

# CHALMERS



## **Pollutant Removal Efficiency in the Välenviken Stormwater Ponds**

*Master's Thesis in the International Master's Programme Applied Environmental  
Measurement Techniques*

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Department of Civil and Environmental Engineering  
Division of Water Environment Technology  
CHALMERS UNIVERSITY OF TECHNOLOGY  
Göteborg, Sweden 2005

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Cover: Välenviken stormwater ponds site in spring; Göteborg, Sweden.

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Göteborg, Sweden 2005

# Pollutant Removal Efficiency in the Välenviken Stormwater ponds

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## **ABSTRACT**

It has frequently been demonstrated that stormwater ponds, i.e. ponds that collect rainwater runoff, are cost-effective measures on removal of stormwater pollutants. The aim of this work was to analyze the efficiency of a system of three small, close connected, off-stream ponds from which stormwater is diverted to a preserved river delta area, called Välenviken, in Southwest of Göteborg. The ponds can be considered as wetland-ponds overgrown with reed vegetation.

In this report, first a literature overview with the pollutants, their sources and concentration ranges normally found in stormwater, are presented. The approach for analyzes of removal efficiency of the pollutants in this study was based on the use of an Event Mean Concentration (EMC) approach applied to many successive storms events, that is, by comparison between the accumulated pollutant load that enters and leaves the ponds during a longer period, with several rain events, in order to estimate the load that the ponds were able to retain. For this purpose flow-weighted water samples from the inlet and the outlet of the pond were monitored during six consecutive storm events during the end of spring 2004.

Parameters assessed include suspended solids, heavy metals (particle-bound and dissolved), poly-cyclic aromatic hydrocarbons (PAH-16), phosphorus and nitrogen compounds and chloride. The ponds show in general a good pollutant removal efficiency, particle-bound in particular. The results are presented in pollutographs. Best results are shown for suspended solids, total (83%) and volatile (75%); lead, cobalt (70% each) and chromium (57%). Comparing with the literature, phosphorous compounds had a very good removal (35% for phosphate, 45% for total P) while nitrogen was effective for ammonia (45%) but less for nitrate (17%). The COD removal (45%) indicates good capacity for degradation of organic matter. PAH-16 removal efficiency could not be calculated because most of the samples were under the detection limit. Some non-carcinogenic PAHs showed an improvement since the small amounts detected in the inlet were not detected in the outlet. Organic matter (such as TOC and DOC) had negative removal.

With exception of some heavy metals, concentrations found in this study were too low to pose a risk of toxic effects. Removal mechanisms as sedimentation, denitrification and uptake by vegetation are discussed and evaluated. Large variation of efficiency results occurred between rain events. Factors that had a negative influence on the pollutant removal are short dry periods between rain events and the small size of the ponds compared to the catchment area. Measures to improve performance are suggested.

This study gives a good idea about the magnitude of efficiency that even very small ponds like the Välenviken have for a wide range of pollutants, and gives a good background for further studies and useful information for monitoring and analyses programs.

Key words: Stormwater, Pond(s), Heavy metals, Nutrients, Mass balance, Stormwater ponds, Wetland-ponds, PAHs.

Avskiljnings Effektivitet av föroreningar i Välenvikens Dagvattendamm  
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## **SAMMANFATTNING**

Dagvattendammar har under de senaste decennierna visat sig vara en kostnadseffektiv åtgärd för behandling av dagvattenföroreningar. Huvudsyftet med denna studie är att analysera effektiviteten att avskilja dagvattenföroreningar för ett system med tre mindre seriekopplade dammar som mynnar i Välenviken vid Göteborgs sydöstra kust. Dammarna kan betraktas som en våtmark eftersom den är övervuxna med vass.

Först presenteras en litteraturstudie med föroreningar och källor samt de halter som normalt hittas i dagvatten. Dammens avskiljningsförmåga beräknas genom en medelkoncentrationsbetraktelse (EMC-Event Mean Concentration) där halter och ackumulerade föroreningar vid dammens in- och utlopp studeras för flera på varandra följande regntillfällen. Automatiska provtagare har installerats vid dammens inlopp och utlopp vilka har tagit flödesproportionella prover på inkommande och utgående dagvatten under sex regntillfällen under våren 2004.

De parametrar som analyserats är suspenderat material, tungmetaller (partikelbundna och lösta), polycykliska aromatiska kolväten (PAH-16), fosfor- och kväveföreningar samt klorid. Dammen uppvisar i allmänhet en bra avskiljning för partikelbundna föroreningar. Avskiljningen presenteras i ackumulerade föroreningsgrafer. Bäst avskiljningseffektivitet fås för suspenderat material; totalt (83%) och organisk (75%), bly och kobolt (70% vardera) och krom (57%). I jämförelse med literatordata uppvisas en mycket bra avskiljning för fosforföreningar (35% för fosfat och 45% för totalfosfor) och för kväveföreningarna var ammoniak (45%) mest effektiv medan nitrat(17%) var sämre. Avskiljningen av COD (45%) indikerar på god kapacitet att bryta ned organiskt material. Avskiljningsförmågan för PAH-16 kunde inte mätas eftersom koncentrationerna för de flesta prover låg under detektionsnivån. Vissa icke-carcinogena PAH:er uppvisade en avskiljning eftersom låga nivåer kunde detekteras i inloppet medan de inte kunde detekteras i utloppet. Organiskt material (TOC och DOC) uppvisade negativ avskiljning.

De uppmätta föroreningshalterna, med undantag för några tungmetaller, är generellt sett låga varför inga eko-toxiska risker befaras för recipienten. Avskiljningsmekanismer såsom sedimentation, denitrifikation och upptag av vegetation diskuteras och utvärderas. Avskiljning effektivitet hade stor variationen mellan nederbörd fallerna. Stor skillnad i avskiljningseffektivitet uppvisas mellan olika regntillfällen. Faktorer som har en negativ påverkan på avskiljningseffektiviteten är korta torrperioder, nederbördstillfällena och liten dammstorlek i förhållande till avrinningsområde. Åtgärder för att förbättra avskiljningseffektiviteten presenteras.

Denna studie ger en bra ide om effektivitets magnitud som även mycket små dammar som Välenviken har att avskilja en bred spännvidd av föroreningar, ge en bra bakgrund till vidare studier samt informationer på utförande av monitoring och analyser.

Nyckelorder: Dagvatten, Damm(ar), Tungmetaller, Näring, Dagvattendammar, våtmark, dammar, PAH:er.



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Göteborg  
October 2004

Regina Dib do Rêgo Monteiro



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## 1. INTRODUCTION

Discharge of urban stormwater may cause adverse effects on receiving waters, including flooding, erosion, sedimentation, temperature rise, oxygen depletion, nutrient enrichment and eutrophication, toxicity, reduced biodiversity and species succession, and associated impacts that compromise water use (Marsalek *et al*, 1998, Novotny and Olem, 1994 and Leonardson, 1994).

Stormwater ponds, i.e. ponds that collect rainwater runoff, have been initially constructed with the objective to control peak flows during heavy storm events and prevent flooding of combined sewer system in urban areas. However, the interest of using these measures to improve stormwater quality has grown since recent studies have shown that they are effective also in removing pollutants, then minimizing the impact in receiving waters. In Sweden, its use has been intensified in the last decade, especially for highway stormwater collection. In 2001, the Swedish road administration agency (Vägverket) had about 400 installations for treatment of stormwater (Svenska Naturskyddsföreningen, 2001; Lindgren and Svensson, 2003), however the efficiency of these installations has rarely been investigated (Vägverket, 2001).

The aim of this study was to investigate the Välenviken ponds efficiency in improving stormwater quality and, to some extent, study the conditions that affect this efficiency. For this purpose was performed a monitoring program for most of the pollutants normally found in stormwater as well as pH, temperature, dissolved oxygen, conductivity, flow and rainfall during the first weeks of June 2004.

The analyses of the pollutant removal efficiency was based on a mass balance approach that involves a comparison between the total pollutant load that enters and leaves the pond system during a series of successive storm events, to assess the ability of the pond to retain pollutants during that period. This is the first time a monitoring program has been carried out in the Välenviken ponds since the construction in 1999. The results are representative for early summer conditions.

The work was carried out in cooperation with the Göteborg Sewage and Water Works (Göteborgs VA-Verk), which is in charge also of the stormwater ponds management in this study. Laboratory analyzes were performed in the Chemical-Environmental lab of the Civil and Environmental Engineering department of Chalmers University of Technology and partly in the VA-Verk laboratory, Lackarebäck, with exception of PAH that was sent to an accredited commercial laboratory.



## 2. LITERATURE OVERVIEW

### 2.1. Stormwater Profile

#### 2.1.1. Composition

Stormwater pollution composition is already well studied. Typical contribution factors for stormwater pollution are traffic load and fuel type, location, proximity of bigger city areas, proximity to air pollutant industry and solid waste incineration and the use of metals, e.g. copper and zinc, as building materials. Other important sources are atmospheric precipitation and animal fecals (Vägverket, 2001). Of course, since rain and snowmelt runoff transport the pollutants, the weather characteristic of the region (rain frequency and intensity and snowing period) plays an important role.

Significant amounts of suspended solids, total (TSS) and volatile or organic (VSS) are found in urban runoff (Malmqvist, 1984).

Other studies (Pettersson, 1999 in Sweden, Marsalek, 1986 in Canada) confirm the findings of a broad investigation in USA under the scope of the National Urban runoff program, NURP (US EPA, 1983), regarding the presence of heavy metals as main toxic pollutants found in urban runoff, where mainly lead, zinc and copper are studied.

The NURP study also detected organic pollutants, despite less frequently and at lower concentrations relatively to concentration detected for heavy metals. Among them, the most frequent are PAHs (Polyaromatic hydrocarbons) that are confirmed also in a study by Pitt et al, 1995. The levels found were too low for acute effects on the ecosystem, but its importance is because many members of the group have potential for carcinogenic chronic effects (Drever, 1997). In Appendix 2, structural formulas of PAH-16 (US EPA, 1993) are shown.

Heavy metals are present in particulate and dissolved phases and PAHs are mostly attached to suspended solid-associated organic matter (Schueler, 1987).

Nutrients, i.e., nitrogen and phosphorus, are also found in stormwater (Marsalek, 2004; Abustan and Ball, 1998), normally more if close to agricultural and grazing cattle areas, and less in urban and suburbs areas, where atmospheric deposition is dominating (Vägverket, 2001). Also the use of fertilizer in domestic gardens (Novotny and Olem, 1994) and animal faeces (Vägverket, 2001) can further contribute to nutrients in stormwater.

Novotny and Olem (1994) observed that despite most street dirt is in coarser fractions, roughly in sizes equivalent to sand and gravel, most pollutants are associated with fine fractions (e.g. 6% of solids with size smaller than 43µm, equivalent to clay and silt fractions,

contain 50% of phosphorus). German (2003), from the analyses of street swept sediments shows this inverse relationship between metals concentration and particle size, with highest concentrations of metals found in the finest fraction of the sediment. He mentions another study (Krein and Schorer, 2000) that shows that PAHs do not follow this trend that metals do. Instead, they were found to have a bimodal distribution with one peak in fine sand and other in fine silt fraction depending on which of the PAHs that are studied.

Both PAH and heavy metals are found accumulated in bottom sediments that yields much higher concentration than in the runoff (Novotny and Olem, 1994 and Jakobsson, 2003).

All these pollutants are considered as diffuse or nonpoint-source pollution, including pollutants from combined sewer overflow systems (CSO) (Novotny and Olem, 1994). In USA, urban storm runoff is considered a major cause of the impairment of the water quality of rivers and lakes (US EPA, 1990).

Also microorganisms, including coliforms bacteria, pathogenic organisms and viruses, were found in both combined and separate storm sewer flows (in a study carried out in Baltimore, Maryland) (Novotny and Olem, 1994). Watt and Marsalek (1994) call attention to the risk of contracting waterborne diseases due to the presence of bacteria in stormwater ponds and recommend monitoring of indicator bacteria (faecal coliform, E.coli, Pseudomonas aeruginosa and faecal streptococci). Ratio value of faecal coliforms to faecal streptococci is referred as indicator of the origin of faecal pollution. Values greater than four indicates human source and less than one, non-human origin (Novotny and Olem, 1994). Also microorganisms in stormwater may cause problems when discharged into a raw water source for drinking water production.

Also salt used as deicing agent is present in the runoff in cold places and is causing corrosion of vehicles and infrastructure with metals loss causing increased concentrations in the snowmelt runoff (Novotny and Olem, 1994).

### 2.1.2. Sources

In Table 1, the sources of pollutants in urban runoff (adapted from US EPA cited in Novotny and Olem, 1994) are presented. The local differences and the age of the report should be noted. Updated data (1, 2, 3 and 4) was added to complement Table 1. Nowadays, the change from asbestos to copper in brake linings may be more significant source of copper (Landner and Lindström, 1999). Also the ban of lead in gasoline may contribute to decrease its concentration in stormwater since then. Also the use of copper in roofs, as occur in Sweden, may add this as a significant source.

Road erosion is normally a source of pollutants, which is especially important during the winter period in regions where studded tires and road-scraper are used.

Besides gasoline and oil, road runoff contains other organics pollutants that are released from asphalt, concrete, tires and other parts of the vehicle where they are often used as additives and from the exhaustion system (Carlsson and Johansson, 2002; Westerholm, 1990). In a compilation from literature, Jakobsson (2003) add that wearing of rubber tire accounts for a major part of PAH released in road environment (mainly fenantren, fluorantren, pyren) besides releases also heavy metals oxides of Zn, Pb, Cr,Cu and Ni. Also that asphalt contain



PAHs such as pyren, krysen, naftalen, acenaften, fluoren, fenantren; chlorated organic pollutants and harmful substances such BHT (butylhydroxytoluen) and ftalates, that can be released then by erosion.

*Table 1. Source of pollutants in urban runoff* (Adapted from US EPA, 1990. Table was updated with inclusion of sources 1, 2, 3 and pollutant 4)

Pollutant	Automobile use	Pesticide use	Industrial/other use
<i>Heavy Metals</i>			
Copper	Brake linings <sup>1</sup> , metal corrosion.	Algicide	Construction material <sup>2</sup> , paint, wood preservative, electroplating.
Lead	Gasoline, batteries.	Wood preservative	Paint, lead pipe
Zinc	Metal corrosion, tires, road salt.		Paint, metal corrosion
Chromium	Metal corrosion		Paint, metal corrosion, electroplating.
Platinum Group Elements <sup>4</sup>	Exhaust catalytic converter material		
<i>Halogenated Aliphatics</i>			
Methylene chloride		Fumigant	Plastics, paint remover, solvent.
Methyl chloride	Gasoline	Fumigant	Refrigerant, solvent.
<i>Phthalate Esters</i>			
Bis(2-ethylexy)phthalate			Plasticizer.
Butylbenzylphthalate			Plasticizer.
D-N-butylphthalate			Plasticizer, printing inks, paper, stain, adhesive.
<i>PAHs</i>			
Chrysene	Tire <sup>3</sup> , gasoline, oil, grease.		
Phenanthrene	Tire <sup>3</sup> , gasoline.	Wood preservative	Wood/ coal combustion.
Pyrene	Tire <sup>3</sup> , gasoline, asphalt		Wood/ coal combustion.
<i>Other volatiles</i>			
Benzene	Gasoline		Solvent.
Chloroform	Formed from salt	Insecticide	Solvent, formed from chlorination.
Toluene	Gasoline, asphalt		Solvent.
<i>Pesticides, and Phenols</i>			
Lindane (gamma-BHC)		Mosquito control, seed pretreatment	
Chlordane	Termite control		
Dieldrin	Insecticide		Wood processing.
Pentachlorophenol			Wood preservative, paint.
PCBs			Electrical insulation and several other industrial applications
<i>Asbestos</i>	Break and clutch lining, tires additive		

The use of catalytic converters is mandatory in all new cars in Europe since 1993. Although the converters remove carbon monoxide, unburned hydrocarbons and nitrogen oxides from vehicle exhausts (Degobert,1995), they also cause increased release of platinum group

elements (PGE), including platinum, palladium and rhodium (the proportion depending on the material composition of the catalyst that is associated also to the fuel type), and cerium as well, that is used as additive (Rauch, 2001).

Platinum Group Elements (PGE) occur mainly bounded to particles and are found accumulated in urban rivers sediments to where they are transported from road surface by stormwater. Indeed, similar composition, analyzed by laser ablation-ICP-MS, in road and river sediments indicates that this might be an important mechanism for the dispersion in the environment (Rauch, 2001).

Based on field results from road sediments in sites with different traffic intensity in Göteborg and from water and river sediments crossing an urban catchment, Rauch (2001) found higher road PGE concentrations in urban sites in comparison with non-urban site. The levels of PGE in the road and river sediments were found to be higher than the concentrations measured in periods prior to the use of catalyst converters. As in other references mentioned, PGEs were found at low levels, in  $\text{ng g}^{-1}$  range for road and river sediments and lower than  $1 \text{ ng l}^{-1}$  in the water and therefore difficult to measure accurately.

Concentrations of lead in road dust have decreased since it was banned as a gasoline additive, which has been observed in experiments carried out in urban areas in Sweden by Rauch (2001). Despite decrease in deposition, significant amounts are still found in urban runoff due to the capacity to strongly bind to soil particles and migrate out very slow (Pettersson, 1999 and Swedish EPA, 2004).

In Olem and Novotny (1994), it is discussed that in cold areas where snow deposition persist for long time, snow deposits are effective trap of street pollutants and that during snowmelt, particulate pollutants - such as suspended solids, both organic and mineral, many metals and phosphates- have an enrichment ratio less than one. The enrichment ratio is defined as the concentration of pollutants in the meltwater (= runoff) over the bulk concentration prior to snowmelt. This low enrichment ratio means that during snowmelt the pollutants remain mostly in the snowpack while high enrichment rate are found for pollutants that are transported by melting water in the dissolved phase.

In one study carried out in Sweden by Westerström (1990), high enrichment ratios (4 to 6) were found for chlorides and nitrates in the beginning of the snowmelt indicating that they are found mostly in the dissolved phase in the meltwater.

From this discussion we can expect that runoff during rain events directly after the snowmelt period has ended will carry higher concentrations of particle-associated pollutants, like metals, PAH and phosphorus, than during other periods of the year.

### 2.1.3. Reference values

Table 2 presents reference values for pollutant levels in stormwater in urban areas in Sweden proposed by Vägverket (2001), after an upgrade from a report about stormwater composition by Malmqvist (1994).

