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Reducing the phosphorus load and the algae blooms in Finnish lakes and the Baltic Sea

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Abstract
Phosphorus is the nutrient, limiting algae growth in most of the lakes and rivers in Finland and therefore a reduction of phosphorus load should be carried out if algae blooms are a problem. In the Baltic Sea a reduction of both phosphorus and nitrogen has earlier been considered to be needed to reduce algae growth but recently also research papers where phosphorus has been pointed out to initially be the limiting nutrient has been published. It has been calculated that a reduction of nitrogen load by 50% to the Baltic Sea would be four times as expensive as a similar reduction of phosphorus load. Today countries in the Baltic Sea catchment area report already some success in reducing loads of phosphorus, but little for nitrogen. Thus the expensive measures to reduce load should be used in reducing phosphorus, instead of nitrogen.

In Finland the first step in this work has been a proper reduction of phosphorus content in urban and industrial sewage waters. This activity started already in the 70ties. The reduction of the phosphorus load in urban wastewater is today 95%. This reduction has resulted in reduced algae (cyanobacterial) blooms in the urban wastewater affected sea areas, lakes and rivers. The second step in Finland will be the reduction of phosphorus in rural wastewater by 85 per cent to be carried out before the year 2014. The third step should be a reduction of phosphorus load from agriculture. An attempt to start this work has been made already 10 years ago when the Finnish Agri-environment Programme was established. However this program has not been successful in reducing phosphorus load, although during 1995-2004 as much as 2.5 billion € has been used. It has been calculated that a chemical treatment to reduce the phosphorus content of all our field waters would not amount more than 0.07 billion €/year. Therefore in our Finnish Agri-environment Programme the chemical treatment of waters from agricultural areas should be included. In this paper a low cost treatment method to reduce phosphorus content in waters from agricultural areas is introduced. If these three steps would be carried out in all the catchment countries, the phosphorus load to the Baltic Sea could be reduced to a level which it was one hundred years ago.

Key words: phosphorus, load, reduction, Baltic Sea, wastewater, agriculture, rural areas, algae bloom, lakes, rivers

Introduction

Pollution of the Baltic Sea probably began as early as in the Middle Ages, when wastewater from the towns of Europe, aggravated by poor hygienic conditions, was discharged into the Baltic Sea. Wastes from small industrial establishments compounded this later. The first signs of marine pollution arose near the cities lying on the shores of the enclosed parts of the Baltic Sea. In these early times, marine pollution occurred only locally. In the late 19th and early 20th centuries, the marine areas affected by pollution grew in the regions where industrialisation developed and use of fertilisers in agriculture intensified. Today the world's largest dead zone in any sea area is found in the Baltic Sea (HELCOM, 1993, Larsen, 2004).

The algae are an important part of the ecosystem and alga blooms are natural phenomena in the sea. However, these mass occurrences of planktonic algae have become more frequent and intense due to the eutrophication of the sea caused by humans. The first algae bloom in the Baltic Sea in spring is characterised by varying portions of dinoflagellates and diatoms. These blooms can form a high algae biomass, reduce water transparency and potentially toxic species can be involved. Despite that, the main concerns are alga blooms during summer, when human leisure activities along the coasts are most intensive. Blue-green alga (cyanobacteria) thrives when the nitrogen is depleted after the spring bloom and when there still are sufficient amounts of phosphorus in the water. The cyanobacteria then have the advantage compared to other algae since they can fix dissolved air nitrogen in the water. The ability to fix air nitrogen together with high water temperature, sunny and calm weather can give rise to massive occurrence of the algae, in other word, large blooms that are easy to identify. The cyanobacteria are a low saline species and can not fix nitrogen nor grow in marine environments as the Kattegat and Skagerrak in the sea areas between Copenhagen and Oslo (Rissanen et al., 2002, BAWS, 2004).

