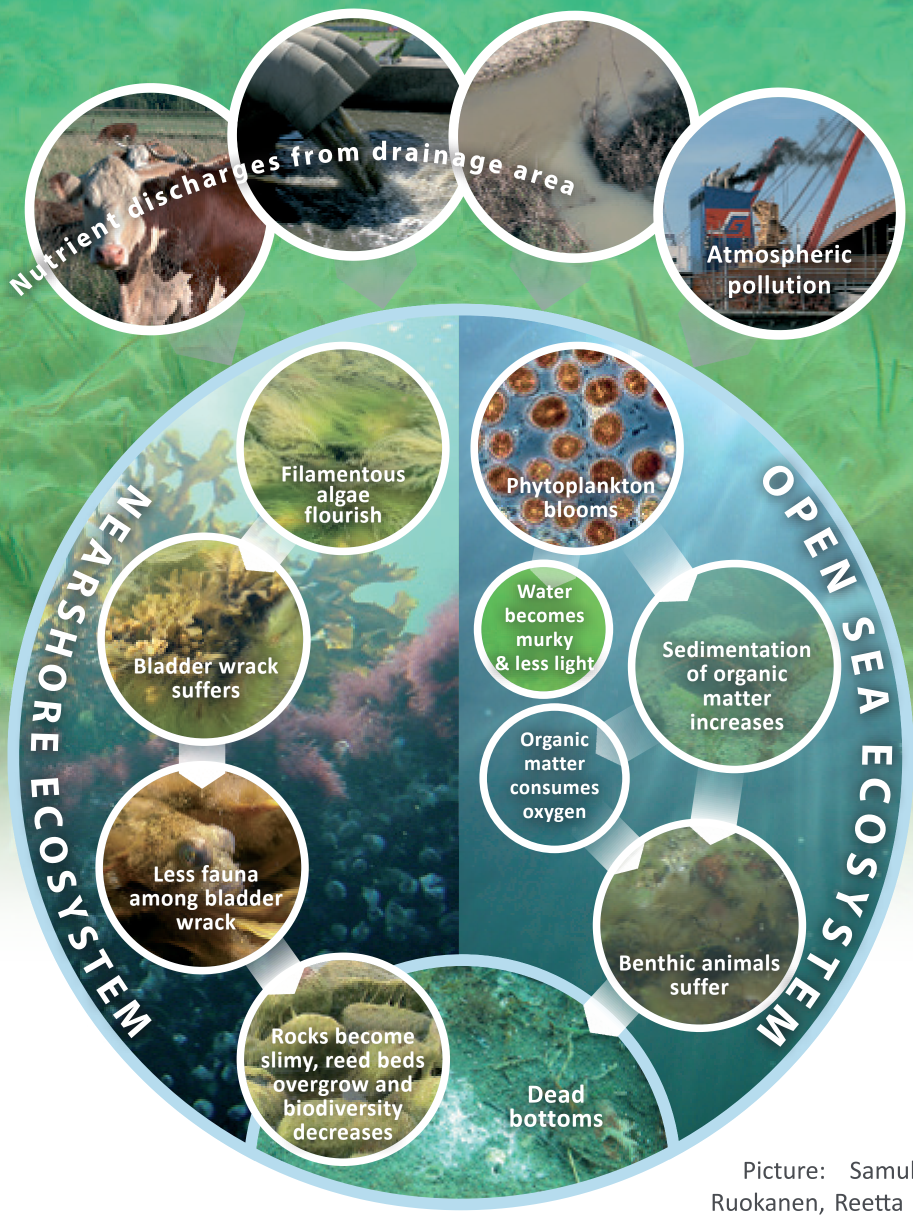
The main sources of nutrients to the waters are communal and industrial wastewaters as well as agricultural production. To improve the state of the water bodies, it is essential to cut down the nutrient load, especially the load of phosphorus, as it is most often the limiting nutrient for phytoplankton production in inland waters.