Table 2. Reference values (schablonvärden) for stormwater pollutants in urban areas (Vägverket, 2001)

Type of area	Lead average (min-max) µg/l	Zinc average (min-max) µg/l	Kopper average (min-max) µg/l	Cadmium average (min-max) µg/l	COD average (min-max) mg/l	Susp. sol. average (min-max) mg/l	Tot-N average (min-max) mg/l	Tot-P average (min-max) mg/l
urban area in general	25 (15-60)	150 (80-300)	50 (25-100)	0.5 (0.3-0.9)	70 (40-120)	120 (50-200)	2 (1-2.5)	0.3 (0.2-0.4)
commercial area	40 (15-70)	240 (100-350)	75 (25-110)	0.5 (0.3-1.0)	160 (110-230)	200 (70-250)	2 (1.0-2.5)	0.3 (0.2-0.5)
residential area	15 (15-40)	120 (60-200)	35 (20-70)	0.3 (0.2-0.5)	60 (45-75)	70 (40-160)	1.5 (1-2)	0.3 (0.1-0.4)
industrial area	40 (10-60)	250 (120-400)	70 (25-110)	0.5 (0.3-0.9)	90 (60-120)	170 (70-230)	2 (1-2.5)	0.3 (0.2-0.6)

## 2.2. Pollutant Removal Efficiency

Stormwater ponds are efficient in removing particles by sedimentation, especially heavier fractions, and since many pollutants are attached to particles, they are also removed in the sedimentation process (Svensson, 1987). Chemical and biological processes also contribute (Mayer *et al.*, 1996)

Thus, pollutants like PAH and heavy metals (especially lead) that to a great extent are associated with particles show good removal efficiency in detention ponds (Lygren *et al.*, 1984) while low removal efficiency is observed for dissolved constituents such dissolved phosphorus, nitrate (NO<sub>3</sub>) and nitrite (NO<sub>2</sub>) and ammonia (NH<sub>3</sub>) (Marsalek, study page 2004)

It is clearly seen that the removal efficiency for a single storm event depends on the amount of pollutants accumulated on the impervious areas during the preceding dry period, and on the rain intensity (Pettersson, 1998; Novotny and Olem, 1994). However, not so simple to visualize is the fact that if the dry period preceding a rain event is short, it can affect the removal efficiency of the pond to be very small or even negative for TSS, Zn and Pb (Pettersson, 1999). This happens because the stormwater entering the pond during the rain event after the short dry period, may contain lower pollutant concentrations than the inflow water in the previous rain event. When this cleaner water volume enters the pond, it displaces a corresponding water volume in the outflow with higher pollutant concentrations than in the inflow. Resuming, in general, longer dry periods between two events and lower rain intensity increases the pollutant removal efficiency (Pettersson, 1998).

Besides the pollutant type and concentrations and rain characteristics, removal efficiency is affected also by pond design. The geometry can, for example, influence the presence of short-circuiting flow and recirculation zones or inactive zones (called dead zones), which imply decreasing residence time for the polluted stormwater in the pond (Persson, 2000), and consequently affects the removal efficiency negatively. Also the pond volume should be large enough to store most of the stormwater entering the pond (and at the same time

## 2. Literature Overview

displace “treated” pond water at the outlet) during the storm event and remain in the pond until the next event (Pettersson, 1998).

Regarding the pond size, it seems that the relationship between removal efficiency and specific pond area (i.e. the surface area of the pond over the impervious catchment area) is highly evident. Based on field results (for total suspended solids, heavy metals and nutrients), Pettersson (1999) found an optimal size of 250 m<sup>2</sup>/ha. Above this value a further increase in size yields just a small increase in removal efficiency and the curve flattens out (Figure 1). This increase of pollutant removal efficiency as a function of specific pond area is presented in Figure 1.

Based on simulation models, Toet *et al* (1990) found the value to be between 200-300 m<sup>3</sup>/ha or 200-300 m<sup>2</sup>/ha with water depth of 1m for removal of suspended solids, phosphorus and heavy metals, which indicates an optimal pond size to be between 2-3% of the connected impervious area.

By long-term field investigation carried out in two ponds in Sweden, one medium loaded pond in Örebro (240 m<sup>2</sup>/ha) and one heavy loaded pond in Göteborg (40 m<sup>2</sup>/ha), Pettersson (1999) found that the removal efficiency for the medium loaded pond for TSS and VSS was 84% and 76% respectively, for metals (zinc, copper and lead) was about 80% except cadmium (50%); for phosphate 74% and for nitrogen 33% (Figure 1). For the heavier loaded pond, removal efficient for TSS and VSS was 70 and 60% respectively, for metals about 30-50% except cadmium (11%), phosphate 40% and nitrogen 7% (Figure 1).

In another pond investigation in Göteborg (specific pond area = 200 m<sup>2</sup>/ha), Pettersson (1998) showed that pollutant removal efficiency was 58% for TSS, 36% for zinc, 47% for lead, about 20% for copper and phosphate and about 17 % for nitrogen (see Figure 1). The deviation in this last pond was attributed to the fact that it is a circular small one with quite short-circuiting flow while the others have a large length to width ratio and more uniformly flow distribution conditions that increase the performance, due to less recirculation and dead zones.

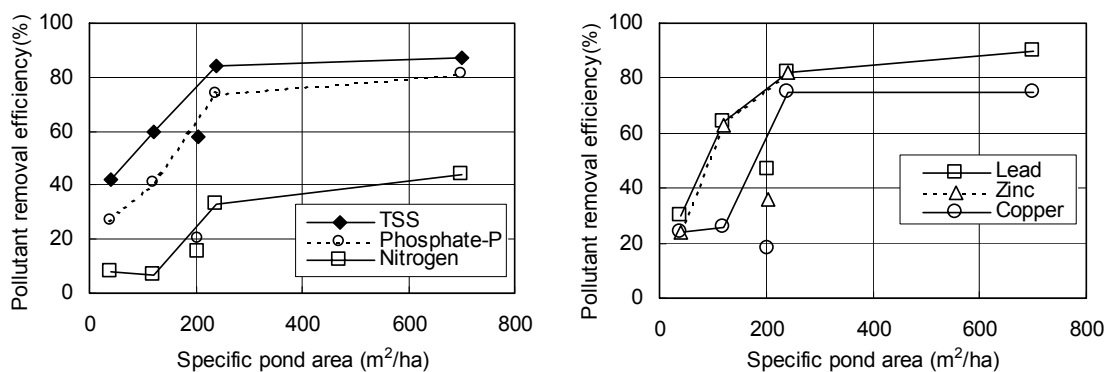


Figure 1. Removal efficiency as function of specific pond area (Pettersson, 1999).

From these experiments, it can also be inferred that higher pollutant removal efficiency is found for suspended solid associated pollutants e.g. TSS, lead and phosphorus while pollutants normally found as dissolved such as cadmium and nitrogen are less effectively removed, see Figure 1.

An extensive research program entitled Wetlands and Lakes as Nitrogen Traps was performed in Sweden to study the retention capacity of different types of wetlands and the processes for nitrogen removal in wetlands, reported by Leonardsson (1994). The project was launched after the eutrophication (see Section 2.3) in the south coastal waters of Sweden became a severe problem in the 1980's. The symptoms were algal blooms, intense production of sulfide from the bottom and death of fish and crustaceans. The main source was farmland runoff but also runoff from forest areas played a role on the nitrogen supply because they covered the major part of the catchments on the Swedish coast. Also grazing cattle in the area contributed to leaking of nitrogen. They concluded that the nitrogen removal in wetlands depends mainly on denitrification<sup>1</sup> (other processes are sedimentation and uptake by vegetation) when most of the nitrogen is supplied in dissolved form as in the farmland areas (90% as nitrate-N) and that the highest percentage retention of nitrogen, phosphorus and particles is during summer low water periods. Denitrification activity is highest at pH 6-8 and increases with increase in temperature (recorded range from 0 to over 30°C) in a rate of 1,5-3 times with a rise of 10 °C (Leonardson, 1994).

For satisfactory results on nitrate removal (over 20% of the load), Jansson *et al* (1994) suggests the inclusion of vegetation (macrophytes) in wetland-ponds as an effective way to provide organic material for enhancing denitrification on the sediments. However, the growth must be restricted so that the plants do not occupy the whole pond, causing canalization of the water flow creating inactive areas as consequence. Vegetation harvest in ponds and wetlands in the beginning of August is the period recorded as the most efficient for maximum nitrogen retention in south Sweden (Granéli *et al*, 1992) at the same time that the risk that the reed species have difficult to return is smaller than if harvest is done in June or July (Weisner & Granéli, 1989).

A common approach to analyze pollutant removal efficiency is by using the Event Mean Concentration (EMC) approach applied to several storm events, that is, by comparing the accumulated pollutant load that enters and leaves the pond during a long-term rain period analyzed (Pettersson, 1999; Van Buren and Watt, 1997). The removal efficiency can be expressed as:  $R(\%) = (M_I - M_O) / M_I \cdot 100$  where  $M_I$  is the pollutant inflow mass and  $M_O$  the pollutant outflow mass.

The mass balance for a specific chemical in the pond water can be written as:

$$M_I - M_O = M_S + M_W + M_A + M_B \pm M_T,$$

where the different masses are indexed as: I is the inflow and O the outflow load; S is the chemical bound to the sediment in the pond, W is the mass in the pond water, A is the chemical mass volatilized, B is the mass fixed by the biota and T the mass arising from transformations, that can be either a production or loss (Watt and Marsalek, 1994). A scheme of this mass balance approach is shown in Figure 2.

<sup>1</sup> Denitrification is the reduction of nitrate to atmospheric N<sub>2</sub> in the sediments by denitrifying bacteria while decomposing organic matter under low aerobic conditions. The nitrate can come from the water column or from the nitrification (oxidation of ammonia in water to nitrate according to the reaction:  $\text{NH}_4 + 2\text{O}_2 = \text{NO}_3 + \text{H}_2\text{O} + 2\text{H}^+$ ) occurring during decomposition of organic matter in the uppermost aerated layer of sediment.

Stormwater ponds are not so effective to remove nutrients as wetlands since the latter ones promote more biological uptake (Bavor *et al*, 2001) and a combination of stormwater ponds and wetlands is very effective when removal of solids, metals and nutrients is intended (Johansson, 1997).

Typical rate of sediment accumulation is between 10-40 mm/yr (Marsalek, 1995). The sediment accumulation also influences pollutant removal efficiency due to the reduction in storage capacity that may be important for shallow, small ponds which may demand sediment removal in more frequent intervals than larger capacity ones. Also more sedimentation is normally found close to the inlet (Pettersson, 1999).

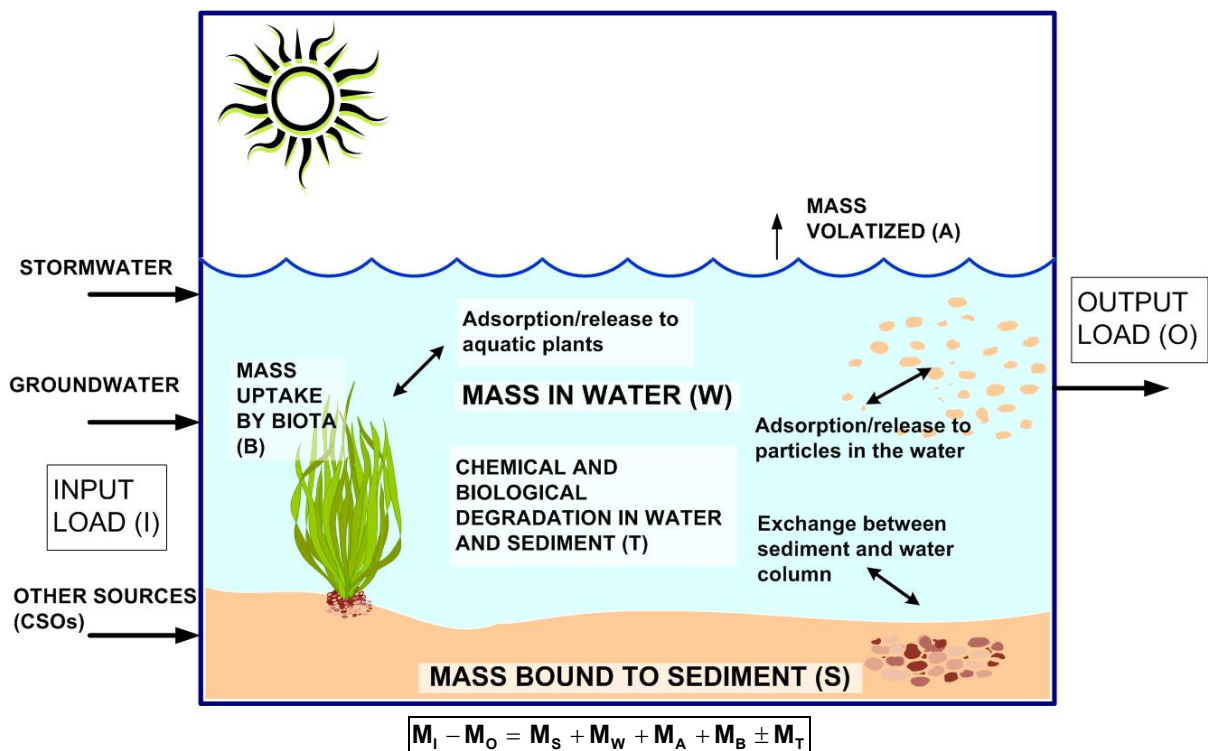


Figure 2. Schematic of mass balance in a stormwater pond

### 2.3. Impact of runoff pollutants in receiving waters

A significant proportion of pollutants are found in dissolved phase in the stormwater, which is more direct bioavailable to be taken by organisms (and with potential to acute toxic effects) than particulate-bound pollutants (Pettersson, 1999). This is confirmed to be true, at least, for metals, where the divalent ion  $Me^{++}$  in many cases has been identified as a toxic compound; and organics (Novotny and Olem, 1994).

Changes in chemical conditions can cause sediment-trapped pollutants to be transformed into mobile forms (Marsalek *et al*, 1997), as anoxic conditions and low pH. The uptake of pollutants by the vegetation, for example fixation of trace metals by phytoplankton (Stumm and Morgan, 1996) and fixation of nutrients by producers (aquatic plants, phytoplankton and nitrification microorganisms)(Novotny and Olem, 1994), reciprocally affects the composition

(quantity and species) of the biological community and, depending on the concentration, even essential elements, can be toxic. Additionally, the pollutants may be released back into the water when the plants decompose after death (Stumm and Morgan, 1996).

### **2.3.1. Disturbance in Chemical balance**

#### *Levels of oxygen*

The dissolved oxygen balance is an important quality parameter for the receiving waters. Diffuse-pollution discharges (that compose the runoff) are rarely a direct threat to the dissolved oxygen level of receiving water bodies. Exception is runoff with high concentrations of biodegradable organics coming from an area with high animal population, from spring runoff from fields with manure spread on still frozen soils and from CSO's (Combined sewer overflows) that demand high levels of oxygen for decomposition (BOD) (Novotny and Olem, 1994).

Nutrient rich discharges affect indirectly the dissolved oxygen level. The nutrients (nitrogen and phosphorus) increase the productivity in surface-water bodies, including streams and estuaries. The productivity impacts the dissolved oxygen balance by: (a) photosynthesis production of oxygen (b) increasing oxygen demand by respiration of algal (phytoplankton) and large plants (macrophytes) and (c) increasing oxygen demand by decomposing dead algal biomass and (d) increasing dissolved oxygen demand by nitrification (see footnote 1 on Section 2.2) (Novotny and Olem, 1994).

The fact that photosynthesis takes place only on sunny days in shallow zones while respiration takes place also in deeper zones and when light is limited (cloudy days and nights) combined with the fact that during storm events there is normally lack of light may be a reason for disturbance of dissolved oxygen level in the receiving waters (Novotny and Olem, 1994).

Oxygen deficiency becomes troublesome when shallow productive water streams flow into deeper ones, like rivers entering reservoirs or bays, estuaries or larger slower moving rivers. Algae biomass may then add to deeper layers and increase respiration rate in waters where only the upper layer does photosynthesis (Novotny and Olem, 1994).

Deep ponds have the risk to become anoxic near the pond bottom, especially during long dry periods when no inflow stirs the pond water body or during winter periods when ice layer covers the pond surface. Particle-bound metals tend to be released from the sediment layer to the water column (dissolved phase) in such anoxic environment (Pettersson, 1996).

#### *Decrease in pH*

Runoff acidity due to acid rain may be neutralized in urban areas by the buffering capacity of carbonates (primary components in concrete, mortars and soil) present in buildings, pavements and sewers pipes (Novotny and Olem, 1994). In fact, despite the characteristic rain acidity in South Sweden (Naturvårdsverket, 2004a), waters in stormwater ponds have kept pH around 7-8 mainly due to the transportation in concrete pipes (Pettersson, 1999).

However, along with the consumption of oxygen, excessive decomposition in sediments produces also the weak acid carbon dioxide and then the hydrogen ions (according to reaction:  $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$ ) that decreases the pH (Jacobsson, 2003). Decreasing pH may increase the release of metals from the negative particle surfaces where they are attached. The mechanism is by ions exchange replacing the metal cations ( $\text{Me}^+$ ) adsorbed on the surface for hydrogen cation ( $\text{H}^+$ ), which means more metals in dissolved form (Drever, 1997).

### ***Eutrophication***

Eutrophication, i.e. excess of biomass production, is not synonymous with pollution, however pollution can accelerate the rate of eutrophication. The net increase of organic matter that drives eutrophication takes place in a surface water body in which organic matter production nourished by nutrients and minerals exceeds its loss by respiration, decay, grazing by higher organisms and outflow. The stage of eutrophication is determined by the trophic state, which is based on few indicators: dissolved oxygen, total phosphorus, transparency, inorganic nitrogen ( $\text{NH}_3\text{-N}$ ) and chlorophyll-a concentration. (Novotny and Olem, 1994). Poor trophic conditions indicate high productivity.

In waters where N/P concentrations ratio (inorganic nitrogen- nitrate, nitrite and ammonium; and phosphorus- phosphate concentration) is higher than 16 (molar ratio) or 7 (concentration ratio), the growth of algae is limited by phosphorus concentration. In waters with N/ P ratio lower than 16 or 7, nitrogen is the limiting factor. Additionally, for lakes, levels of nitrate above 5 mg  $\text{NO}_3\text{-N/l}$  may indicate sewage contamination (Bydén *et al*, 1996).

Normally nitrogen is the limiting factor in marine environment while phosphorus is the limiting factor for inland waters (Leonardsson, 1994 and Bydén *et al*, 1996).

It was observed during summer, anoxic conditions ( $\text{DO} < 2.0\text{mg/l}$ ) in water-sediment interface in stormwater detention ponds studied in Canada (Marsalek, 2004) following high productivity due to accelerated oxygen consumption during decomposition of organic matter. It was observed also high levels of ammonia-N released from the decomposition.

### ***High conductivity***

High conductivity during winter is associated to the use of salt (sodium chloride,  $\text{NaCl}$ ) as de-icing road agent. Besides increased corrosion of metals from pipes and vehicular parts (Novotny and Olem, 1994), the use of salt increases the concentration of certain heavy metals in dissolved phase by ion exchange (Löfgren, 2000). On the other hand, field results from Pettersson (1999) show that high conductivity during a snowmelt event caused increase of dissolved Zn and Cu but decrease in the concentration of dissolved Pb and Cd when compared to condition of lower conductivity during a storm event in the autumn.