In 1997 Pietiläinen reported phosphorus as the major nutrient limiting algae growth in Finnish lakes. In our lakes algae bloom is considered probable when the phosphorus level in the water is above 0.05 mg/l (KVVY, 2004). In Finnish field waters this level is exceeded distinctly as the average content in our field area waters is about 0.5 mg/l. In a lake with long turnover time phosphorus content may stay below the level required for an algae bloom by sedimentation of erosion particles and plankton. However the Finnish lakes are mostly shallow and have a short turnover and that in combination with a high field percent in the catchment area make a lake a probable algae bloom lake.

Focus on phosphorus reduction

The input of nitrogen to the Baltic Sea is today fourfold compared to the situation one hundred years ago, but the input of phosphorus is eightfold (Wulff, 1995). In the past a reduction of both phosphorus and nitrogen was considered to be needed to reduce algae growth in the Baltic Sea. However during last years increasingly the opinion has been presented that the expensive measures against nitrogen output (for example in agriculture), imposed by authorities in order to diminish eutrophication in the coastal waters, are doomed to failure as evidently phosphorus is initially the limiting nutrient (e.g. Söderström, 1996).

When modelling the impact of 50% reduction in both nitrogen and phosphorus on the Baltic Sea it has been observed that this situation will favour blue-green algae blooms in the southeastern Baltic Sea. The scheduled 50% reduction measures of both nitrogen and phosphorus seem to be not suitable to abate eutrophication in the Baltic Sea. Algae cannot compensate a shortage in dissolved phosphorus and therefore a possible solution can be an increased reduction of the phosphorus load. Phosphorus is an element that potentially limits the phytoplankton production in the Baltic Sea (Schernewski and Neumann, 2002a). Schernewski and Neumann, (2002b) point out that a more pronounced reduction of the phosphorous loads might prevent an increase in blue-green algae blooms compared with a reduction of 50% for both phosphorus and nitrogen. This because if reducing both by 50%, will favour blue-green algae blooms in the south-eastern Baltic Sea.

Theoretical analysis made by Elofsson (2003) show that if the elasticity of substitution between nutrients is small, emission reductions should, to larger extent, be focussed on one of the nutrients. The reason is that if the load of one of the nutrients is reduced substantially, the other nutrient cannot be taken up by growing algae and therefore, cannot cause any harm. Applied to cost-effective reductions in algae production in the Baltic Proper, which is the basin in the Baltic Sea that receives the largest nutrient loads, the empirical model indicates that a stronger focus on phosphorus reductions compared to nitrogen reductions can be cost-effective if policy-makers want to reduce algae production. This contrasts with the Baltic-wide policy with equal reduction rates for nitrogen and phosphorus (Elofsson, 2003).

Treatment of urban waste waters

In the Baltic Sea catchment area the first step in reducing the phosphorus load should be a chemical treatment of wastewater from all cities. The city of St Petersburg will be a remarkable part of this work. Chemicals are not used to precipitate phosphorus at the wastewater treatment plants in St Petersburg, Russia, although it is a well-known and reliable way to enhance phosphorus removal. Simultaneous precipitation is the most widely used method in

Finland, where the phosphorus reduction in properly treated wastewater (urban areas including 80 % of the population) already in the year 1996 was 93% (Finnish Wastewater Treatment, 1997). The reduction percentages are calculated including bypasses and overflows. Most often ferrous sulphate is used, which is dosed partly before the presedimentation basin and partly in the stream entering the secondary sedimentation. Ferrous iron is oxidised into ferric iron in the aeration basin where the main precipitation effect occurs. St. Petersburg waste water treatment will approach the Finnish standards when the South-Western waste water treatment plant and Northern tunnel Collector are ready, the chemical phosphorus removal started and direct discharges closed. From the point of views of the load reductions, the most important single measure is the chemical phosphorus removal, which alone will cut the biologically available phosphorus load in the Golf of Finland by 18%. This measure will have a notable effect on the cytobacteria blooms throughout the Golf of Finland making the N/P-ratio unfavourable for the nitrogen-fixing cyanobacteria (Kiirikki et. al., 2003).