One of the most economically effective and fastest ways to combat eutrophication is to enhance the phosphorus removal from cities' wastewater treatment plants. HELCOM (Baltic Marine Environment Protection Commission) recommends reaching a yearly average of 0.5 mg/l phosphorus in treated wastewaters. It is essential also to secure sustainable sludge handling as the phosphorus removed from the wastewater stays in the sludge.



Picture: Janne Gröning for John Nurminen Foundation

EUTHROPICATION IN THE BALTIC SEA



Picture: Samuli Korpinen, Lotta Ruokanen, Reetta Ljungberg, Essi Keskinen, Seppo Knuuttila, Metsähallitus

The unique Baltic Sea

The Baltic Sea is a relatively small and shallow sea, but approximately 85 million people live in its exceptionally large catchment area using the sea for various purposes. Only the shallow and narrow Danish straits Skagerrak and Kattegat link the Baltic Sea with the ocean, which means that the water in the Baltic Sea exchanges slowly and harmful substances stay in it for decades. What comes to the recovery of the health of the Baltic Sea ecosystem, eutrophication is the key problem.

A unique feature of the Baltic Sea is its brackish water – a mixture of fresh and saline seawater. Brackish water and cold wintertime create a challenging environment for organisms in the Baltic Sea. Many species of the Baltic live on the extreme limits of their adaptability and the flora and fauna of the sea are very sensitive to changes in the environment. The International Maritime Organization (IMO) designated the Baltic Sea as a Particularly Sensitive Sea Area in 2004.

ENHANCED NUTRIENT REMOVAL TECHNOLOGY

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Introduction

Nutrients like nitrogen and phosphorous cause eutrophication of lakes, slow flowing rivers and especially of the Baltic Sea. The emissions of nutrients mainly come from agriculture, point sources like industry and wastewater treatment plants. Nitrogen can only be removed by biological processes applying nitrification and denitrification. Most of the nitrogen fractions will be conversed to molecular nitrogen and will be transferred into the atmosphere. Phosphorous, which is often more critical for the quality of the water bodies, can be eliminated by chemical or biological measures. Phosphorous is accumulated in the sludge and leaves the process via the sludge disposal.

Nitrogen Removal

Nitrification is carried out by autotrophic, obligatory aerobic microorganism (dominantly Nitrosomonas and Nitrobacter). CO_2 serves as a carbon source and ammonia respectively nitrite as an electron donor. For the win of energy they need dissolved oxygen (aerobic conditions). The nitrification takes place in two steps:

$$1\,NH_4^+ + 1{,}5\,O_2 \rightarrow 1\,NO_2^- + 1\,H_2O + 2H^+ \quad \text{nitritation (Nitrosomonas)}$$

$$\underline{2\,NO_2^- + 1{,}0\,O_2 \rightarrow 2\,NO_3^- \quad \text{nitratation (Nitrobacter)}}$$

$$1\,NH_4^+ + 2\,O_2 \rightarrow 1\,NO_3^- + 1\,H_2O + 2H^+ \quad \text{+ Energie (425 kJ/mol)}$$

The nitrifying bacteria are highly specialised and sensitive to influences of the environmental factors like inhibitors and toxic substances, low or high pH-values. For example NH_3-concentrations from 0.1 to 1 mg/l can already inhibit Nitrobacter. The nitrification is mainly influenced by following factors:

- Adequate sludge age ~10 -15 d
- Optimal pH-value 6,8 - 8,5
- Sufficient oxygen transfer in the aerated tank ~ 1,5-2,0 mg O2/l
- Acid is produced
- Dependence on temperature
- NH_4-N-load peaks
- Possible low input of solid matter