In Bäckström *et al* (2004), field studies in soil water in road vicinity demonstrate a strong relationship between metals (Cd, Zn, Pb and Cu) mobilization and the increase in electrical conductivity due to the use of deicing in roads during winter. In the same work another study is mentioned where this was observed (for Zn and Cd) also in surface waters adjacent to



roads where deicing with NaCl is used. The main mechanism seems to be through ion exchange, where protons are released due to the excess of sodium. The lowering in pH produces change in metals speciation. In general, reduces organic matter associated form and increases free ion and/or chloride complexes percentiles. For Zn for example, speciation shifts from 90% organics complexes during summer, to approximately 50% as organic complexes and the rest 50% as free  $Zn^{2+}$  ions during the period of deicing. A maximum of 5% of chloride complexes was also observed.

### 2.3.2. Toxicological and Ecotoxicological Effects

Dissolved oxygen is the most important parameter for protecting fish and aquatic biota. Fish-kill oxygen critical level varies. Cold water fish (salmon, trout) and associated biota requires higher levels of dissolved oxygen than warm species. Values of 4 mg/l and 3 mg/l respectively are the lowest (water quality criteria USEPA) to prevent fish kills but higher concentrations are necessary to preserve the biological integrity of the receiving waters (Novotny and Olem, 1994).

Certain heavy metals, e.g. Cu, Mn, Ni, Mo and Zn are micronutrients, i.e., are needed in trace amounts for plant and animal growth (Drever, 1997). Although the biota is able to protect themselves against small concentrations of even strongly toxic elements such as lead and cadmium in the environment, increased concentrations of heavy metals (even those essentials for biological systems) may cause adverse effects, especially if present in dissolved form since they are more bioavailable (Turner, 1995). The proportion of dissolved heavy metals is affected by environmental conditions, for example pH, oxygen and salt as described in the previous sections.

Also metals can bind covalently to organic groups and these organic-metal compounds are highly lipophilic and thus have high potential of bioaccumulation in organisms. Some of them can be very toxic as tetra-alkyl-lead (Walker *et al*, 2001 in Jakobsson, 2003)

Regarding PAH, those in Appendix 2 marked with asterisks (\*) are considered as carcinogenics, which have high molecular weight consisting of eighteen carbons or more (Jakobsson, 2003). Ecotoxicological data are shown in Appendix 2b where  $LC_{50}$  is referred as the pollutant concentration which is lethal to half of the number of organisms studied and BCF means the Bio Concentration Factor which refer the extent to which a chemical is concentrate in tissue above the level in water, i.e., the concentration in the organism/concentration in the environment. A BCF larger than 100 for fish indicates that the substance has potential to bioaccumulate in the organism (Adams, 1995).

High pollutant levels causing acute toxicity to aquatic life were found in runoff from commercial area with high traffic until almost zero toxicity in a residential area with low traffic density in a study done in Milwaukee (Novotny and Olem, 1994).

Pd, Pt and Rh as well as other heavy metals, can accumulate in freshwater and estuarine sediments and their effect on aquatic life will depend on their biological availability (Rauch, 2001). Metals in solution are usually considered more biologically available than those associated with solids, although at higher concentration in food, sediments and suspended

particulates is a potentially important source of metals to the diet of aquatic organisms (Rauch, 2001).

Sediment toxicity was used for (chronic) ecotoxicological assessment of a creek-pond system in Kingston, Canada, that collect runoff from a mix of residential, commercial, light industrial, and highway catchments. Results indicated that average pond sediments concentrations are exceeding Lowest Effect Level (LEL) for PAHs and heavy metals (Cd, Cr, Cu, Pb and Zn were above, Ni was below) but not Severe Effect Level (SEL) when compared to sediment quality guidelines, what means that sediment is considered marginally polluted and can potentially impact aquatic life (Marsalek *et al*, 2002).

PAH and heavy metals concentrations in sediments accumulated in gully pots for stormwater collection from highways in Sweden also exceeded the Swedish EPA criteria for high polluted sediments in lakes and watercourses (Jakobsson, 2003).

Platinum Group Elements (PGE) were believed to remain relatively inert under environmental conditions and the low environmental concentrations have not been show to directly affect ecosystem or human health. However, the presence of PGE in all biomonitor samples (macroinvertebrate *Asellus aquaticus*) collected from two rivers and a stormwater pond in Göteborg indicates that a fraction of PGE is bioavailable and may represent a ecological risk due to uptake by aquatic life, especially in the case of palladium that shows to be more bioavailable than Pt and Rh (Rauch, 2001). It may also affect human via food chain since aquatic macro invertebrates form an integral diet of freshwater fishes (Hallawell, 1986).

Indeed, from exposure experiments, PGE were found to be toxic to *Asellus aquaticus* with mortality rate of 47, 34 and 39% for Pd, Pt and Rh respectively, after 24h exposure to 500µg/l standard solutions (Rauch, 2001). Besides, Platinum has been found to be toxic to others aquatic organisms as the water flea *Daphnia magna* (Biesinger and Christensen, 1972), the freshworm *Variegatus lubriculus* (Velts et al., 1996), the green algae *Scendesmus subsicatus* (Lustig, 1997) and the marine bacterium *Photobacterium phosphoreum*, used in Microtox test (Wei and Morrison, 1994).

Platinum is also recognized to be toxic to human by effects observed from occupational exposure in automobile catalyst production where it showed potent sensitizer effect from dermatitis to severe asthma (Lindell, 1997). Moreover, platinum is know, from use in cancer treatment since the 1960`s, to interact with DNA and prevent cell division (Rosenberg *et al*, 1965).

As occur with other heavy metals, speciation is an important issue for PGE bioavailability, for example in the case of platinum salts, with Pt (IV) being observed to be more bioaccumulated than Pt(II) (Rauch, 2001).

### **2.4. Best Management Practices (BMP`s)**

Stormwater BMP`s can be defined simply as the control and treatment strategies used to mitigate stormwater impacts. Among the BMP`s, stormwater ponds are used to control flow and thereby reduce runoff peaks, and enhance stormwater quality by physical, chemical and biological processes as well add to visual amenity and recreational possibility. In the past, they were also considered to provide habitat to aquatic and wildlife but recent studies

indicates that this purpose is compromised because pollutants may accumulate in the food chain (Lawrence *et al*, 1996 and Bishop *et al*, 2000)

Table 3 presents a summary of the applications, drawbacks and advantages of different stormwater BMPs compiled from literature in German (2003), Novotny and Olem (1994) and Jakobsson (2003).

Wetlands are more efficient than detention ponds in terms of their abilities to reduce stormwater bacterial and nutrient loads to receiving waters (Bavor H. J. *et al*, 2001). Leonardsson (1994) reported relative retention, i.e., retention expressed as percent of the load, for wetlands-ponds from -44 to +36% for phosphorus (measured as total phosphorus in 2 ponds) and -14 to +28% for nitrogen (total nitrogen and nitrate in 7 ponds).

A constructed wetland with floating and emergent vegetation in Taiwan, which aimed at removing non point source pollutants from stormwater and part of untreated wastewater from a university campus, reported a removal of 88% for nitrogen, 81% for COD, 85% for heavy metals and 60% for the total suspended solids (Kao, C. M. *et al*, 2001).

The wetlands and Lakes as Nitrogen Traps program, mentioned above, recommend the use of wetland-ponds as the most attractive alternative for nitrogen removal. However, a major problem of using wetlands as a mean for reducing nitrogen transport from farm areas to the Swedish coast was that most of the transport occurred during the coldest months of the year (with high precipitation and high runoff) when there is very low production of organic matter (i.e. no plant growth for nutrient uptakes). So, the retention time in the wetlands is too short to permit efficient removal by biological processes during this time of the year (Jansson *et al*, 1994). Thus, significant removal on an annual basis can only be accomplished if the transport of nitrogen during summer corresponds to a significant portion of the annual load.

Conventional treatment plants are not suitable for treatment of stormwater due to the difficulties in taking care of high flow intensity during a rain event, and to the high load of heavy metals that may contaminate the sludge that then become improper for using as farmland fertilizer (Pettersson, 1999).

Street cleaning is appropriate to remove coarser particles (while street washing and surface runoff are selective for finer particles), thus, it alone does not remove pollutants associated to the more fine particles but may be a complement to other techniques (German, 2003 and Novotny and Olem, 1994).

## 2. Literature Overview

Table 3: BMPs for stormwater pollution management.

BMP strategy/ Measures	Advantages and Drawbacks
<p><i>Source control/</i></p> <ul style="list-style-type: none"> <li>. Reduce the construction material pollutant sources;</li> <li>. Reduce of movable sources (from traffic).</li> </ul>	<p>Best and most sustainable way to reduce pollutant load, Hard to implement (requires participation of different organizations and citizens commitment)</p>
<p><i>Non-structural measures<sup>1</sup> /</i></p> <ul style="list-style-type: none"> <li>. Street sweeping . remove sediments and metals from street surface before is washed off and add to stormwater pollution</li> <li>. Filter insets for gullypots (little change)</li> </ul>	<p>&gt;Very effective if place has climate with long dry periods, for removing grit after snowmelt and if parking lots and streets dominate the catchment /limited effectiveness to fine particles removal</p> <p>&gt;Limited capacity to treat water from heavy storms and need regular maintenance</p>
<p><i>Structural measures<sup>2</sup>/</i></p> <ul style="list-style-type: none"> <li>. Infiltration systems (porous pavement systems and infiltration basins, infiltration trenches or wells)→Capture a volume of runoff and infiltrate it on the ground.</li> <li>. Detention systems →Designed to temporarily impound the stormwater for gradual releasing to the receive stream or sewer system and completely empty out between runoff events</li> <li>. Retention systems (wet ponds, underground pipes or tanks) → Designed to capture and retain a volume of runoff until it is displaced in part or total in the next runoff event.</li> <li>. Constructed wetland systems→ Similar to detention/retention systems but the surface or bottom contains wetland vegetation.</li> <li>. Filtration systems→ Use combinations of granular filtration media (such as sand, soil, organic carbon or membrane) to remove runoff constituents.</li> <li>. Biofilters → Designed to convey and treat shallow flow (swales) or sheet flow runoff (filter strips) between impervious road or parking lot and drainage sewers.</li> <li>. Control of erosion from pervious area (e. g. vegetative cover, sodding and mulching)</li> </ul>	<p>&gt;Reduce surface runoff, filtration of pollutants, aquifer recharge and reduce need for storm drainage/less feasible if impermeable subsoils, poor longevity if not adequate maintenance (clogging by sed. and oil), contamination of shallow aquifer, and porous pavement is inadequate in heavy traffic road and where sanding practice is used.</p> <p>&gt;Effective water quantity control/ not water quality control.</p> <p>&gt; Flood and water quality control, low cost for ponds, underground installations optimize space / result in hardly polluted sediment that must be appropriately handle and small particles pass through. Ponds demand large surface areas of ~ 200 m<sup>2</sup>/ ha impervious catchment area (see Section 2.2).</p> <p>&gt; Flood and water quality control. Effective pollutant removal, even removal of dissolved particles, including metals and organic, low cost / Demand large areas, result in hardly polluted sediment that must be appropriately handle, vegetation needs to be harvested.</p> <p>&gt;Besides solids and nutrients, it has high affinity for absorbing and removing toxic compounds/ effective only for control of runoff from small sites, risk of clogging .</p> <p>&gt;Help reduce impervious surface, thus reduce runoff flow, some infiltration. Remove pollutants by filtration (especially particulate)/Low efficiency with large storms.</p> <p>&gt;Prevents addition of pollutants by soil loss, especially from slopes</p>

<sup>1</sup> reduce amount of pollutants able to be washed off from surface by rain and do not demand changes in the drainage system

<sup>2</sup> changes in the drainage system and demand construction work

### 3. SITE BACKGROUND

The wet pond system in this study was constructed in 1999 and aimed at retaining stormwater from a urban catchment area on the southwest part of Göteborg before discharged into Välenviken, the Stora Ån river delta in connection to Askin beach place in Southwest of Göteborg (see map in Appendix 1). The system consists of three small ponds, connected in series, with a total area of approximately 2000 m<sup>2</sup> (with the sizes distributed as 35%, 35% and 30%) and provides a total permanent pool water volume (during dry weather) of about 600 m<sup>3</sup>. The ponds are shallow with depths of 0.70 m, 0.15 m and 0.15 m respectively and are close connected as can be seen in Figure 5.

The pond inlet consists of a 1.2 m wide ditch downstream a concrete stormwater pipe system. There is a stormwater by-pass overflow structure, located upstream both the pond inlet and the ditch, that starts to divert stormwater directly to Välenviken when the inflow to the ponds exceeds 0.15 m<sup>3</sup>/s (150 l/s), which occurs during heavy storm events. The maximum flow to the ponds is estimated to be 350 l/s during very heavy storm events. The outlet (of the third pond) consists of a 3 m wide rectangular weir, see Figure 7.

The ponds are off-stream ponds, i.e. no significant baseflow only some groundwater leakage into the pipe system, with inflow from runoff only during storm events. The pond bottom consists of clay. Today the ponds are to a great extent covered by dense vegetation of reed macrophyte *Phragmites australis* ("vass" in Swedish), which is a type of grass-like plant that grows near water (Figure 3). The maintenance of the ponds is limited to sporadically cut of overgrown vegetation. The sediment accumulation has not been measured. But since the ponds are very shallow it is likely that even small amounts of bottom sediment accumulation may reduce the pollutant removal efficiency.



Figure 3. Reed (*Phragmites australis*)  
Source: Västra Frölunda Naturvårdsförening, 2004



Figure 4. Highland cattle.  
Source: Västra Frölunda Naturvårdsförening, 2004

### 3. Site background

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During very heavy storm events the sewage pipe system, that has an overflow channel connected to the stormwater system, may discharge sewer overflow to the stormwater system and the Välenviken ponds. The sewage system origin from the islands - Styrösö, Brännö, Asperö- including the residential areas Tynnered and Näset (see Figure 5). Toilet paper that indicates the occurrence of overflow has been found in the inlet grid during this project work.

Highland cattle were introduced in the grazing land area around the ponds in 1992 (Figure 4) and there is a path for them through the ditch and the ponds inlet that may also contribute to organic load.

The connected catchment (see map in Appendix 1) covers residential and commercial areas of totally 193 ha with an impervious area share of 60 ha, which corresponds to a specific pond area (i.e. pond area over impervious catchment area) of 33 m<sup>2</sup>/ha (0.33%). Thus, these ponds seem to be too small to achieve high pollutant removal efficiency compared to previous studies of Pettersson (1999), see Section 2.2.

The last pond is frequently inundated by seawater during high tide.

This is the first time monitoring and measurement of pollutant removal efficiency, for improving water quality, has been carried out in this pond since the construction in 1999.

## 4. MONITORING PROCESS

The objective of the monitoring was to determine the pollutant removal efficiency of the ponds. A mass balance approach is applied, and is described in Section 2.2. Thus, the monitoring will allow to see how the three ponds contribute to the quality improvement of the stormwater origin from the urban catchment area connected, i.e. the runoff contaminated with pollutants originating from buildings corrosion, road erosion and mainly traffic of vehicle, before discharged into the bay Vålenviken and then to the sea.

The possibility that overflow from the sewage system coming from the islands and other areas on the west part of Göteborg each the ponds was analyzed in terms of nutrients load, but no bacterial analyses was performed. Baseflow values were analyzed from manually taken samples in between rain events. Proceedings for preservation and handling of samples are presented in Appendix 3.

### 4.1. Settling considerations and Analysis proceedings

The pollutant removal efficiency cannot be determined based on results of only one single storm event (Pettersson, 1999). Data from several successive storm events were analyzed to smooth out single storm events variations (including negative rates that can happen when one storm event is preceded by a short dry period causing smaller load of pollutants in the inflow compared to the outflow).

The main limitation of this study is that the time of monitoring does not cover all seasons; however the results are very representative for the end spring/beginning summer period.

The three ponds were considered as one system and two measurement points were selected, the first point was in the overflow chamber upstream the pond inlet ditch and the second point was at the pond outlet (Figure 5).

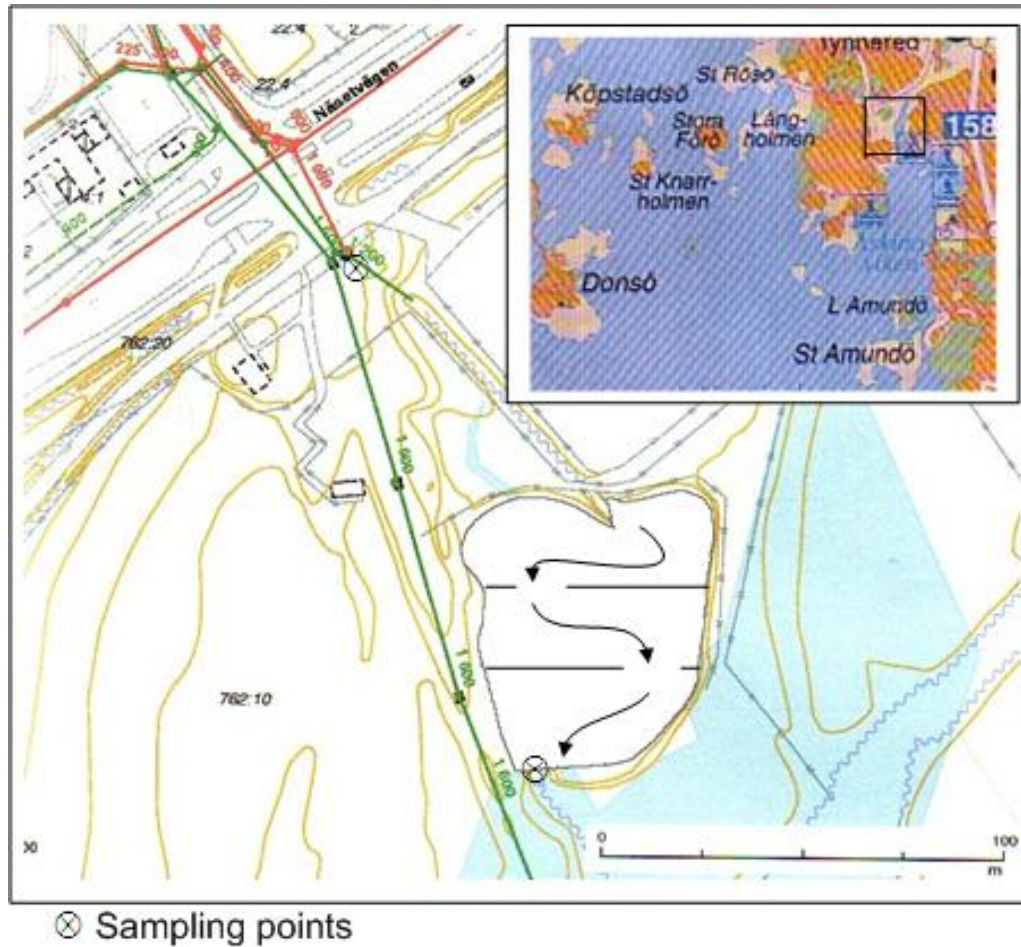


Figure 5. Ponds area with ditch upstream to the pond inlet, flow scheme and outlet. The green lines are stormwater pipes and the red are sewage pipes (the numbers are pipe diameter in mm). The green one that passes along the west side of the pond is the upstream stormwater overflow to Välenviken.