Rural wastewater

Treatment of rural wastewater in Finland shall be carried out before the year 2014. The minimum reduction in phosphorus should be 85%. This will be a very difficult task as besides the phosphorus reductions substantial reductions in nitrogen and biological oxygen demand are also stipulated. The methods available are poorly working or are expensive. In many municipalities the costs of connecting also the villages long away from centre of the municipality to the central sewage treatment plant has recently been investigated.

Phosphorus load from agriculture

In countries like Finland where we have succeeded to reduce the phosphorus load from industry and municipalities to a very low level the phosphorus load from agriculture is now high compared to other sources. It has been estimated to be as high 60 % of the total phosphorus load in Finland.

In the past decades the soil test phosphorus has increased continuously. In the 1960s easily soluble phosphorus in surface soils nearly doubled and it continued to increase at a more moderate pace until the end of the 1990s despite the substantial reduction in use of fertilisers in the beginning of the decade. In recent years the P status of surface soils has appeared to be stabilising but so far no positive effects on water quality have been observed. In a study concerning 19 agriculturally loaded lakes during years before the agri-environmental programme, 1990 to 1994 and the period after, 2000 to 2002 Ekholm et al (2004) found an increase in the total phosphorus in 10 of the lakes, a decrease in 7 of the lakes and an equally high total phosphorus content in two of the lakes. Also in the Gulf of Finland the phosphorus content in

the water has not decreased. As a matter of fact the phosphorus contents have been exceptionally high during the past years (Raateoja, 2004)

Each farmer taking part to the Finnish Agri-environment Programme (93% of farmers corresponding 98% of the cultivated area in Finland) has to draw up a cultivation plan, keep records on cultivation practices, make soil fertility analyses every 5 years and attend a training of two days (FAEP, 2004). Also the use of phosphorus is in this Program restricted and this is one of the reasons why a good reduction in our use of fertiliser phosphorus has taken place

In agricultural use fertiliser phosphorus levels are now 10 kg/ha compared to the earlier 30 kg/ha. The soil phosphorus content (acid ammonium acetate extractable) in Finnish fields has decreased in five years 8 % (Mäntylahti, 2002). If the cultivation practices have been the same the dissolved reactive phosphorus (DRP) load would also have lowered 8 %. However at the same time changes in agricultural practices are increasing the DRP load. One of the most dramatic changes is when a farmer starts using direct drilling. In the first published studies the increase of the DRP load in surface flow field waters has been as high as three to four times as without direct drilling (Puustinen, 2004).

Material and methods

In this study wastewater, field water and stable area surface flow water were treated chemically using ferric sulphate compounds. The treated wastewater was a typical rural wastewater from a one family house. The wastewater tanks were emptied ten days before the test period. The dosage of the chemical (130 g of FERIX-3) was done for three months. For more details of the used chemical see Kemira (2005a). The chemical was dosed into the toilet water every day. The sampling of the untreated toilet water was done the day before the treatment period started from the second septic tank and the sampling of the treated water was done twice from the same tank during the test period. The field water and the stable area water were collected from ditches and treated in containers with different doses of ferric sulphate. For more details about the used chemical (PIX-115) see Kemira (2005b). The field and stable area waters in the 50 l containers were stirred after the chemical treatment and before the sampling of the settled water it was let stand for one hour. The water samples were analysed for dissolved reactive and total phosphorus as described by Uusi-Kämppä and Yläranta (1996).

Results and discussion

Chemical treatment of rural wastewater

The rural wastewater in Finland usually passes through two septic tanks without further treatment. In this test, treating wastewater daily with a small dose (130 g) of ferric sulphate the phosphorus reduction remained good still during the third month (see Table 1.) measured from the second tank of a household for two people. Using this simple method a very low cost reduction, especially in the dissolved reactive phosphorus was possible.

The field of know-how in rural wastewater treatment should be developed. Similarly to the industrial and urban wastewater treatment also the rural wastewater treatment need a well working control system with sanctions in case of poor treatment result reduction. If the sanctions are high enough there will be a need for professional people working in this field. These companies emptying the wastewater tanks when needed and maintaining chemical dosers could guarantee a proper reduction of phosphorus to their customers.