The nitrification is the most sensible process in the chain of nutrient removal. For enriching nitrifiers in the system it is necessary to provide sufficient sludge age (retention time of the sludge in the process), which is depending on the temperature (according German DWA A 131 standard)

$$t_{TS,aerobic} = SF \times 1.6 \cdot 1/_{\mu max} - f_T \text{ [d]}$$

- SF: factor regarding the variation of NH_4-N-load (1.8 to 1.45 depending on the size of WWTP)
- 1,6: factor of safety regarding inhibitors, short pH variations, etc.
- μ_{max},: maximum growth rate of nitrifying bacteria (0.47 d^{-1})
- f_T: Factor of temperature ($1{,}103^{(15-T)}$)

As nitrifies can not store their substrate (ammonia) it is important to balance the load by providing a sufficient tank volume, building a storage for raw sewage or treating the return of ammonia from the sludge station separately.

Denitrification

Denitrification describes the microbial conversion of bound oxygen in the nitrate (NO_3) instead of solved oxygen by heterotrophic bacteria. The separation of the oxygen from nitrate takes place in several sub-steps from nitrite (NO_2-N), via nitrous oxide (N_2O) and nitrogen monoxide (NO) to free nitrogen (N_2). 2.9 g O_2 can be generated per g NO_3-N. A large part (about 75-80 %) of the microorganism in the activated sludge is able to denitrify. The simplified reaction equation can be given according to MUDRACK, KUNST (1991):

$2\ NO_3^- + 10\ [H] + 2\ H^+ \rightarrow N_2 + 6\ H_2O$

During nitrate respiration the win of energy for organism is about 10 -20% smaller; this is the reason why microorganisms prefer respiration of solved oxygen, when available. Therefore strict anoxic conditions (no dissolve O_2) have to be provided for denitrification. Thus, within the constructional design of tanks and flumes overfalls and high turbulences have to be avoided.

Picture: Activated sludge with pre-denitrification

As organic carbon (measured as COD, BOD_5) is degraded during the process of denitrification, there must be a sufficient amount of BOD_5 available. The needed stoichiometric ratio of BOD_5/N is 2.86, which is a limiting value. For a sufficient denitrification process ratios from 4 to 6 are demanded. Also the biodegradability of the carbon source in the sewage has an influence, so a large part of easy degradable substances (like organic acids from food industry) will enhance the denitrification process. The denitrification is influenced by following factors:

- Anoxic conditions → no dissolved O_2
- Sufficient substrate (BOD_5/N > 4); maybe external carbon-source
- Recycling of nitrate and time for denitrification respectively
- Oxygen is gained back
- Acid is bound
- Stirring of water-sludge-mixture (power density 3-4 W/m_3)
- No inhibitors

Processes of nitrification/denitrification

Figure 1 shows the most proofed nutrient removal technologies in the field of municipal wastewater treatment (v. der EMDE (1987).

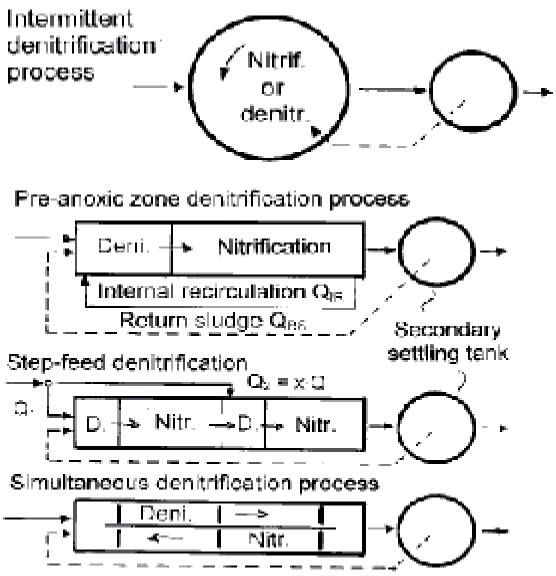


Figure 1: Established processes of nitrification/ denitrification in municipal WWTP

Mostly applied nitrogen removal practices are the pre-anoxic zone, the simultaneous and the intermittent processes. With high BOD_5/N-ration and/or lower effluent NO_3-N requirements the pre-anoxic zone method should be preferred. To fulfil strict limiting values the simultaneous/intermittent denitrification show advantages due to high necessary recycling ratios. The intermittent process efforts the installation of measurement and control systems. Sometimes in cases of low alkalinity and low BOD_5/N-ratio the step-feed or cascade denitrification is favourable. External C-sources have to be added in cases of unfavourable conditions (extremely low limiting values, hard degradable BOD or for seasonal reasons).