Automatic stormwater sampling with two ISCO 6700 samplers (Figure 6) (equipped with 24 one liter plastic bottles) was performed in both measuring points. Each sampler had a flow module installed, at the inlet an ISCO 750 with a v-h probe (measuring velocity and water level) was installed in the inlet pipe and at the outlet an ISCO 720 module with a pressure probe was installed in the pond 20 cm below the dry weather water surface (Figure 5). At the outlet a 157° weir notch was installed (Figure 7) and the flow was calculated, using the water level above the notch, by the following expression:

$$Q = C \frac{8}{15} \cdot (2g)^{\frac{1}{2}} \cdot h^{\frac{5}{2}} \cdot \tan \frac{\theta}{2}$$

where Q = stormwater flow (m<sup>3</sup>/s)  
 C = flow coefficient (set to 0.6 in this case)  
 h = water surface height above the weir notch (m)  
 θ = weir notch angle (157°).

Each sampler was programmed to take flow-weighted samples that were analyzed in the lab, after each storm event, to measure the pollutant concentrations. A stormwater volume between 100-200 m<sup>3</sup> passing the measuring point was used as interval between sampling and each filled bottle, consisted of 3 sub samples, representing maximum 600 m<sup>3</sup> of stormwater



per bottle. The minimum flow to trigger start and stop of the equipment was set to 10 l/s for the inlet and 5 l/s for the outlet. Both samplers have a built-in logger that stores all sampling and flow data. A schematic of the instrumentation is show in Figure 8.



Figure 6. ISCO 6700 sampler



Figure 7. Weir notch (157°) at the outlet.

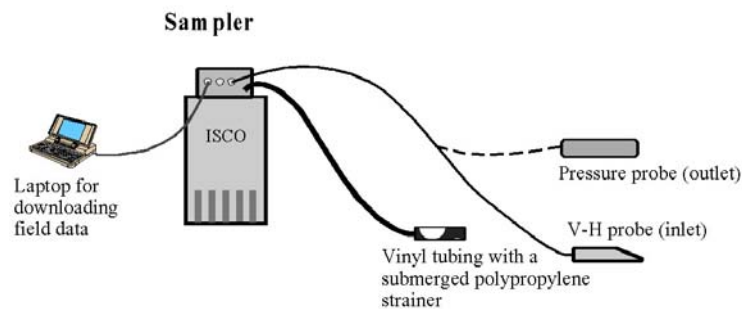


Figure 8. Schematic of the automatic sampler

To calculate the total pollutant removal efficiency of the pond, stormwater volumes obtained from the loggers (integrate flow intensities over time of sampling) and the data of pollutant concentration (from lab analyses of composite samples) for both the inlet and the outlet was used to calculate the total load (mass) of the pollutants that, respectively, enters and leaves the pond during each of the storm events (Figure 9a).

Secondly, cumulative pollutographs (pollutant masses) were calculated and then plotted as a function of the stormwater volume (all storm events studied) for the inlet and outlet (Figure 9 b). The total pollutant removal was then considered as the difference between the pollutant load of the inflow and outflow stormwater.

## 4. Monitoring Process

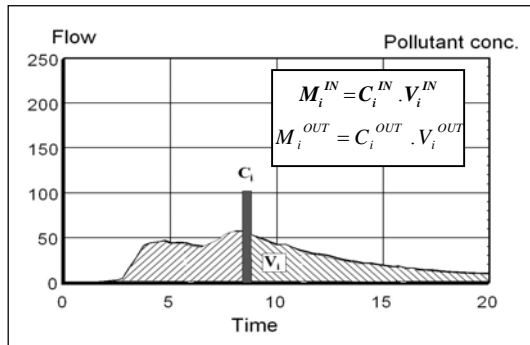


Figure 9a. Principle for calculation of the pollutant load per storm event.

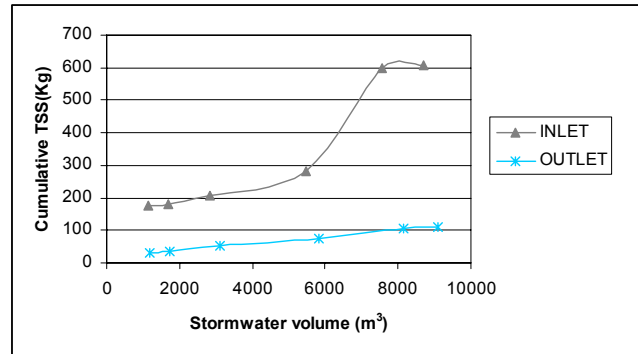


Figure 9b. Cumulative pollutant load for all the monitored storm events

For particulate bound pollutants, an almost linear curve in the cumulative graph shows that the outflow always contains small, not removable particles and therefore, 100% pollutant removal is not a possible goal to reach (Pettersson, 1999).

### 4.2. Parameters Monitored and Methods

Dissolved oxygen, pH and conductivity were directly measured in the pond with a multiprobe equipment.

*Comments:* The oxygen normally is not a problem when ponds do not suffer from frost effects. They are also too shallow to develop stratification. It is known that the low oxygen can increase the dissolution of the metals and the release of phosphate from the sediment.

Heavy metals (total metal concentration and dissolved) were analysed with a method according to SS-EN ISO 11885:1997 by inductively coupled plasma mass spectrometry (ICP-MS). The dissolved heavy metals concentration was measured as the concentration after filtration of the stormwater sample through a 0.45  $\mu\text{m}$  cellulose acetate filter.

*Comments:* There is little of copper roof in the catchment area. Despite lead is not expected in high concentrations due to the ban of its use as additive in Sweden, the interest is due to the high toxicity.

#### **Principle of ICP-MS method (Rauch, 2001):**

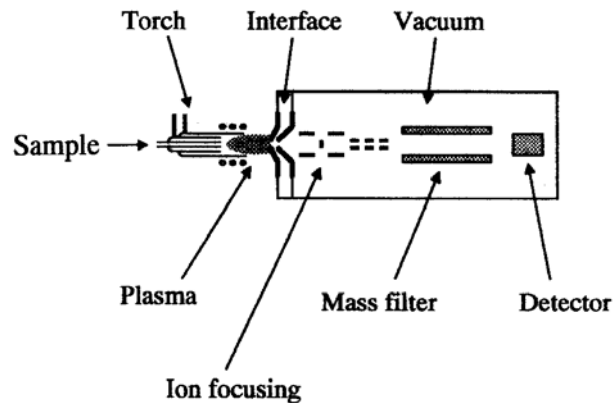
ICP-MS stands for *Inductively Coupled Plasma- Mass Spectrometry*. Basically, the plasma is a highly ionized gas that is used to convert elements in the sample to ions which are then separated by mass in a mass spectrometer. It allows the different elements (and their isotopes) to be separated and their concentrations determined with high sensitivity (can be detected at nano gram [ng] levels in aqueous solution).

Typically, the plasma is formed by argon gas flowing through an electromagnetic field (generated by a copper load coil to which radiofrequency is applied) where it is kept in a state of partial ionization and reach very high temperatures (6 000-10 000°C). The core of the ICP-MS system is the interface through which ions from the plasma (at high temperature atmospheric pressure) enter the high-vacuum room temperature chamber of the mass

spectrometer. Once introduced into the plasma, the sample is vaporized, atomized and ionized and then, the ions formed are extracted into a mass spectrometer. The samples can be a gas, microdroplets or solid microparticles. If liquid is analyzed, a nebuliser has to be used to form the droplets. If solid, the sample needs to be converted to micrometer sized or vaporized and laser ablation or electrothermal vaporization can be used as introduction techniques.

The interface is composed of two successive cones with millimeter orifices through which the ions are extracted from the plasma. After the interface, ions are focused through ions lenses and introduced into the mass filter based on their mass-to-charge ratio ( $m/z$ ). The most common mass filter is a quadrupole mass analyzer. It consists of four metal rods suspended parallel to a central axis and with opposite pairs connected together where direct current and radio frequency voltages are applied. The ions to be analyzed are introduced along the axis. For a given voltage, only ions with a specific  $m/z$  ratio will have a stable trajectory and emerge at the other end of the quadrupole, where they are detected. Figure 10 is a cross section of an ICP with a quadrupole MS.

Figure 10. Cross section of a quadrupole ICP-MS instrument.  
Source: Rauch,2001



Suspended Solids (Total-TSS and volatile-VSS). Analysis methods according to SS- EN 872:1996 and SS 028112. Detection limit: 2 mg/l. Concentration analyses after filtration of sample through a GF/A glass fiber filter (1.6 $\mu$ m).

Nutrients (Total-N, Nitrate, Nitrite and Ammonium; Total-P and Phosphate-P). Analysis methods according, respectively, to SS028131-1, SS028133-2, SS-EN 26777:1993; SS028126-2 and SS028127-2, by spectrofotometry using Hatch equipment DR 2010 model.

*Comments:* It is expected that the presence of reed in the ponds have positive influence in the removal efficiency of nutrients.

Total organic carbon (TOC) and dissolved organic carbon (DOC). Analysis method according to SS-EN 1484:1997, Detection limit: 0.1 mg/l. Final CO<sub>2</sub> determination carried out by IR spectrometry. DOC is considered as the carbon content measured on a water sample that been filtered through a 0.45  $\mu$ m filter. TOC is the carbon content of the unfiltered sample.

Chloride (Cl<sup>-</sup>). Analysis method according to SIS 028120-1. Detection limit: 1 mg/l.

#### 4. Monitoring Process

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PAHs. Analysis using High Performance Liquid Chromatography (HPLC). Structural formulas of the PAHs analyzed is presented in Appendix 2.

Chemical Oxygen Demand (COD). It is an approximate measure of the theoretical oxygen demand, i.e. the amount oxygen that is consumed for total oxidation of both dissolved and suspended organic compounds to inorganic sub products (also oxidation of some inorganic compounds like chloride). It includes the amount of oxygen consumed by biologically active organic substances and non-biological oxidation, e.g. by U.V. (Encyclopedia homepage, 2004 and Bidén, 1996). Analysis method COD<sub>Mn</sub> according to SS 028118-1:1981 where the oxidant reagent is potassiumpermanganate (KMnO<sub>4</sub>).

**Principle of HPLC method** (Analytica website, 2002 and Harwood, 1999):

HPLC stands for High Performance (or Pressure) Liquid Chromatography where the sample to be analyzed is injected via a loop to the mobile phase (a liquid), and the components are separated from each other as a mobile phase is transported through a column.

By varying the material in the column (i.e. the stationary phase) and/or the mobile phase, different separation systems can be designed. The liquid mobile phase, like the method name says, plays a major role in the separation and methanol, water and acetonitrile are commonly used.

The stationary phase is composed of extreme fine spherical particles, with a very big surface for adsorption (200-300 m<sup>2</sup>g<sup>-1</sup>) normally modified silica gel in which hydrocarbons and other groups were added to change the polarity. The particles characteristics allow the column to be hardly packed which demands high pressure to the eluent pass through it.

Normally a UV (ultraviolet) detector is coupled and allows the detection of compounds with strong UV absorption, e.g. aromatic compounds such as PAHs. Diode array detector or a scanning UV detector are different types of UV detector that can be used, the last recording an entire spectrum. It can also be used a fluorescent detector for fluorescent compounds (or fluorescent made compounds by derivatization) that can be up to 1000 times more sensitive than the UV detector. Detection can be at very low pg levels accordingly to Hüsgen *et al* (1993). Its high specificity also results in less interference from the background (i.e. from solvent or impurities). It is applied in the detection of plane PAHs. Figure 11 shows a schematic of a HPLC instrument.

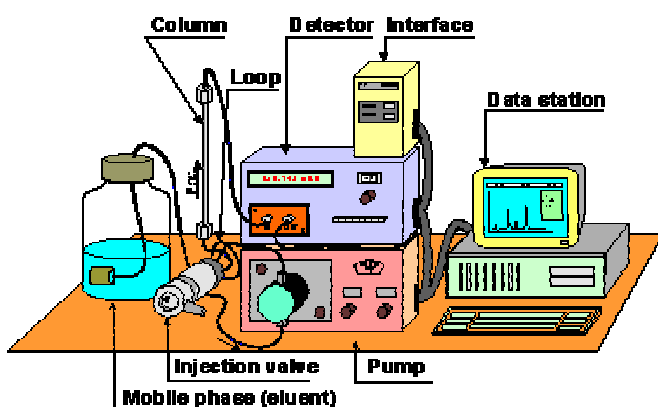


Figure 11. Schematic of a HPLC instrument. Source: Kazakevich, Y. and McNair, H.M.(1996).

## 5. RESULTS AND DISCUSSIONS

The water quality monitoring in the Välenviken ponds (as described in Chapter 4) was performed during June 2004 and included 6 storm events (11, 12, 15, 19-20, 22 and 23 of June 2004) with rain intensity and frequency as presented in Figure 12.

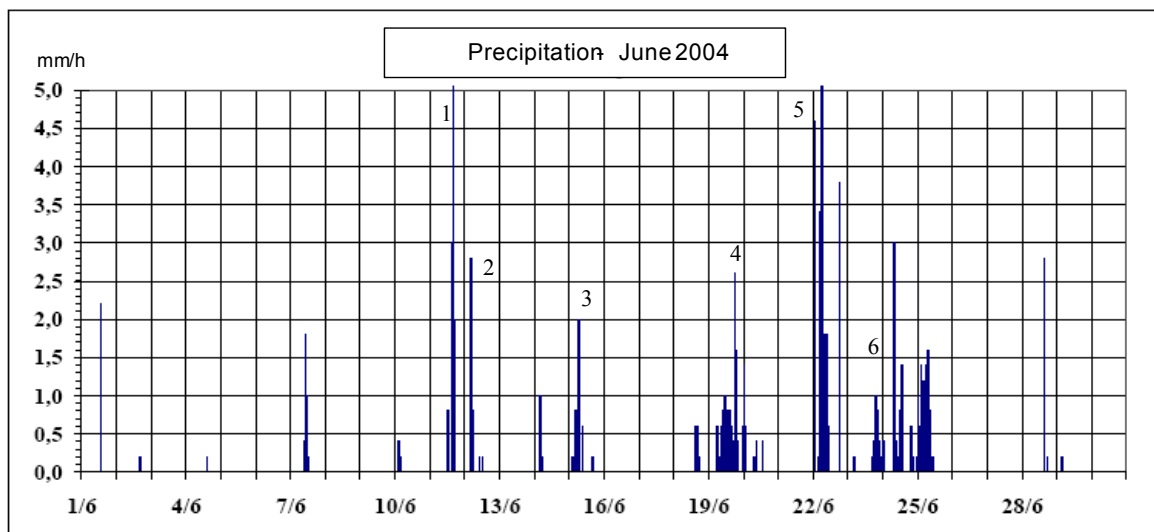


Figure 12. Precipitation in June 2004 measured on Skansen Lejonet in the center of Göteborg city. June was a rainy month with average temperature of 13.9°C and total rain volume of 90 mm.

Source: Miljöförvaltningen (2004)

The rain depth and volumes of stormwater entering and leaving the ponds during each storm event is presented in Table 4.

Table 4. Stormwater volumes and rain depth per storm event.

Storm	Stormwater Volume (m <sup>3</sup> )		Rain depth (mm)*
	In	Out	
1 (11/6)	1148	1182	9.7
2 (12/6)	546	550	2.0
3 (15/6)	1130	1370	5.8
4 (19-20/6)	2645	2733	15.6
5A (22/6)	2076	1599	15
B (22/6)		713	-
6 (23/6)	1154	938	3.2
<b>Sum</b>	<b>8699</b>	<b>9085</b>	<b>51.3</b>

\* calculated by integration of rain data (mm/min versus time) measured at Barlastplatsen, the closest on-line rain gauge to the Välenviken ponds

## 5. Results and Discussions

Flow is dependent of rain depth. Hydrographs in Figure 13 show that the response of the inflow has an instant flow peak that decreases afterwards while the outflow rises after a short delay and has a smother curve. A good thing about the flow pattern in the ponds is that the pond geometry in study already have a kind of baffles as suggested by Buren *et al* (1996) which cause a zig-zag flow effect that may increase pollutant removal effectiveness.

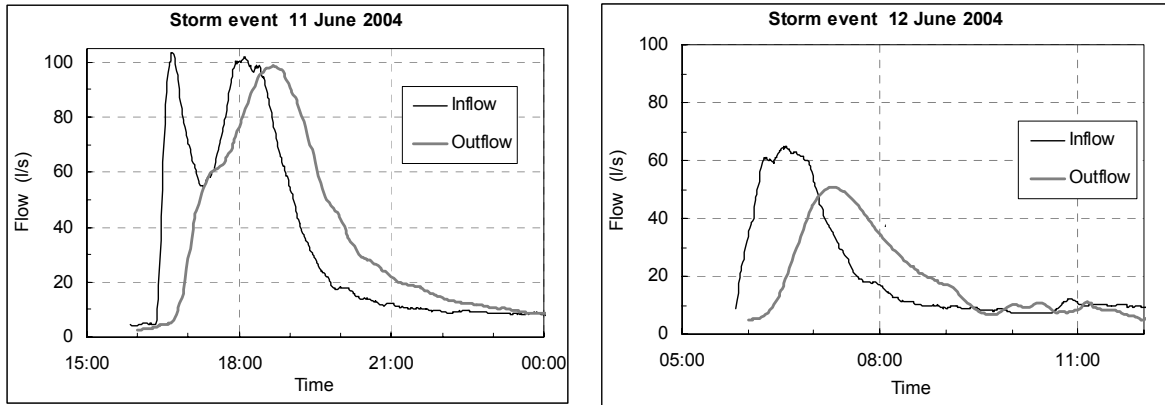


Figure 13. Hydrographs with inflow and outflow response of the storm events 11 and 12 of June 2004.

In Appendix 4 all details of the water quality results for the parameters measured at the inlet and outlet from the six storm events are presented. This includes concentration of suspended solids, total (TSS) and volatile (VSS); organic compounds, such as total organic carbon (TOC) and dissolved organic carbon (DOC); nutrients; chloride and heavy metals-total and dissolved. Also the calculated load (masses) for each parameter from the six events measured are presented, as well as the stormwater volume entering and leaving the ponds for each storm event.

After processing these data SMC's (Site Mean Concentrations) are presented in Table 5, and were used to calculate the removal efficiency (R) to avoid errors due to inaccuracy in the flow measurements, by the following expression:

$$R = \frac{(SMC_{in} - SMC_{out})}{SMC_{in}} \cdot 100$$

where

- R = removal efficiency of considered pollutant (%)
- $SMC_{in}$  = inflow site mean concentration of considered pollutant (mg/l or  $\mu$ g/l)
- $SMC_{out}$  = outflow site mean concentration of considered pollutant (mg/l or  $\mu$ g/l)

The Site Mean Concentrations for the six analyzed storm events was calculated as:  
 $SMC = \Sigma M / \Sigma V$  (the sums are values for all six storm events measured) and is an average pollutant concentration for the site (see Table 5 for details).

Cumulative pollutant data are presented in Appendix 5 (pollutant load and volume of stormwater accumulated along the storm events for the inlet and outlet) then used to create the pollutographs presented in Appendix 6.