Chemical treatment of waters from agricultural areas

Waters from field areas are a big contributor to the dissolved reactive phosphorus (DRP) load. In Finland typical field water DRP content is 0.13 mg/l. This does not seem very high but amounts to 0.4 kg/ha per year. DRP is directly available for algae growth and therefore the reductions in DRP should be an essential part of the phosphorus to be removed. A removal of only particle phosphorus from field waters can end up in an increasing secchi depth, more light and higher amount of blue-green algae in our lakes and rivers. In table 1 can be seen how field water containing a typical content of DRP (0.126mg/l) can be effectively treated using 0.04 mg/l of ferric sulphate solution (11.5 w/w iron). In areas with higher content of phosphorus (critical source areas) like horse stable areas the used amount of chemical must be increased. To receive a good reduction in total phosphorus the used doses should be further increased. This can be needed in areas with clayey soils, where the particulate phosphorus can contribute equally high amounts of the algae-available phosphorus as the dissolved reactive phosphorus. It has been shown that the contribution from particulate phosphorus under poorly oxygenated marine conditions to the algae-available load may be as high as 2-3 times that of DRP (Uusitalo and Ekholm, 2004, Uusitalo, 2004).

Table 1. Dissolved reactive phosphorus and total phosphorus of field water, stable water and rural wastewater, before and after treatment with ferric sulphate.

Water and treatment	Dosages	Dissolved Reactive Phosphorus (DRP)	Reduction in DRP	Total phospho-rus	Reduction in total phospho-rus
	ml/l	ml/l	%	mg/l	%
Field water		0,126		0,765	
Ferric sulphate (PIX-115) treated	0,04	0,017	87	0,758	1
Ferric sulphate treated	0,12	0,009	93	0,04	95
Stable area water		0,394		0,696	
Ferric sulphate treated (PIX-115)	0,08	0,019	95	0,594	15
Ferric sulphate treated	0,16	0,009	98	0,106	85
Ferric sulphate treated	0,24	0,011	97	0,038	95
Rural wastewater (24.10.00)		13,561		15,603	
Ferric sulphate (Ferix-3) treated (15.11.00)	130 200l/d	0,063	100	0,385	98
Ferric sulphate treated (26.01.01)	130 200l/d	0,328	98	3,515	77

In Finland also other chemical methods have been introduced. Aura (2000) tested a method, which offers farmers a simple way to remove dissolved orthophosphate, particulate phosphorus and solid particles from runoff water. Suspended soil material could be bound into small aggregates with aluminium hydroxy polymers of low molecular weight. Inside the aggregated, soluble phosphate is bound into oxides so that it is no longer algae-available

These two above described methods lower the pH of the treated water. This is not a big problem as the lake water in seriously by agriculture affected lakes in Finland is not acid. However, if the field soil is very acid or has a low buffer capacity, the pH of the cleaned water can be raised, by the addition of calcium carbonate powder, to a value of about 7 and no monitoring of water pH is required.

Conclusions

In Finland and the other countries in the Baltic Sea catchment area there is still much to be done to reduce the phosphorus load. The first step should be a chemical treatment of wastewater from densely populated areas. This wastewater is already treated properly in many countries with a good reduction in phosphorus. Because treatment of city wastewater to reduce phosphorus is very cost effective a 95% reduction of phosphorus should be carried out in a very near future in all catchment countries. The city of St Petersburg will be a remarkable part of this work. In many cities like Gdansk in Poland this improvement work has now started (Swinarski, 1999).

Also in rural areas the wastewater should in the future be treated to reach a substantial reduction in phosphorus but not in nitrogen. The money saved omitting nitrogen could be used to help countries with difficulties to come up with these phosphorus reductions

In the reduction of phosphorus load from agriculture a chemical treatment of waters from all areas high in phosphorus should be carried out to receive a reduction of close to 90%. This should be included in all agricultural runoff programs in the Baltic Sea catchment area.

In countries like Finland with a numerous lakes and rivers with algae problems these reductions would be high enough to make algae blooms in lakes and rivers very rare and the input of phosphorus to the Baltic Sea would be at the level one hundred years ago.

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