Phosphorous removal

Phosphorous can be removed by chemical, biological or combined measures. The **chemical P-removal** includes several subsiding procedures where chemical and physical mechanism play an important role:

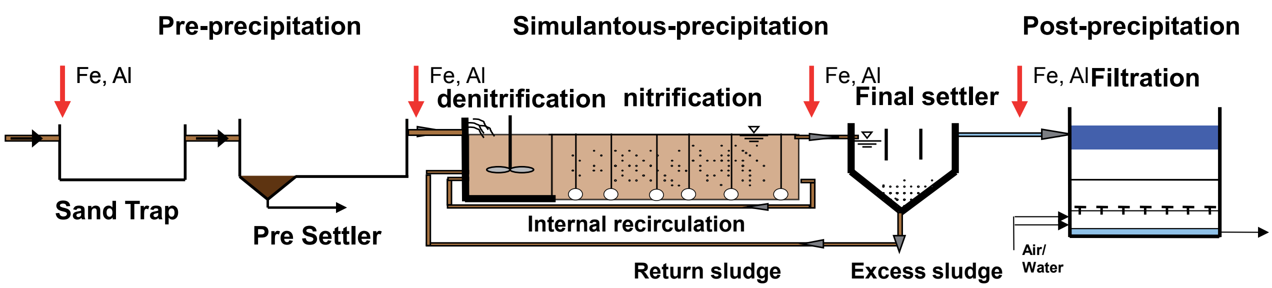
- Dosage and complete mixing-in of the coagulant into the sewage flow of the sewage (small flow into big flow!)
- Destabilisation of the fluid mostly takes place at the same time and place with the dosage
- Generation of particular substances from the cations of the coagulants (Fe^3+, Al^3+, Ca^2+) and the anion of phosphate (PO_4^{3}-) as well as other anions (precipitation reaction),

$$Me^3+ + PO_4- \rightarrow MePO_4$$

- Aggregation into micro-flocs
- Building of bigger flocs which can be separated. A mixing with low energy input is required. Parallel flocculation appears so that suspended solids and organically bound phosphorous can be precipitated also.
- Separation of the flocs using sedimentation, flotation, filtration or combination

In dependence on the dosage location of the coagulant different kind of precipitation methods (pre-precipitation, simultaneous precipitation, post-precipitation) can be distinguished:

Figure 2: Different methods of precipitation



Depending on the sewage quality several side-reactions can appear and that an over dosage of the coagulant therefore is always necessary. This is taken into account with the β-factor (recommended values 1.2 for simultaneous precipitation).

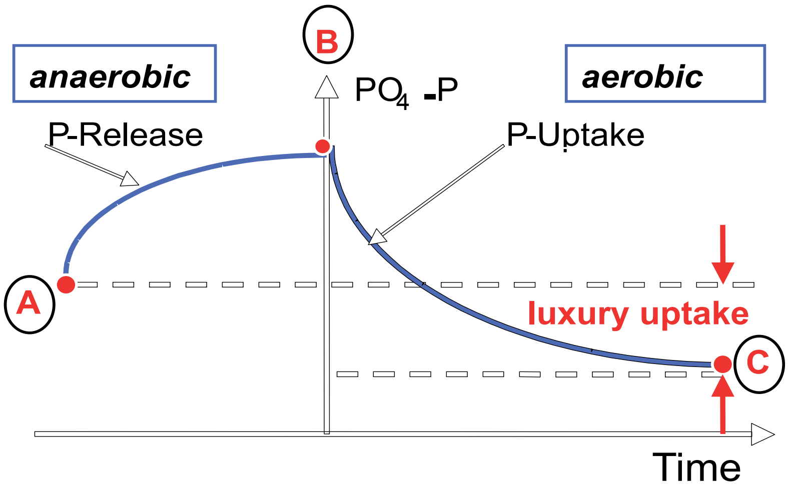
Within the **biological phosphorous removal** specialised bacteria are generated under certain process conditions which can take up more phosphate than they would use for their growth and store it as polyphosphate. This can be achieved when the bacteria alternate continuously between anaerobic and aerobic conditions **(Figure 3)**.