The concentration values measured during the storm events for the different pollutants are compared with the guidelines from the Swedish environment protection agency (Naturvårdsverket), presented in Appendix 7, or with values found in the literature in case of missing specific guidelines. Also the efficiency on removal of pollutants is analysed and possible factors that could have influenced on the performance are discussed.

Table 5: Site Mean Concentration and Removal efficiency

	SMCs		R(%)
	C <sup>in</sup>	C <sup>out</sup>	
TSS (mg/l)	70.0	12.1	<b>83</b>
VSS (mg/l)	17.6	4.4	<b>75</b>
TOC (mg/l)	6.8	7.2	<b>-7</b>
DOC (mg/l)	7.7	8.3	<b>-8</b>
COD (mg/l)	6.5	3.6	<b>45</b>
NO <sub>3</sub> -N (mg/l)	0.86	0.72	<b>17</b>
NO <sub>2</sub> -N (mg/l)	0.01	0.02	<b>-30</b>
NH <sub>3</sub> -N (mg/l)	0.21	0.12	<b>45</b>
Tot-N (mg/l)	1.62	1.68	<b>-4</b>
PO <sub>4</sub> -P (mg/l)	0.22	0.14	<b>35</b>
Tot-P (mg/l)	0.47	0.25	<b>46</b>
Cl <sup>-</sup> (mg/l)	15.2	18.8	<b>-24</b>
Zn <sub>t</sub> (µg/l)	167.0	110.6	<b>34</b>
Cu <sub>t</sub> (µg/l)	35.8	17.3	<b>52</b>
Pb <sub>t</sub> (µg/l)	10.1	3.1	<b>69</b>
Cd <sub>t</sub> (µg/l)	2.4	1.9	<b>22</b>
Ni <sub>t</sub> (µg/l)	4.5	2.9	<b>36</b>
Cr <sub>t</sub> (µg/l)	5.5	2.4	<b>57</b>
Co <sub>t</sub> (µg/l)	1.5	0.47	<b>68</b>
Zn <sub>d</sub> (µg/l)	45.1	24.4	<b>46</b>
Cu <sub>d</sub> (µg/l)	14.5	9.8	<b>32</b>
Pb <sub>d</sub> (µg/l)	0.53	0.49	<b>8</b>
Cd <sub>d</sub> (µg/l)	0.12	0.08	<b>33</b>
Ni <sub>d</sub> (µg/l)	2.07	2.17	<b>-5</b>
Cr <sub>d</sub> (µg/l)	1.52	1.21	<b>20</b>
Co <sub>d</sub> (µg/l)	0.20	0.18	<b>10</b>
	ΣV <sup>in</sup> = 8699 m <sup>3</sup>	ΣV <sup>out</sup> = 9085m <sup>3</sup>	

$$\text{SMC}^{\text{in}} = \frac{\sum M^{\text{in}}}{\sum V^{\text{in}}}$$

$$\text{SMC}^{\text{out}} = \frac{\sum M^{\text{out}}}{\sum V^{\text{out}}}$$

$$\text{R}(\%) = \frac{C^{\text{in}} - C^{\text{out}}}{C^{\text{in}}} * 100$$

Subscript *t* and *d* in the table means total fraction and dissolved fraction of metal concentrations respectively

## 5.1. Suspended Solids

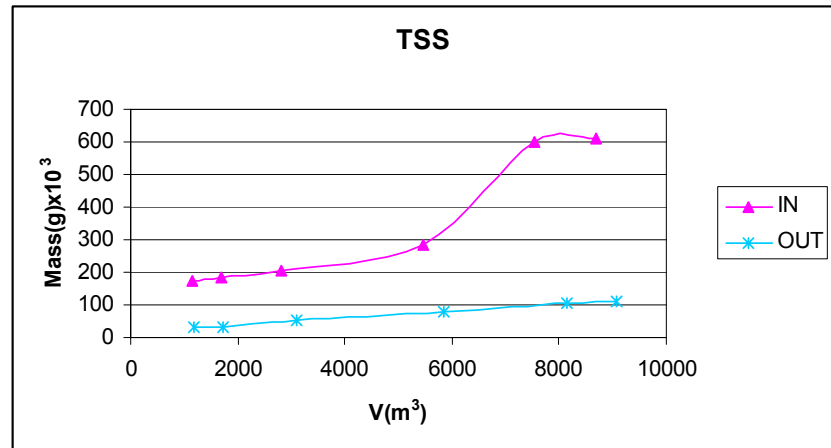
There are no Swedish guidelines for receiving and natural waters but average TSS concentrations entering the pond (about 70 mg/l) is found in the normal range for stormwater in urban residential areas in Sweden (see section 2.1.3). The pollutograph in Figure 14 shows

## 5. Results and Discussions

an efficient removal (83%) of suspended solids by sedimentation in the pond. VSS that corresponds to the organic part of this solid fraction, is also efficiently removed (75%) (see pollutograph in Appendix 6).

These high removal efficiency values indicates that flow conditions for sedimentation and specific pond volume are sufficient to allow settling of these solid particles.

Figure 14. Pollutograph of TSS. The difference in mass from the inlet to the outlet has been retained in the ponds indicating good removal efficiency.



### 5.2. TOC and DOC

Total organic carbon (TOC) values represents the amount of organic carbon present in both dissolved and particulate organic matter but does not gives any information about the type of organic material.

Accordingly to the Swedish-EPA classification of TOC in lakes and watercourses (see Appendix 7) the SMC of TOC was found to be in the upper low level range, almost moderately high (Class2/3), for the inlet (SMC 6.8 mg/l) and outlet (SMC 7.2 mg/l).

Dissolved organic carbon (DOC) concentrations entering and leaving the pond (SMC is 7.7mg/l for the inlet and 8.3mg/l for the outlet) is much higher than the typical concentration in rainwater (that is about 0.5 to 1.5 mg/l)(Hoffman et al, 1980), also much higher than in low biological productivity lakes ( that is from 1 to 3 mg/l) and even little above the range for eutrophic lakes (that is from 2 to 5mg/l) (Thurman, 1985).

The fact that the concentration of DOC was found in half cases higher than the TOC deserved investigation and error in the equipment and in the way of treatment of samples (filter material) was detected.

Although the accuracy has been compromised, since the error was done in a systematic way in both the inlet and outlet, the concentrations can be compared, so that the retention rates are more or less reliable and may give a good indication, at least in terms of magnitude, about the removal efficiency.

The results indicate that both TOC and DOC have not been removed in the pond. The removal rate is -7 % and -8 % for TOC and DOC, respectively. See pollutographs in Figure 15 and Appendix 6.

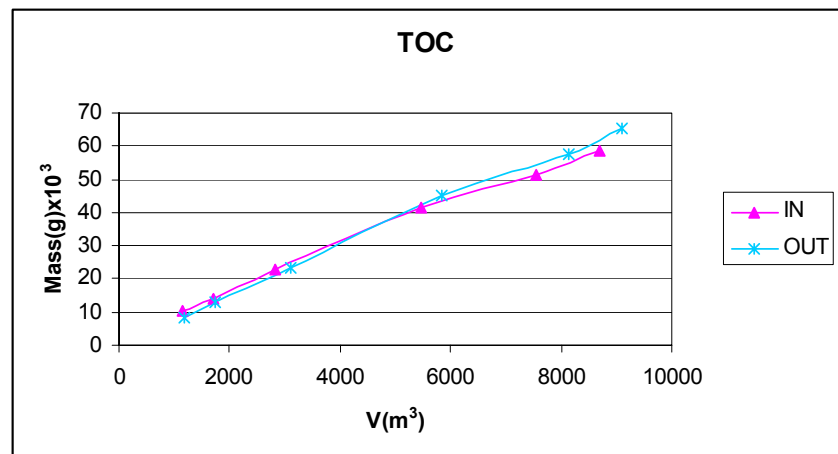


It is worth to mention that some inaccuracy is also inherent to the measurement technique. The analyses of TOC requires that suspended solids are somewhat settled before put in the spectrometer what cause partly exclusion of organic matter that naturally does not occur with DOC that is already a filtrate sample (see Section 4.2 ). This loss is naturally bigger in the sample containing largest amount of suspended solids as in the inlet than in the outlet. Also when the particles settle, it is possible that they bring some smaller particles, possibly already in the range of dissolved matter, i.e. below  $0.45\mu\text{m}$ , with them what increases even more the losses.

A better approach should consider the average TOC concentration by doing 3 different sub samples for each water sample instead of only one, which minimizes possible measurement errors and therefore increases statistics reliability.

It is expected that organic matter entering the ponds as natural DOC in the stormwater (mostly humic substances from soil water) that is already facing some difficult to be decomposed could persist along transport through the pond. It is likely that removal of organic matter is being overwhelmed by the addition in the ponds itself coming from the dense vegetation, from cow excrements washed from the surrounding pasture and intense decomposition rate aggravate by the present of sewage. DOC compounds in rainwater, in form of formate, acetate and oxalate, appear in low concentrations and tend to biodegrade rapidly (Drever, 1997).

*Figure 15. Pollutograph shows that TOC is passing through the pond without being removed.*



### 5.3. COD

The Chemical oxygen demand (COD) in the inlet varies from low to moderately high (SMC  $6.5\text{ mgO}_2/\text{l}$ ) and in the outlet is low (SMC  $3.6\text{ mgO}_2/\text{l}$ ) accordingly to the Swedish EPA classification.

The information COD gives is the amount of oxygen necessary for oxidation of organic matter and other inorganic compounds as chloride for example. Thus, since there is lower oxygen demand in the outlet than in the inlet, it might have been consumed along the pond due to natural oxidation (for example by microbial and U.V degradation). This removal (45%) is a good indication of the pond capacity for degradation. The COD pollutograph is shown in Figure 16.

## 5. Results and Discussions

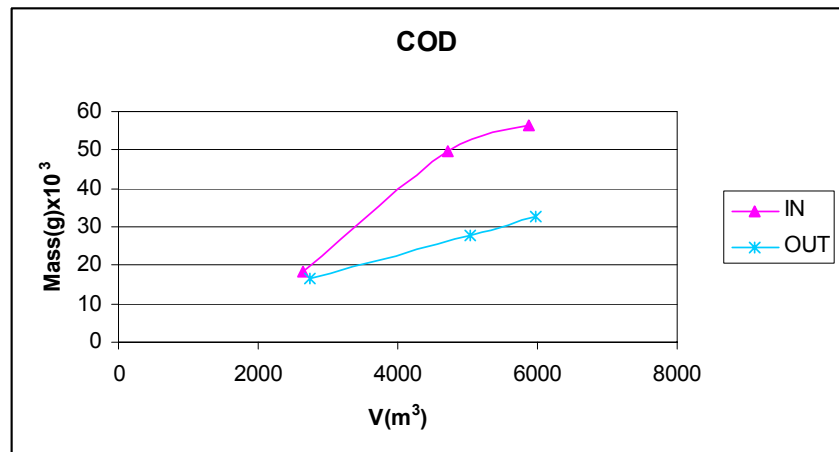
Even if this demand was totally used for organic oxidation, it is not possible to do a direct correlation between amount of COD (in mg oxygen/l) and the amount of organic matter oxidized (measured in mg C/l ) because we do not know its exact composition to do the stoichiometric equation . For example,  $64 \text{ g/m}^3$  of COD is consumed for oxidation of methane ( $\text{CH}_4 + 2 \text{ O}_2 \rightarrow \text{CO}_2 + 2 \text{ H}_2\text{O}$ ) while only  $32 \text{ g/m}^3$  is enough for acetic acid ( $1/2 \text{ CH}_3\text{COOH} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ ) although both reactions use same amount of carbon (Henze et al, 1992).

Another point is that even considering that no removal of TOC has occurred, the organic matter present in the water still could have used the oxygen demand for partially being degraded to smaller units only, while keeping the same number of carbons.

On the other hand, the removal rate obtained for oxygen demand (COD) is not so accurate as estimation of a long-term removal efficiency due to fact that this parameter was analyzed for only the 3 last storm events. For a more accurate result more analyses would be required, but the result obtained is still a good indication.

COD results can suffer interference of chloride that is an oxidisable inorganic material that also reacts with the test reagent (encyclopedia homepage, 2004 and  $\text{COD}_{\text{Mn}}$  standard,1981). However, the levels of chloride found in the ponds are not considered high enough to give significant interference, i.e. below  $300 \text{ mg/l}$  (see also Section 5.6).

Figure 16. COD pollutograph



Tests of Biological Oxygen Demand (BOD) could also be useful as it indicates the biodegradable capacity of the organic material. However, COD has an advantage due to the short time of analyses (3 h) compared to 5-7 days for BOD. Although the COD can not differentiate between levels of biologically active organic substances and those biologically inactive, it includes the U.V. degradation that in such shallow ponds is likely to be very significant too and could not be measured by BOD.

### 5.4. pH and temperature

The pH was found to be close to neutral (pH 7) in the ditch inlet and pond outlet both during background levels (measured on 17<sup>th</sup> May 2004 following a 54 hr dry period) and following stormwater events (Table 6a and 6b). As expected, eventual stormwater acidity has been

neutralized on its way through pavements and concrete sewer pipes to the ponds (see also Section 2.3.1). Temperature values in table 6a and 6b.

Table 6. Temperature and pH values.

a. Background

	Ditch Inlet	Pond 1	Pond Outlet
Temp (° C)	12.5	14.0	16.6
pH	7.6	7.3	7.6

b. Following storm events

	Rain 1+ 2		Rain 3	
	IN	OUT	IN	OUT
Temp (° C)	14.3	15.0	14.5	16.2
pH	7.3	6.8	7.6	7.7

## 5.5. Oxygen

It was observed that oxygenation at least for the second and third ponds is not a problem due to the shallow depth and the excessive winding conditions close to the seashore. In the first pond (70 cm depth) it was observed high oxygenation levels (>10 mgO<sub>2</sub>/l) in the surface layer despite difficult to measure a stable value because the wind, while a surprisingly fast decrease of oxygen at deeper layers. Already at 50 cm below the water surface the content decreased to about 4-5mgO<sub>2</sub>/l until almost 0 at the sediment interface. It is likely this can be explained by an intense organic degradation rate at sediment levels, especially if sewage has been added to the pond, combined with a greater water mixing flux in the surface layer than at the bottom. However, more measurements should be done to confirm this condition.

## 5.6. Chloride

The removal efficiency for chloride was negative (about -20%). The average concentration (SMC) of chloride measured in the outlet stormwater was 18.8 mg/l ranging from 16 to 30 mg/l, which is above the concentration range of 11 to 23 mg/l and the average of 15.2 mg/l found in the inlet stormwater (Appendix 4 and Table 5).

It must be taken into consideration that it is possible that the higher concentrations measured in the pond outlet mostly likely is caused by an invasion of salted water during high tide in the third pond that is the pond closest to the sea, more than inherent incapacity for removal.

But still the concentration of chloride measured in the ponds were very low compared to the levels in the poor salted Baltic sea (around 2.5 to 3.8g/l measured at Öland latitude) (Noaa database, 2004). In fact it is in the normal range found for lakes in the west coast of Sweden (Bidén, 1996). Thus, it is not expected any significant metal mobilization due to high levels of chloride. See pollutograph in Appendix 6

## 5.7. Nutrients

As described in Section 2.1, phosphorous and nitrogen compounds are also found in stormwater in urban areas but not at these high amounts as in agricultural areas. However, besides the atmospheric deposition that normally is the main source in urban areas, the load in Välenviken ponds received contribution from the surrounding pasture too and sporadically from sewages too. The parameters monitored were: total phosphorus, phosphate ( $\text{PO}_4^{-3}$ ), total nitrogen, nitrate ( $\text{NO}_3^-$ ), nitrite ( $\text{NO}_2^-$ ) and ammonia ( $\text{NH}_3$ ), see details in Section 4.2.

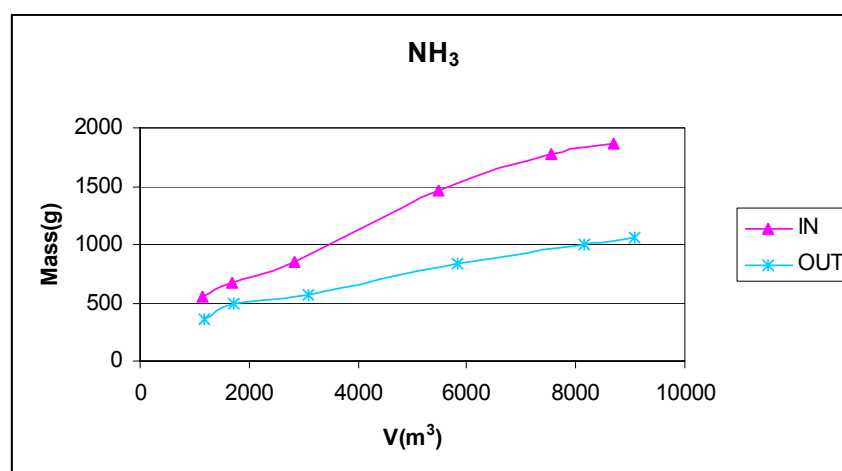
### 5.7.1. Nitrogen compounds

In general, the pond system was not effective on removal of nitrogen, except for ammonia. Total nitrogen (Total-N) had a negative removal rate (about -4%) and the concentration in the inlet (SMC 1.62 mgN/l) and outlet (SMC 1.68 mgN/l) is considered very high according to the Swedish EPA classification for lakes and watercourses (Appendix 7) but it is in the normal range for stormwater from urban areas in Sweden (see Section 2.1.3 Table 2).

#### Ammonia

This dissolved form of nitrogen had good removal (about 45%) as can be seen in Figure 17. Besides direct plant uptake in the pond, this must basically be due to the oxidation of ammonia to nitrate (nitrification) in the water column.

Figure 17. Pollutograph for ammonia. Cumulative results indicates good removal efficiency.



#### Nitrate

Removal of nitrate was not so effective but still positive (about 17%). Average concentrations, at the inlet 0.86 mgNO<sub>3</sub>/l and at the outlet 0.72 mgNO<sub>3</sub>/l, corresponds to the largest portion of nitrogen compounds, which means that most of the nitrogen appears in dissolved phase, which is in a biologically available form.

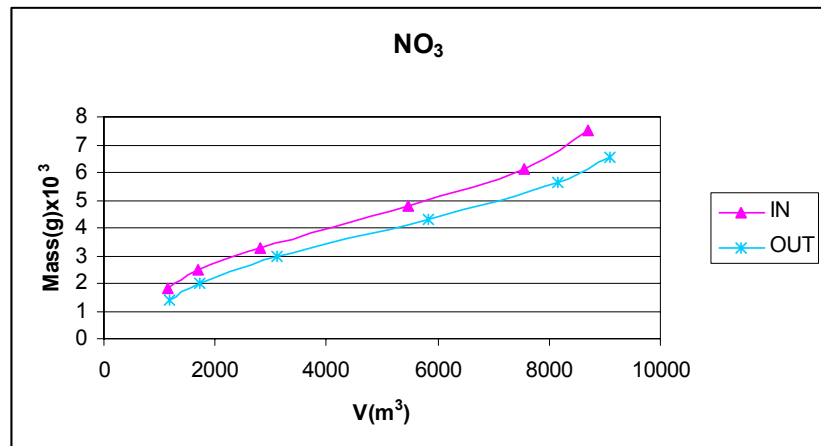
The pond behavior for nitrate retention, showed in Figure 18, does not differ from other ponds in literature, which also show low removal efficiency for nitrogen in this form.