1) Under anaerobic condition easily degradable substrate (e.g. acetate) is respired by P-accumulating bacteria (PAO) while using stored polyphosphate as energy resource. This offers a growth advantage of those bacteria (e.g. Acinetobacter). PO_4 is released into the anaerobic reactor.

2) In the aerobic zone the PAO fill up their polyphosphate storage again but on a higher level than before (luxury uptake).

Several processes to implement the enhanced biological P-removal have been developed mainly in the 1990's. The simplest and most wide-spreaded method is the UCT-process, which is applied all over the world. An another option is the modified UCT, which has the disadvantage of a lower mixed liquor sludge content in the anaerobic reactor.

Figure 3: Principal curve of the P-concentration in a WWTP with biological P-removal [Schönberger, 1990]



Picture: Good practice for the dosage of chemicals

The enhanced biological P-removal delivers following advantages**:**

- No additional agents like coagulants are required
- Diminishing of salt emissions into the water bodies
- Lower sludge amount than with the chemical P-removal
- No additional heavy metals in the sludge
- No influence on the nitrification process

As disadvantages you can mention:

- Additional reactors have to be installed
- Tendency of foaming in digesters
- Increase of the dewaterability
- Generating of MAP/$CaPO_4$-coats in pipes and pumps

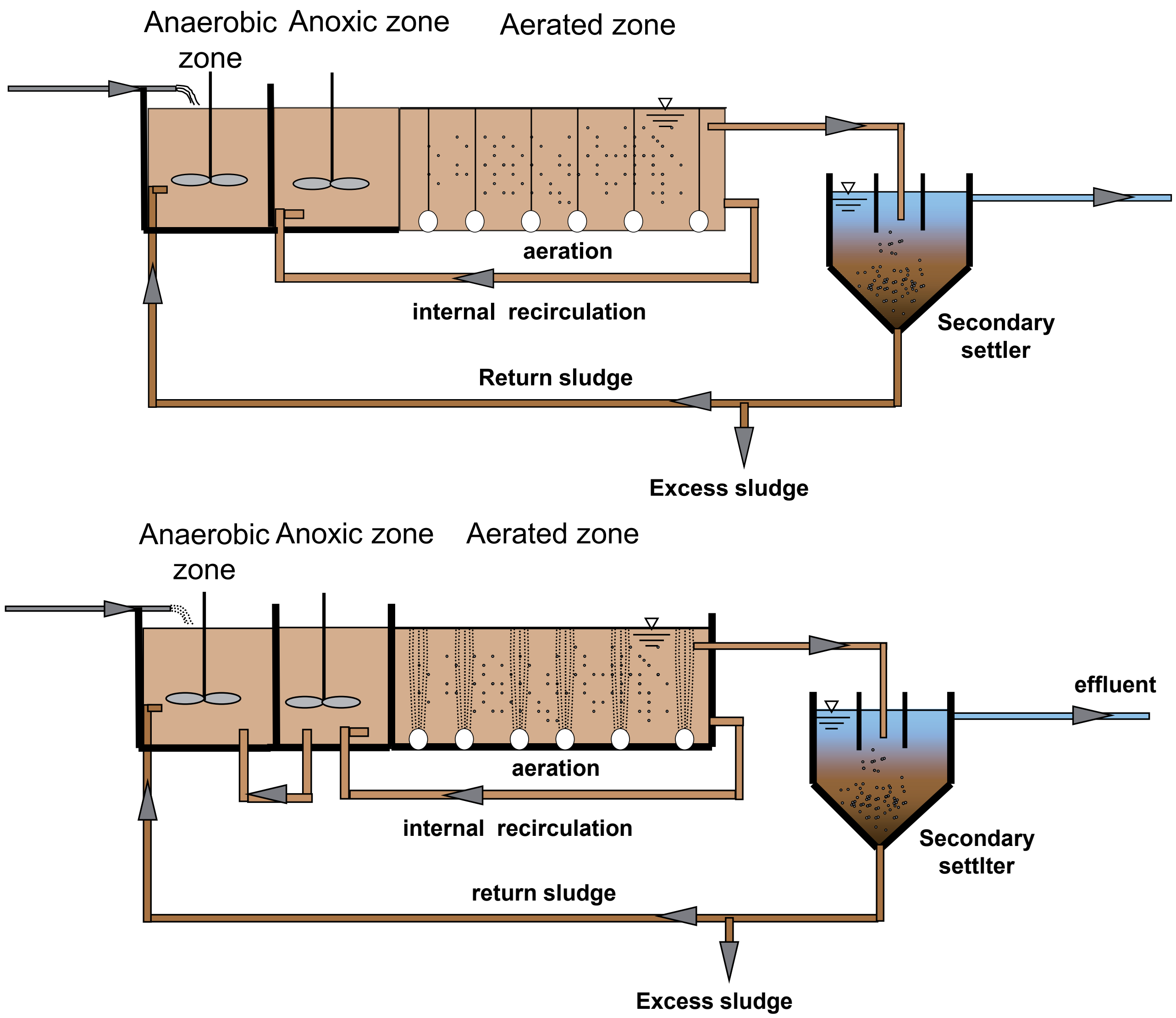


Figure 4: Common processes for the enhanced P-Removal (above: UCT; down: modified UCT)

The dimensioning of the anaerobic tank is based on the contact time $t_c = V/(Q_{rs}+Q_{in})$ which is recommended at least to 0.75 h.

Under following conditions enhanced biological P-removal can be recommended:

- No or very low O_2 Input or NO_3-N input in anaerobic tank is preferable
- Favourable BOD/P-ratio (30 : 1)
- High content of volatile fatty acids (> 100 mg/l)
- Sufficient O_2-input into the activated tank to realize a high P-uptake

Also measures to support the enhanced biological mechanism can be applied; so e.g. an acidification of the primary sludge can improve the process as well as a by-pass of the primary settler.

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Project partners

Project consortium consists of 12 partners from 5 Baltic Sea region countries:

- Project Management: Union of the Baltic Cities, Commission on Environment (Finland)
- Preparation and coordination of investments in Belarus: John Nurminen Foundation (Finland)
- Capacity building: Techical University of Berlin (Germany)
- Belarusian waste water utilities of Grodno, Molodechno, Baranovichi and Vitebsk
- Belarusian Universities: Belarusian National Technical University, Brest State Technical University and Polotsk State University
- Water Utilities of Daugavpils (Latvia) and Kaunas (Lithuania)

PRESTO - Project on Reduction of the Eutrophication of the Baltic Sea Today

improves quality of local waters and the Baltic Sea by reducing nutrient load through transnational investments, capacity building and awareness raising.

PRESTO main objectives:

1. To decrease transnational nutrient load to the Baltic Sea, originating from municipal waste waters
2. To improve quality of water of two transnational rivers: Neman and Daugava
3. To increase knowhow on modern water treatment technologies and advanced nutrient removal techniques
4. To increase awareness about the harmful effects of nutrient enrichment in watercourses and methods how to tackle the problem.

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UNION OF THE BALTIC CITIES