It is certain that uptake by the growing vegetation in the pond to a significant part corresponds to this removal at least during the growing season when reed (*Phragmites australis*, see Figure 3 and cover page) has spread and cover most of the pond area.

The denitrification process, where nitrate is transformed to  $N_2$  (see Section 2.2), may occur in the first and deepest pond only, due to the need of low oxygen levels (that was measured close to the bottom of the first pond, see Section 5.5). On the other hand, it is likely that more nitrate is released, especially in the other two ponds, by the aerobic decomposition of the dead plant material left during previous year growing season which may contribute to a in-pond generated load and jeopardize the removal. Also small amounts may be added in the water column by conversion of the ammonia that enters the ponds with the stormwater.

Concentration of nitrate is far below the level of 5mg/l (contamination level), which indicates no sewage contamination (See Section 2.3.1-*eutrophication*).

Figure 18. Pollutograph for nitrate ( $NO_3^-$ ). This cumulative graphic shows that this biological available form of nutrient had small but positive removal and it was more or less constant during monitoring period.



### Nitrite

A very small part of the nitrogen in the inlet appears as the dissolved nitrite ( $NO_2$ ) form. Its removal showed a negative rate (- 33%) (see pollutograph in Appendix 6). The increase of nitrite occurs, though, only in a very narrow range, from 0.013mg  $NO_2^-$ /l to 0.017 mg  $NO_2^-$ /l.

However, under normal conditions it is not expected any accumulation of nitrite but its oxidation to nitrate. In oligotrophic lakes nitrite is expected as almost zero and in eutrophic lakes up to 0.030 mg/l. An increase in nitrite may indicate a disturbance in the biological process and that accumulation of organic material is happening, for example by contamination with sewage or intense biological decomposition activity under low oxygen conditions (Bydén *et al*,1996).

### 5.7.2. Phosphorus compounds

Total phosphorus and phosphate ( $PO_4^{-3}$ ) showed reasonable removal rates, 46% and 35% respectively, which are very good considering the results found in literature for nutrients. This means that the uptake of  $PO_4$  by plants (this inorganic dissolved form is the most bio-

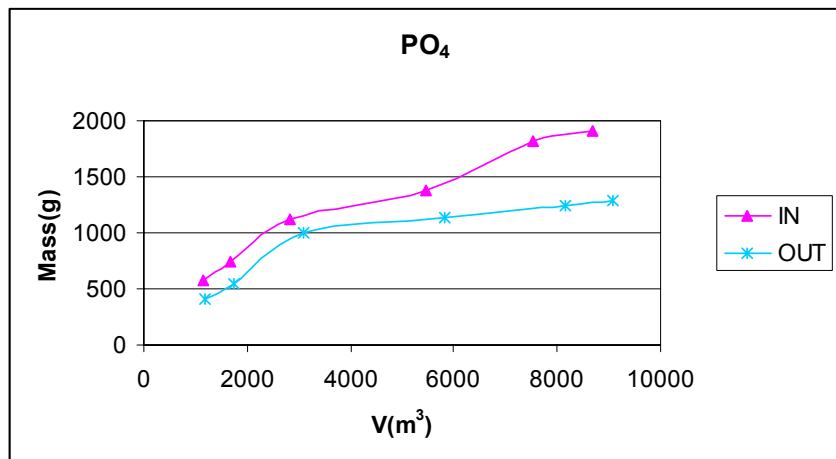
available form and the only one that plants can take up) and its immobilization (as mineral complexes) in the sediment is relatively efficient in the pond. Besides the removed phosphate, it is likely that a fraction of total-P that is bounded to particles (organic and inorganic) has also been removed in the process of sedimentation. Phosphate pollutograph is presented in Figure 19.

Even if desorption of phosphorus from the mineral complex occurs in the sediment under conditions favoring denitrification (low oxygenation) in the first pond, phosphorus may be adsorbed again along the other two shallow ponds.

Concentration of total phosphorus in the inlet (SMC 0.47mg /l) and in the outlet (SMC 0.25mg/l) is considered *extremely high* according the Swedish EPA classification for total phosphorus in lakes (describing the lake as hypertrophic). Concentration entering the ponds is also above the average value for stormwater in urban areas in general, being already in the range in industrial areas.

Based on Bydén et al (1996), N/P concentration ratio higher than 7 confirms that phosphorus, not nitrogen as for sea water, is the limiting factor to biological production which is the normal behavior for lakes (see also Section 2.3.1, *eutrophication* ).

Figure 19. Phosphate( $PO_4^{-3}$ ) pollutograph.



## 5.8. Heavy Metals

All metals, with exception of dissolved nickel had positive removal (Table 5). The Swedish EPA states that the best way to evaluate the risk of effects in organisms by metals is through analyses of their concentration in water. Metal concentrations in the range up to class 2 in the Swedish EPA classification (from class 1-low to 5- very high, see Appendix 7) are considered not high enough to cause measurable biological effects. However, a more careful judgment about the risks needs to take into consideration also the deviations from the reference values (Appendix 8) that are “normal” metals levels found in similar environment not polluted by local sources. A general rule of thumb is: the higher the value is compared to the reference value, the higher is the risk for negative effects (Swedish EPA, 2004). Here, the reference values for lakes in South Sweden and small watercourses will be used (Appendix 8).

Deviation from class 2 (small) to class 4 (large) means lake water that is increasingly being polluted by local or more diffuse sources while class 5 (very large) means accentuated influence by local sources. The deviation value means how many times the concentration are larger than the reference value. Metals concentrations in stormwater ponds are naturally higher than the reference values; however, if removal of metals in the pond is good, these deviations are much lower in the outlet water.

Since biological effects (see Section 2.3.2) in great level depends in which form the metals appear, it is recommended to perform studies to check these bioavailable forms especially if the levels are in class 3 or above. How much of the metal is in dissolved form may be an indication of its potential availability. Another point is its capacity to bound to the DOC (more for copper and lead according to Drever, 1997) and then become unavailable.

Heavy metals are mostly removed through settling by strongly adsorption onto insoluble organic matter and to manganese and iron oxides (present as coat on clay minerals from the bottom of the ponds and in soil runoff) that are insoluble at high pH. Metal retention in the sediments is also possible through formation of insoluble metal sulfides (sulfide released by an oxygen-depleted layer of organic-rich sediment). Complexation to dissolved organic matter contributes to metals in solution. The dominant species in solution, at least for copper, zinc, lead and cadmium, is a divalent cation (free or complexed) (Drever, 1997).

The uptake of essential metals (see Section 2.3.2) in trace amounts by organisms affects significantly the dissolved concentrations only in environments where concentrations are low but in polluted water this removal is likely to be small compared to the amounts in solution or to the amounts removed by adsorption process (Drever, 1997).

## Zinc

Compared to the average value for stormwater from urban areas (see Table 2 Section 2.1.3) the total zinc levels entering the pond is considered as *high* (Class 4) according to the Swedish EPA classification for water in lakes and watercourses. Despite its relatively good removal (about 34%), there are still *high* levels of zinc leaving the pond (SMC 110 µg/l, see Table 5). This gives a *very large* deviation from the reference value (84 and 55 times, in the inlet and outlet respectively, see Appendix 8) that indicates that exposition to such level may pose risk for biological life.

There is indication that most of this concentration is immobilized (in solid organic matter and clay minerals in the sediment) by observation of the small percentage found in dissolved form in the inlet and outlet (Appendix 4), however, it still corresponds to *moderately high* levels despite half has been retained in the ponds. Pollutographs for total and dissolved Zinc are shown in Appendix 6.

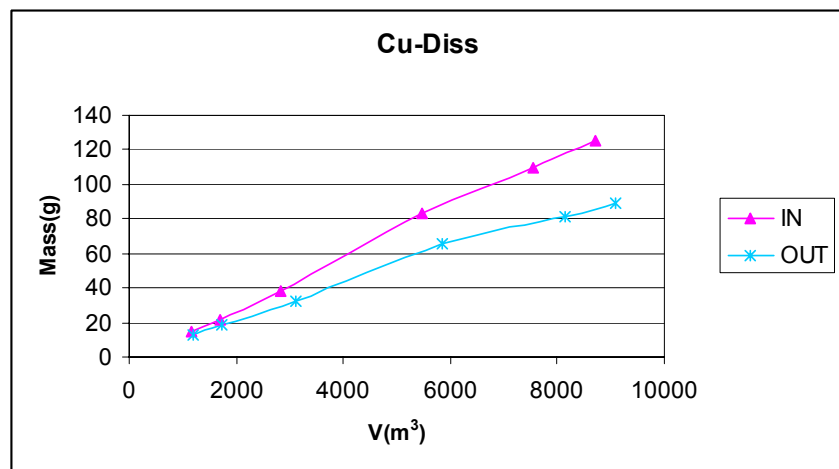
## Copper

Concentration of copper entering the ponds is in the range of stormwater from urban areas in general (more close to residential area in fact, see Table 2 section 2.1.3) but is considered at *high* levels (Class 4) in the Swedish EPA classification for lakes and watercourses and continue *high* when leaving the ponds (about 17 µg/l) despite good removal along the ponds

(little above 50%). This gives a *very large* deviation (72 and 34 times for inlet and outlet respectively) from the reference values, putting also copper as concern for biological effects. Although it is an essential element, it can be harmful to algae and fish already at 2-5 µg/l (Bidén, 1996).

Considerable percentage of the total copper is in dissolved form (40% in the inlet and 60% in the outlet, see Appendix 4). Although the pond was relatively efficient to remove copper (32%), just the dissolved part is already high enough to classify copper concentration in the outlet water to the *moderately high* to *high* level. Due to the great affinity of copper to DOC (Drever, 1997; Stumm and Werner, 1996), it is most likely that part of it is unavailable to organisms, which reduce the risk for toxicity. Pollutographs are shown in Figure 20 and Appendix 6.

Figure 20. Pollutography for dissolved copper



### Lead

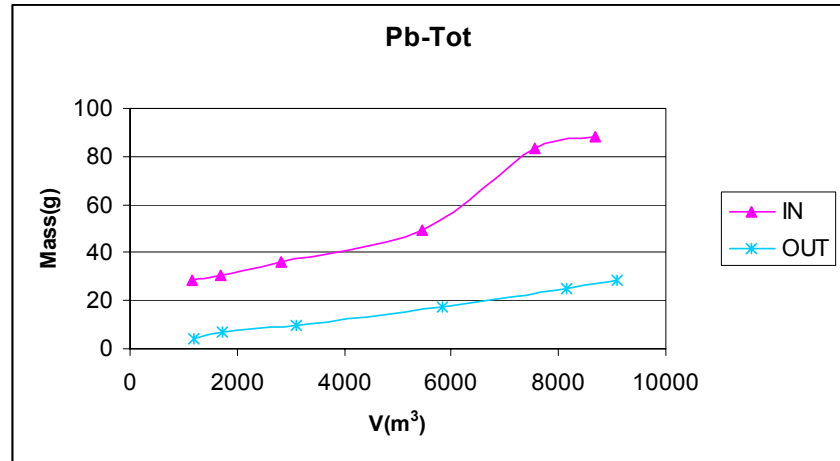
Lead had a very good removal in the pond, almost 70% (Figure 21), which reduced the concentration from *high* level (Class 4) of the inflow stormwater to a limit between *high - moderately high* (Class 3) levels of the outflow stormwater, according to the Swedish EPA classification system for lakes and watercourses. Lead concentration in the inlet water is considerably low compared to the normal range of stormwater from urban areas in general and from residential areas (see Table 2 Section 2.1.3). There is a very large deviation from reference values (Appendix 8) compared to the inflow stormwater and a noteworthy deviation compared to the outflow, which also is putting lead to a concern for effects on biological life.

On the other hand, a very small part of the lead enters and leaves the pond in dissolved form and both levels are *low*, suggesting that despite the high total values, it mostly appear in a biologically unavailable form.

Interesting to observe is the close correlation between lead accumulation and the suspended solids curve, especially the organic part (see Figure 25 and Appendix 6). In fact, this should be expected due to the high affinity of this metal to attach to particles and sediment, which in turn is responsible for the pond high efficiency in removing this metal (see also Section 2.2).



Figure 21. Lead pollutograph.



## Cadmium

Cadmium has presented the lowest removal rate (just above 20%) among the metals (Table 5). This behavior was also observed in other pond studies (see Section 2.2). Levels of total cadmium are considered as *very high* (Class 5) according to the Swedish EPA classification system for both inflow and outflow stormwater and show a *very large* deviation (150 and 120 times for the inflow and outflow stormwater respectively) from reference values (see Appendix 8). Measured site mean concentrations (SMC's) are even above the range for stormwater from urban and industrial areas in Sweden (see Table 2 in Section 2.1.3).

A very small percentage of the total cadmium is present in dissolved form (Appendix 4). This is somewhat unexpected since cadmium is considered as very mobile, i.e., less able to attach to particles, which gives an indication that most of it is in a less toxic form. However, only considering the dissolved part, the cadmium concentration in the inlet is still around the limit *low-moderately high* level for lakes and watercourses but the pond outflow concentration (after a 33% removal) is significantly reduced. Pollutographs are shown in Appendix 6.

## Nickel

Nickel is present at *low* levels (Class 2) in both inlet and outlet, for lakes and watercourses, indicating the load of this metal is unlikely to be of concern regarding biological effects. Deviation in the outflow water, in comparison to reference values of unpolluted lakes, is however still large. Removal efficiency of total nickel in the pond was good, 36%, but not efficient in removing the dissolved fraction of nickel (-5%). Pollutographs for nickel are shown in Appendix 6.

## Chromium

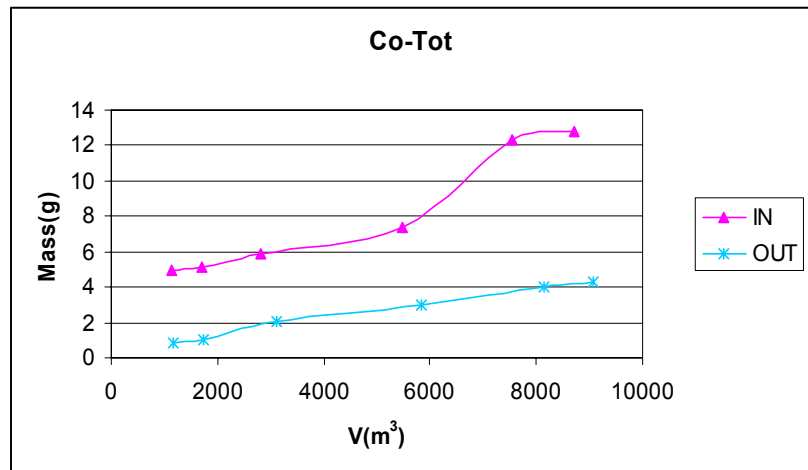
A little more than half of the total inflow chromium load was removed (57%) in the pond. The chromium concentrations entering the ponds went, from the *low-moderate high* limit levels (Class 2-3), down to the *low* level (Class 2), in the outflow stormwater. Besides that, outflow water showed very small deviations from reference values for lakes and

watercourses. The dissolved form corresponds to a considerable part of the chromium load in the inflow (about 70%) and about half in the outflow (see Appendix 4). About 20% of the dissolved chromium was removed in the pond (Table 5).

### Cobalt

Removal of total cobalt in the pond was high (68%) but the removal of dissolved cobalt was very low, but still positive (10%), see Table 5. The Swedish EPA does not have any quality criteria for cobalt in lakes and watercourses, but there are reference values for comparison with not polluted environments (Appendix 8). From this comparison, we observed that total cobalt concentration in the inflow had a *large deviation*, but after passing through the pond the treated stormwater (outflow) exhibit a *low deviation*, indicating high potential for the pond to remove toxic effects. Pollutographs are shown in Figure 22 and Appendix 6.

Figure 22. Cobalt Pollutograph . The pond was very efficient on removal of this metal to levels close to lakes not affected by pollution.



### 5.9. PAH

Results from analyses of PAH compounds are presented in Table 6. The Swedish EPA has not established an environmental quality criterion for PAH in surface waters. However, an assessment of the current condition is possible to carry out by a comparison with the reference values for soil and groundwater pollution, the last being the most restrictive one (see Appendix 9). The reference value is the pollutant concentration level above which the pollution may cause potential risk for health and/or environmental harm. The more the reference value is exceeded, the more serious the conditions are.

The concentration of PAH found in this study was below the detection limit for all outlet samples except for one storm event where PAH was detected (although not included in the carcinogen group) (Table 7) and this values was also below the reference value for polluted groundwater, that is 0.2 µg/l for carcinogenic PAH and 10µg/l for the other PAHs. Also the concentrations of PAH in the inlet samples, when detected, were also below these reference values.

Table 9.1, in Appendix 9, presents the assessment of PAH conditions based on the Swedish reference values for polluted groundwater. For this results we can state that the levels of PAH found in the pond water does not represent any potential toxic risk.

It is difficult to draw any clear conclusions regarding the pond removal efficiency for PAH. However it was possible to observe that, at least for the PAH not belonging to the carcinogen group, the small amount in the inlet was removed to the point that it could not be detected any longer in the outflow stormwater.

Table 7. PAH results from measurements in the Välenviken pond system

a. INLET

	storm 1+2		storm3		storm4		storm5		storm6
PAHs* (µg/l)	< dl		< dl		< dl		0.1		< dl
PAHs** (µg/l)	0.14		0.065		0.09		0.24		<dl

\*carcinogenic; \*\*non-carcinogenic; dl=detection limit

b. OUTLET

	storm 1+2		storm3		storm4		storm5A	storm5B		storm6
PAHs* (µg/l)	< dl		< dl		< dl		< dl	<dl		<dl
PAHs** (µg/l)	0.047		< dl		< dl		< dl	<dl		<dl

\*carcinogenic; \*\*non-carcinogenic; dl=detection limit

## 5.10. Water Residence Time

Normally the dry period length, between rain events, is a good indication of the residence time for stormwater in the pond, i.e. the time the stormwater remains in the pond, and when the processes of the pollutants removal, by sedimentation and plant uptake (of dissolved compounds), are as most effective. Pettersson (1999) estimates that more than 90% of the pollutant removal takes place during this period of quiescent conditions.

However, a more accurate estimation of the residence time of the stormwater in the pond, beyond this dry period, is to add also the dynamic residence time that includes the period the stormwater stays in the pond during the rain event.

In the case of the Välenviken pond system, a large portion of the stormwater passes directly through the pond, which happens for small ponds connected to a large catchment area (i.e. a large runoff volume displaces the smaller dry weather pond volume). Thus, a portion of the treated stormwater will have a very short stay in the pond since the pond volume will be exchanged by the inflowing stormwater volume, which decreases the overall residence time.

This is the case for storms 1, 3, 4, 5 and 6 (11, 15, 19, 22 and 23 June 2004, respectively) when a significant part of the stormwater is transported through the pond during the event.

## 5. Results and Discussions

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The pond volume is estimated to 600 m<sup>3</sup> and only storm 2 (550 m<sup>3</sup>) had all its volume retained in the pond.

In this case, the dynamic residence time is given by:

$$T_{Res,dyn} = \frac{T_{R1} + T_{R2}}{2}$$

Where:

$T_{R1} = T_{600} - T_{start}$ , that corresponds to the time when the first 600m<sup>3</sup> of the stormwater volume passes through the outlet minus the start time of inlet flow, i.e. the time the first flush of stormwater appears in the outlet that is the same as dynamic residence time for only the pond water volume.

$T_{R2} = T_{vTot} - (T_{vTot} - T_{600})$  that corresponds to the time that the difference between the total volume and the pond volume stays in the pond or the dynamic residence time of the discharged water.

Table 8 shows the dry (between storm events) and dynamic residence times for the storm events studied. Details are shown in Appendix 11.

*Table 8. Dry and dynamic stormwater residence times in the Välenviken ponds.*

Date	$T_{Res,dyn}$ (h)	$T_{Res,dry}$ (d)
11/6/2004	6.4	1.4
12/6/2004	-	0.2
15/6/2004	7.3	2.7
19-20/6/2004	11.6	3.8
22-23/6/2004	9.0	1.8

### 5.11. Oil leaking

During monitoring period came the information about an accident that happened one year ago at a power plant in the catchment, which resulted in diesel oil leaching into the stormwater system and also into the pond. It was carried out a restoration of the soil around the leaking oil tank and it was installed an about 30 cm thick floating cord in the ditch and the first pond inlet with absorbing material to retain oil floating at the water surface.

Although, it is hard to evaluate the effects of this release to the pond without monitoring specific with this intention, it is possible to say that the problem with the contamination of the pond by diesel is that, although aliphatic hydrocarbons are less problematic because they are less soluble in water and generally biodegradable and certainly was significantly retained in the adsorbing material installed in the pond, there are other compounds as aromatic hydrocarbons (like benzene, toluene, xylene and ethylbenzene) that are somewhat soluble in water, volatile and relatively resistant to biodegradation and very likely part has passed through the pond without being retained.

## 5.12. Sewage contamination

There was also a sewage leaking to the stormwater system and thus to the pond but it was fixed on 21<sup>st</sup> of May and therefore it is unlikely this affected the measurements. In case of sewage contamination it should be expected, besides faecal organic material and its degraded forms, increased levels of nitrate and phosphorus and faecal bacteria such as coliforms .

## 5.13. Single events effects

The removal efficiency is dependent not only of stormwater volume and the pond design but also the dry period between the rains. In fact, very large variations in removal rates can be observed for at different storm events depending on rain characteristics. Normally removal being effective in association with longer dry periods and low rain depths while the opposite, short dry periods and high rain depths, produces low removal or even negative rates (see Section 2.2 for details).

Figure 23 to 26 shows removal rates for TSS and VSS, nutrients and heavy metals for each storm event monitored in this study. Event 5 and 6 were considered as only one event due to the almost uninterrupted flow between the two rains. In Appendix 10 the detailed removal rate results are presented.

Table 9 shows details of the behavior of suspended solids, lead and total-P for four selected storm events.

In the graphs, the lowest removal rate for the suspended solids, nutrients and the metals occurred for storm 2, which was preceded by the shortest dry period of only 7 hours.

On the other hand, event 1, which was preceded with a longer dry period, was the most effective for all pollutants in general. Also the very close correlation between lead and VSS can be seen in Figure 25.

Looking at Figures 23 and 26, the variation in removal efficiency for storm 5-6 indicates that, despite the short dry period of less than 2 days and the long rain has been enough to remove solids in suspension and associated pollutants, as lead and phosphorus, it was not so effective to the nitrogen compounds that needs longer dry periods of at least 3-5 days reported in literature (Leonardson, 1994).

Figure 23. Removal rate of nutrients per storm event

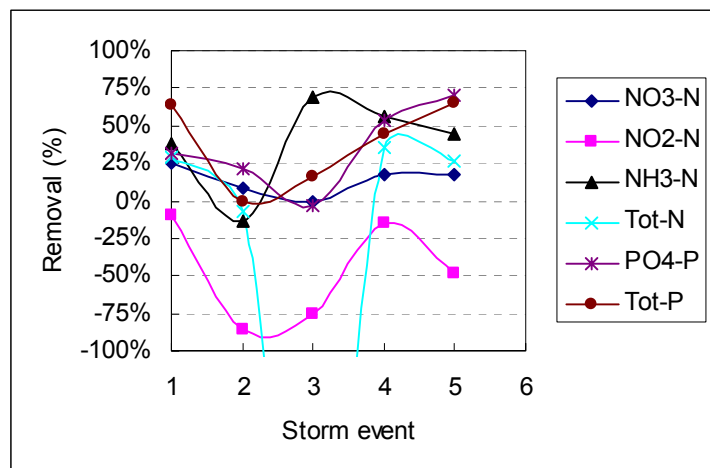


Figure 24. Removal rate of Suspended Solids per storm event

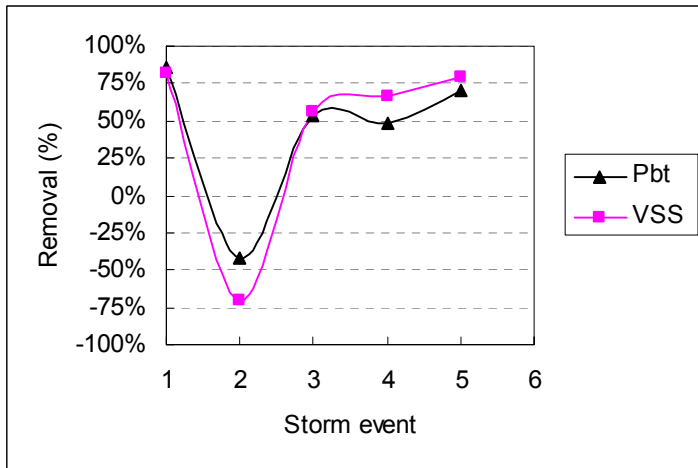
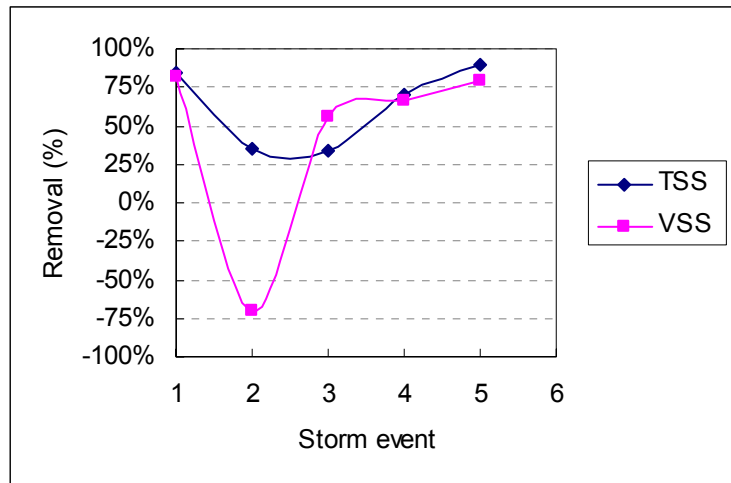


Figure 25. Removal rate of Lead and Organic Suspended Solids per storm event.

Figure 26. Removal rate of Heavy metals per storm event

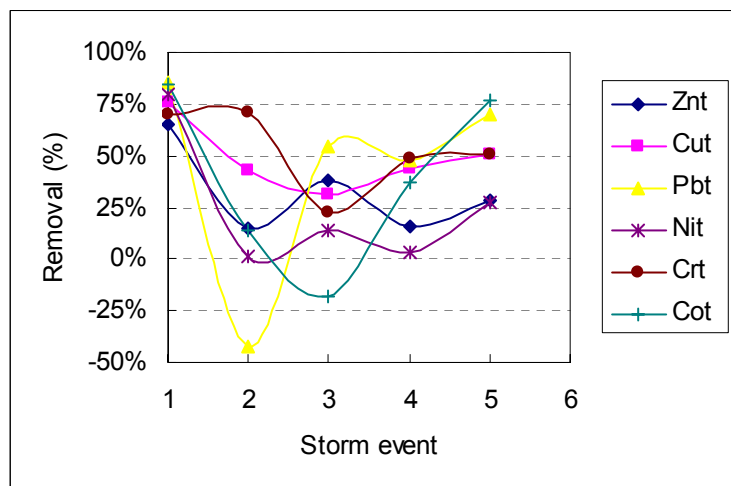


Table 9. Effect of different rain characteristics on the pollutant removal rates.

Storm Event	Dry period (d)	Rain depth* (mm)	Duration* (h)	Removal rate (%)		
				TSS	Lead	Total-P
1	1.4	10	5.5	84	85	64
2	0.2	2	6.0	35	-42	0
3	2.7	6	5.5	34	54	16
4	3.8	16	19	70	48	44
5-6	1.8	18.0	20	90	70	66

\* Based on rain data at Barlastsplatsen, the closest rain gauge to the ponds

It is worth to observe in Table 9 that the shortest dry period, associated with the precedent strong rain, seems to be determinant for the very low efficiency of storm 2; whilst the very large rain lengths, despite the high volume, seem to be determinant for the high removal efficiency of storms 4 and 5-6.





## 6. CONCLUSIONS AND FURTHER STUDIES

This study demonstrates that even very small ponds like the Välenviken may be very efficient on removal of quite a wide range of stormwater pollutants, despite possibility disturbance by residual oil and sewage pollution. It gives also a good background for further studies and useful information for monitoring implementation as well performing of analyses.

Parameters like organic matter had some measurement problems and COD had some reduced number of samples, which imply more monitoring to ensure the accuracy of results. Extended sample collection was not possible due to delay of equipment installation, lack of rain during the month of May and the lost of many rains during the first weeks of June until the flow-weight sampler was operating accordingly.

In general, the pond was very effective on removal of suspended solids and metals, notably total concentration of lead, cobalt (each almost 70%) and chromium (57%). Reasonable good efficiency was observed on removal of oxygen demand (about 45% for COD) which is a good indication of the ponds capacity for degradation of organic matter. Considering the values found in literature for nutrients, phosphorous compounds had a very good removal (about 35% to phosphate and 45% on total P) while for the nitrogen compounds was effective for ammonia (45%) but not nitrate (17%).

Even though the pond system has a small size in relation to the catchment area and the two last ponds are too shallow causing a short residence time for the pollutants that have to be retained good removal efficiency was observed. To increase the total pond volume by making the last two ponds deeper (although keeping them shallow to prevent stratification) combined with an unevenly bottom surface to enlarge sedimentation area may be a way to improve the general performance.

A sediment removal strategy must also be adopted because sooner or later the sediment will have to be removed due to the reduction in volume that compromises the removal efficiency.

To improve nutrient removal it is necessary the harvest and transport part of the plant material growing in the ponds, especially in the two last ponds. By doing that, besides to take away the nutrients within the biomass and giving space to more nutrient storage capacity, it prevents nutrient release during other seasons when decomposition may overcome the vegetation uptake.

Also, vegetation growth should achieve a balance to ensure that incoming water can be uniformly distributed in the pond without creating dead zones in the already too small area for sedimentation and denitrification.

## 6. Conclusions and further Studies

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Anoxic conditions found on the sediment level of the first pond suggest that permanent loss of nitrogen by denitrification may be happening and the supply of organic matter by reed vegetation (*Phragmites australis*) is highly desirable.

Although phosphorus can be desorbed from the sediment under the oxygen free condition that favors denitrification, comparatively, it still has a good area to be adsorbed on its way through the last two well oxygenated ponds, especially considering its affinity to clay, material on the bottom of the ponds.

Regarding Polyaromatic Hydrocarbons (PAH), it is difficult to draw any conclusions regarding pond efficiency since the concentrations in most of the samples were under detection limit, however it was possible to observe that, at least for the PAH not belonging to the carcinogen group, the small amount detected in the inlet was removed to the point that it could not be detected any longer in the outlet. Swedish EPA does not have guidelines for PAH but by comparison of the results with the restrictive reference values in groundwater it was possible to state that the levels found in the pond water does not present potential toxic risk.

The pond efficiency on removal of heavy metals was in general very good. However, for lead, zinc, copper and cadmium, this removal was not yet enough to reduce the high levels entering the ponds (class 4 and 5 in the Swedish EPA guidelines) to levels fairly low to prevent risk of biological effects. Special concern is the fact that a considerable part of copper appears in dissolved form.

Nickel and chromium levels were already low and cobalt levels became low after removal. Although this suggests that these metals are unlikely to be a concern regarding biological effects, the still large deviations from the reference values for nickel and chromium observed in the water leaving the ponds deserve some attention.

It is expected that the dilution of the stormwater in the shallow river delta water contribute to reduce the acute risk of exposure of organisms to the pollutants. The risk for toxicity is likely to be higher in the ponds itself, due to the accumulation of pollutants in the sediments. It can occur, for example, direct exposure of fish and higher animals to resuspended contaminated sediments or contaminants released to the water or indirect exposure to animals higher up in the food chain by predation and harvesting of plants and animals directly exposed at the contaminated sediment-water interface.

In fact sparse specimens of small fishes were observed in the ponds during the period of study. A step further this study should be the consideration of ecotoxicological tests in the pond and the delta to take into account potential bioconcentration (accumulation in the especime body) and bioaccumulation (accumulation within food chain) that could happen.

Finally, the level of nutrients in the ponds indicates that either the volume of sewage leaked to the ponds in May was small or, if significant, its impact has already being reduced until the period when the monitoring was done.

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## 8. APPENDICIES

### Appendix 1 - Map from Välenviken and catchment area.

(catchment area outlined in red)

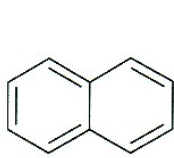


source: VA-verket (1992)

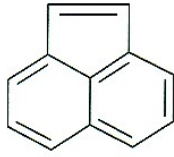
## Appendix 2 - PAHs compounds

### 2a. Structural formulas

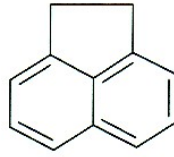
Source: Jakobsson(2003)



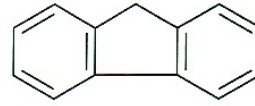
1. Naftalen  
 $C_{10}H_8$



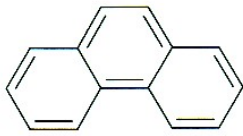
2. Acenaftalen  
 $C_{12}H_8$



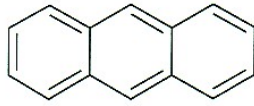
3. Acenaften  
 $C_{12}H_{10}$



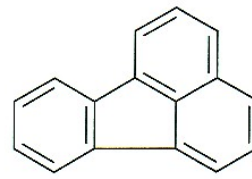
4. Fluoren  
 $C_{13}H_{10}$



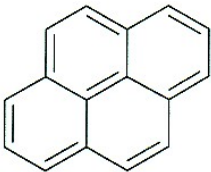
5. Fenantren  
 $C_{14}H_{10}$



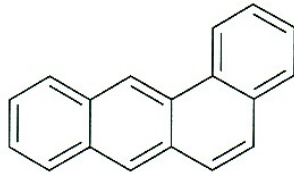
6. Antracen  
 $C_{14}H_{10}$



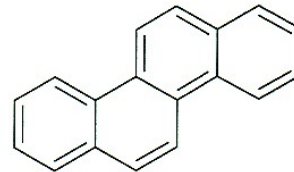
7. Fluoranten  
 $C_{16}H_{10}$



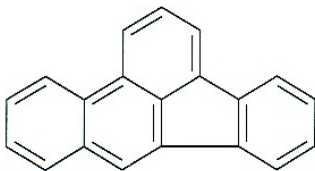
8. Pyren  
 $C_{16}H_{10}$



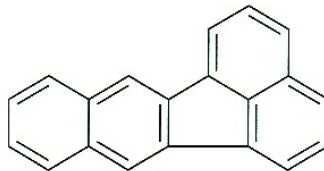
9. \*Bens(a)antracen  
 $C_{18}H_{12}$



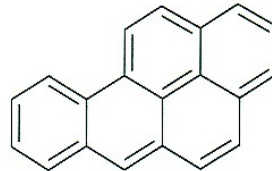
10. \*Krysen  
 $C_{18}H_{12}$



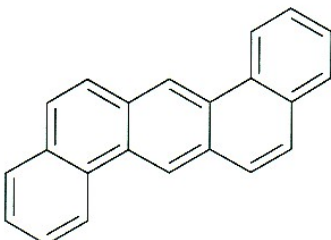
11. \*Bens(b)fluoranten  
 $C_{20}H_{12}$



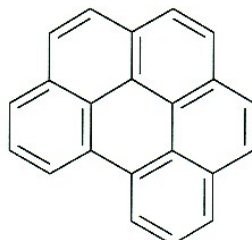
12. \*Bens(k)fluoranten  
 $C_{20}H_{12}$



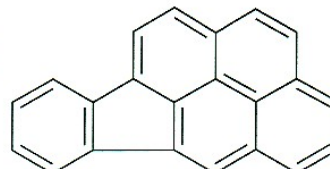
13. \*Bens(a)pyren  
 $C_{20}H_{12}$



14. \*Dibens(ah)antracen  
 $C_{22}H_{14}$



15. Benso(ghi)perylene  
 $C_{22}H_{12}$



16. \*Indeno(123cd)pyren  
 $C_{22}H_{12}$

## 2b. Chemical, physical and ecotoxicological data for PAH-16.

PAH	Melting point (°C)	Boiling point (°C)	Vapor pressure (Pa)	Solubility (mg/l)	Log P <sub>ow</sub>	LC <sub>50</sub> (mg/l)	BCF (fish)
1. naftalen	80	218	7.2	31	3.6	1.2-6.4	79-426
2. acenaftülen	90-95	279	0.9	3.9	4	0.2-3.7	387-631
3. acenaften	95	279	0.3	3.5	3.9	254-1270	400
4. fluoren	116	295	0.08	>0.19	4.2	219-830	501
5. fenantren	99	340	0.02	1.18	4.5	0.4-1.4	2512
6. antracen	217	340	0.001	>0.004	4.5	0.06-0.3	501-794
7. fluoranten	111	375	0.001	0.26	5.2	0.005-0.6	1584
8. pyren	156	404	6*10 <sup>-4</sup>	0.013	5.2	0.001-0.2	2511
9. *bens(a)antracen	158	437	3*10 <sup>-5</sup>	0.014	5.9	0.01	10000
10. *krysen	256	448	0.006	0.002	5.8	1.0-1.4	6309
11. *bens(b)fluoranten	167		2*10 <sup>-5</sup>	0.0012	5.8	0.03-0.8	10000
12. *bens(k)fluoranten	217	480	2*10 <sup>-5</sup>	0.00055	6.8		12589
13. *bens(a)pyren	176	495	3*10 <sup>-7</sup>	>0.0038	6.5	0.001-0.3	501-5012
14. *dibens(ah)antracacen	266	524	4*10 <sup>-10</sup>	0.0006	6.7	0.001-0.2	10000
15. benso(ghi)perylene	222	>500	1*10 <sup>-8</sup>	0.0003	6.9	0.8	26100
16. *indeno(123cd)pyren	162	536	1*10 <sup>-8</sup>	0.062	7.66		18100

Source: Jakobsson (2003)

**Appendix 3 - Preservation and handling of samples**

Parameter	Type of container	Preservation technique	Place of analysis	Max. time preservation	Additional comment	Analysis
pH	P,G	- transp.lower T than initial	on site* lab	6h		Multiprobe multiline WTW
Conductivity	P,G	cool 2°-5° C	on site* lab	24h		Multiprobe multiline WTW
Temperature		direct	on site			Multiprobe multiline WTW
Diss. Oxygen	P,G	direct	on site			Multiprobe Multiline P4 Christian Berner
Ammonia	P,G	Acid.to pH<2 H <sub>2</sub> SO <sub>4</sub> conc (2ml/L) + cool 2° -5° C	lab (before warm to room temp and neutralize with NaOH 5.0N)	24h	Interference: chlorine <sup>1</sup> (p. 491 DR2010)	Hach Photometry (DR2010)
Nitrate	P,G	Acid.to pH<2 H <sub>2</sub> SO <sub>4</sub> conc (2ml/L) OR cool 2° -5° C	lab (before warm to room temp and neutralize with NaOH 5.0N)	24h	Interference: chloride <sup>1</sup> (>100 mg/L) (p.446DR2010)	Hach Photometry (DR2010)
Nitrite	P,G	cool 2° -5° C. Use filtrate S.Solids <sup>1</sup>	lab. (warm to room temp) <sup>1</sup>	24h	Interference: very high nitrate <sup>1</sup> (>100 mg/L)(p. DR2010)	Hach Photometry (DR2010)
T- Nitrogen	P,G	Acid.to pH<2 H <sub>2</sub> SO <sub>4</sub> conc (2ml/L) + cool < 4° C <sup>1</sup>	lab. (before warm to room temp and neutralize with NaOH 5.0N) <sup>1</sup>	28 days <sup>1</sup>		Hach Photometry (DR2010)
T-Phosphorus	G	cool 2° -5° C  Acid.to pH<2 H <sub>2</sub> SO <sub>4</sub> conc (2ml/L) + cool < 4° C <sup>1</sup>	lab  lab (before warm to room temp and neutralize with NaOH 5.0N) <sup>1</sup>	24h  1 month	Interference: high level metals <sup>1</sup> (p.661DR2010)	Hach Photometry (DR2010)
(ortho) phosphates	G	cool 2° -5° C	lab	24h	Interference: high level metals <sup>1</sup> (p.637DR2010)	Hach Photometry (DR2010)
Suspended Solids	P,G	direct  dark, below8°C	lab  lab	4h (24h J) 24h	Analysis: filter through glass fiber filter <sup>2</sup>	SS-EN 872:1996
Heavy metals, dissolved	P	filtration+ Acid.to pH<2	lab	1 month	Analysis: pré-digestion with nitric acid (ISO 15587-2)	ICP-MS
Total Chloride	P,G	-	lab	1 month		
TOC and DOC	G  P	Acid.to pH<2 H <sub>2</sub> SO <sub>4</sub> conc ; cool 2° -5° C and storage in the dark.  Freeze -20°C	lab  lab	1 week  1 month	if suspected volatile org, carry out without acidif. within 8h (page 5 standard)	SS-EN 1484:1997
COD <sub>Mn</sub>			lab			SS-028118:1981

<sup>1</sup> Note in Hach technique<sup>2</sup> Note in correspondent Standard

**Appendix 4 - Measurement results**

INLET

	storm1 (11/6/2004)		storm 2 (12/6/2004)		storm 3 (15/6/2004)		storm 4(19-20/6/2004)		storm 5 (22/6/2004)		storm 6 (23/6/2004)		ΣMi inlet(g)
	C1(mg/l)	M1(g)	C2(mg/l)	M2(g)	C3(mg/l)	M3(g)	C4(mg/l)	M4(g)	C5(mg/l)	M5(g)	C6(mg/l)	M6(g)	
<b>TSS</b>	152.8	175357	12.7	6934	22.3	25199	28.5	75427	152.2	315863	8.7	10078	608858
<b>VSS</b>	38.5	44141	3.3	1802	8.7	9831	9.8	26009	33.0	68543	2.75	3174	153499
<b>TOC</b>	8.84	10143	6.92	3781	7.73	8734	7.16	18941	4.73	9817	6.41	7393	58808
<b>DOC</b>	8.65	9927	6.08	3319	7.45	8417	8.83	23350	6.67	13837	6.97	8043	66893
<b>COD</b>	-	-	-	-	-	-	7	18515	15	31140	6	6924	56579
<b>NO3-N</b>	1.6	1837	1.2	655	0.7	791	0.576	1524	0.642	1333	1.187	1370	7509
<b>NO2-N</b>	0.021	24	0.014	8	0.008	9	0.014	37	0.008	17	0.013	15	109
<b>NH3-N</b>	0.48	551	0.22	120	0.16	181	0.23	608	0.15	311	0.08	92	1864
<b>Tot-N</b>	3.1	3559	1.3	710	1	1130	1.4	3703	1.5	3114	1.6	1846	14062
<b>PO4-P</b>	0.5	574	0.32	175	0.33	373	0.1	265	0.21	436	0.07	81	1903
<b>Tot-P</b>	1.44	1653	0.41	224	0.77	870	0.18	476	0.34	706	0.12	138	4068
<b>Cl<sup>-</sup></b>	11	12628	23	12558	21	23730	14	37030	10	20760	22	25388	132094
<b>Vi (m<sup>3</sup>)</b>	1148		546		1130		2645		2076		1154		ΣV <sup>in</sup> = 8699

	storm1 (11/6/2004)		storm2 (12/6/2004)		storm3 (15/6/2004)		storm 4(19-20/6/2004)		storm 5 (22/6/2004)		storm 6 (23/6/2004)		ΣMi inlet(g)
	C1(µg/l)	M1(g)	C2(µg/l)	M2(g)	C3(µg/l)	M3(g)	C4(µg/l)	M4(g)	C5(µg/l)	M5(g)	C6(µg/l)	M6(g)	
<b>Zn<sub>t</sub></b>	262.53	301.38	122.5	66.88	138.3	156.24	137	363.20	197	409.65	135	155.32	1452.7
<b>Zn<sub>d</sub></b>	40.14	46.08	31.6	17.25	41.8	47.20	52	136.52	52	107.44	33	38.18	392.7
<b>Cu<sub>t</sub></b>	51.49	59.11	16.2	8.86	21.3	24.02	34	89.17	47	97.33	29	33.16	311.6
<b>Cu<sub>d</sub></b>	13.15	15.09	11.8	6.43	14.9	16.87	17	44.80	13	26.35	14	16.19	125.7
<b>Pb<sub>t</sub></b>	24.91	28.59	3.24	1.77	5.02	5.68	5.0	13.12	16.5	34.32	3.9	4.49	88.0
<b>Pb<sub>d</sub></b>	0.98	1.12	0.49	0.27	0.63	0.72	0.3	0.77	0.6	1.22	0.4	0.52	4.6
<b>Cd<sub>t</sub></b>	0.14	0.16	0.03	0.01	0.19	0.21	4.4	11.74	2.9	6.09	2.4	2.79	21.0
<b>Cd<sub>d</sub></b>	0.04	0.05	0.04	0.02	0.11	0.12	0.11	0.29	0.24	0.49	0.09	0.10	1.1
<b>Ni<sub>t</sub></b>	9.49	10.89	2.61	1.42	2.38	2.69	3.1	8.32	5.6	11.56	4.1	4.67	39.6
<b>Ni<sub>d</sub></b>	1.62	1.86	1.29	0.71	1.33	1.51	1.3	3.40	4.0	8.22	2.0	2.33	18.0
<b>Cr<sub>t</sub></b>	14.51	16.66	9.08	4.96	3.60	4.07	1.49	3.93	6.03	12.52	5.16	5.95	48.1
<b>Cr<sub>d</sub></b>	3.69	4.24	1.27	0.69	1.49	1.68	1.11	2.92	1.29	2.67	0.91	1.05	13.3
<b>Co<sub>t</sub></b>	4.29	4.92	0.44	0.24	0.65	0.73	0.56	1.49	2.39	4.96	0.42	0.48	12.8
<b>Co<sub>d</sub></b>	0.51	0.59	0.16	0.08	0.19	0.21	0.14	0.36	0.18	0.38	0.14	0.16	1.8
<b>Vi (m<sup>3</sup>)</b>	1148		546		1130		2645		2076		1154		ΣV <sup>in</sup> = 8699

t=total, d=dissolved. Vi=Stormwater volume

8. Appendicies

OUTLET

	storm 1 (11/6/2004)		storm 2 (12/6/2004)		storm 3 (15/6/2004)		storm4(19-20/6/2004)		storm 5 (22/6/2004)			storm 6 (23/6/2004)		
	C1(mg/l)	M1(g)	C2(mg/l)	M2(g)	C3(mg/l)	M3(g)	C4(mg/l)	M4(g)	C5-A(mg/l)	C5-B(mg/l)	M5-A+B(g)	C6(mg/l)	M6(g)	ΣMi outlet(g)
<b>TSS</b>	24.6	29018	8.3	4565	14.8	20276	8.5	23139	13.0	9.1	27299	5.7	5378	109675
<b>VSS</b>	6.9	8097	5.6	3080	3.8	5206	3.3	8973	6.6	2.85	12612	2.35	2204	40172
<b>TOC</b>	7.06	8341	8.12	4464	7.65	10476	7.91	21615	5.55	5.43	12742	8.31	7792	65431
<b>DOC</b>	8.67	10246	6.69	3680	7.07	9687	10.12	27658	8.33	5.82	17463	7.41	6953	75687
<b>COD</b>	-	-	-	-	-	-	6	16398	5	5	11560	5	4690	32648
<b>NO<sub>3</sub>-N</b>	1.2	1418	1.1	605	0.7	959	0.474	1295	0.517	0.722	1341	0.978	917	6537
<b>NO<sub>2</sub>-N</b>	0.023	27	0.026	14	0.014	19	0.016	44	0.013	0.008	26	0.022	21	152
<b>NH<sub>3</sub>-N</b>	0.3	355	0.25	138	0.05	69	0.1	273	0.09	0.025	162	0.07	66	1061
<b>Tot-N</b>	2.2	2600	1.4	770	4.2	5754	0.91	2487	0.99	1.1	2367	1.4	1313	15292
<b>PO<sub>4</sub>-P</b>	0.34	402	0.25	138	0.34	466	0.046	126	0.052	0.041	112	0.048	45	1288
<b>Tot-P</b>	0.52	615	0.41	226	0.65	891	0.1	273	0.097	0.088	218	0.08	75	2297
<b>Cl<sup>-</sup></b>	15	17730	16	8800	25	34250	16	43728	16	18	38418	30	28140	171066
<b>Vi (m<sup>3</sup>)</b>	1182		550		1370		2733		1599	713		938		ΣV <sup>out</sup> =9085

	storm1 (11/6/2004)		storm 2 (12/6/2004)		storm3(15/6/2004)		storm4(19-20/6/2004)		storm 5 (22/6/2004)			storm6 (23/6/2004)		
	C1(µg/l)	M1(g)	C2(µg/l)	M2(g)	C3(µg/l)	M3(g)	C4(µg/l)	M4(g)	C5-A (µg/l)	C5-B (µg/l)	M5(g)	C6(µg/l)	M6(g)	ΣMi outlet(g)
<b>Zn<sub>t</sub></b>	90.3	106.76	104.4	57.41	85.4	116.99	116	317.61	136	113	297.27	116	109.13	1005.2
<b>Zn<sub>d</sub></b>	23.7	28.05	29.8	16.40	20.9	28.60	29	80.14	22	18	48.85	21	19.85	221.9
<b>Cu<sub>t</sub></b>	12.6	14.85	9.3	5.09	14.7	20.10	19	52.47	15	24	41.05	25	23.60	157.2
<b>Cu<sub>d</sub></b>	11.1	13.16	9.8	5.39	10.2	13.96	12	32.95	7	8	15.98	9	7.99	89.4
<b>Pb<sub>t</sub></b>	3.67	4.33	4.60	2.53	2.30	3.14	2.6	7.04	3.6	3.5	8.19	3.6	3.38	28.6
<b>Pb<sub>d</sub></b>	0.62	0.73	0.62	0.34	0.60	0.82	0.5	1.31	0.3	0.5	0.88	0.4	0.36	4.4
<b>Cd<sub>t</sub></b>	0.03	0.04	0.14	0.07	0.10	0.14	3.2	8.69	2.6	2.0	5.54	2.9	2.68	17.2
<b>Cd<sub>d</sub></b>	0.05	0.06	0.03	0.02	0.04	0.05	0.08	0.21	0.12	0.11	0.27	0.15	0.14	0.7
<b>Ni<sub>t</sub></b>	1.92	2.27	2.58	1.42	2.05	2.81	3.0	8.11	2.9	4.1	7.52	4.6	4.32	26.4
<b>Ni<sub>d</sub></b>	1.48	1.75	1.49	0.82	1.61	2.20	2.5	6.71	2.9	2.4	6.26	2.2	2.02	19.8
<b>Cr<sub>t</sub></b>	4.34	5.12	2.62	1.44	2.79	3.82	0.77	2.11	4.30	1.36	7.85	1.33	1.25	21.6
<b>Cr<sub>d</sub></b>	2.91	3.43	1.27	0.70	1.26	1.72	0.91	2.48	0.80	0.89	1.91	0.83	0.78	11.0
<b>Co<sub>t</sub></b>	0.68	0.80	0.38	0.21	0.77	1.05	0.35	0.96	0.44	0.37	0.96	0.33	0.31	4.3
<b>Co<sub>d</sub></b>	0.24	0.28	0.23	0.13	0.26	0.36	0.16	0.45	0.17	0.09	0.34	0.14	0.13	1.7
<b>Vi (m<sup>3</sup>)</b>	1182		550		1370		2733		1599	713		938		ΣV <sup>out</sup> = 9085

t=total, d=dissolved. Vi = Stormwater volume

## Appendix 5 - Cumulative Mass and Volumes

### CUMULATIVE INLET

	M1	M1+M2	M1+M2+M3	M1+M2+M3+M4	M1+M2+M3+M4+M5	M1+M2+M3+M4+M5+M6
TSS	175357	182291	207490	282917	598780	608858
VSS	44141	45942	55773	81783	150325	153499
TOC	10143	13923	22657	41598	51415	58808
DOC	9927	13246	21663	45013	58850	66893
COD	-	-	-	18515	49655	56579
NO3-N	1837	2492	3283	4807	6139	7509
NO2-N	24	32	41	78	94	109
NH3-N	551	671	852	1460	1772	1864
Tot-N	3559	4269	5399	9102	12216	14062
PO4-P	574	749	1122	1386	1822	1903
Tot-P	1653	1877	2747	3223	3929	4068
Cl <sup>-</sup>	12628	25186	48916	85946	106706	132094
Znt	301.38	368.26	524.50	887.70	1297.35	1452.68
Znd	46.08	63.33	110.53	247.06	354.49	392.67
Cut	59.11	67.97	91.99	181.15	278.48	311.64
Cud	15.09	21.53	38.40	83.19	109.55	125.73
Pbt	28.59	30.36	36.04	49.16	83.48	87.96
Pbd	1.12	1.39	2.11	2.89	4.10	4.62
Cdt	0.16	0.17	0.39	12.12	18.21	21.00
Cdd	0.05	0.07	0.19	0.48	0.97	1.07
Nit	10.89	12.31	15.00	23.32	34.88	39.55
Nid	1.86	2.57	4.07	7.47	15.69	18.02
Crt	16.66	21.62	25.68	29.62	42.13	48.09
Crd	4.24	4.93	6.61	9.54	12.21	13.26
Cot	4.92	5.16	5.89	7.38	12.34	12.82
Cod	0.59	0.67	0.89	1.24	1.62	1.78
	V1 (m3)	V1+V2 (m3)	V1+V2+V3 (m3)	V1+V2+V3+V4 (m3)	V1+V+V3+V4+V5 (m3)	V1+V2+V3+V4+V5+V6 (m3)
Vol	1148	1694	2824	5469	7545	8699
Vol(onlyCOD)	-	-	-	2645	4721	5875

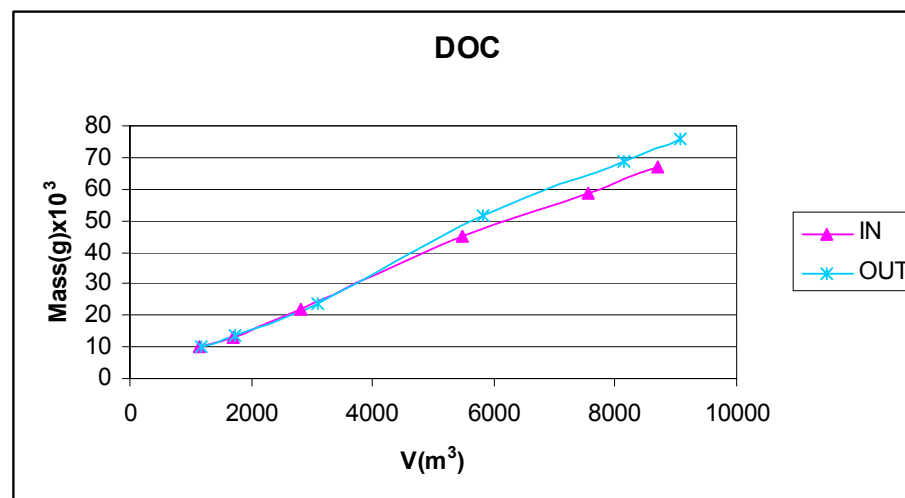
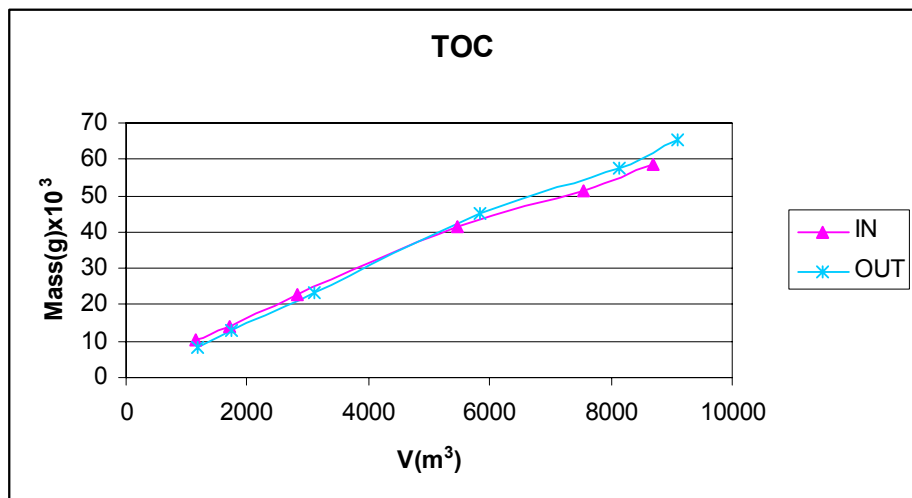
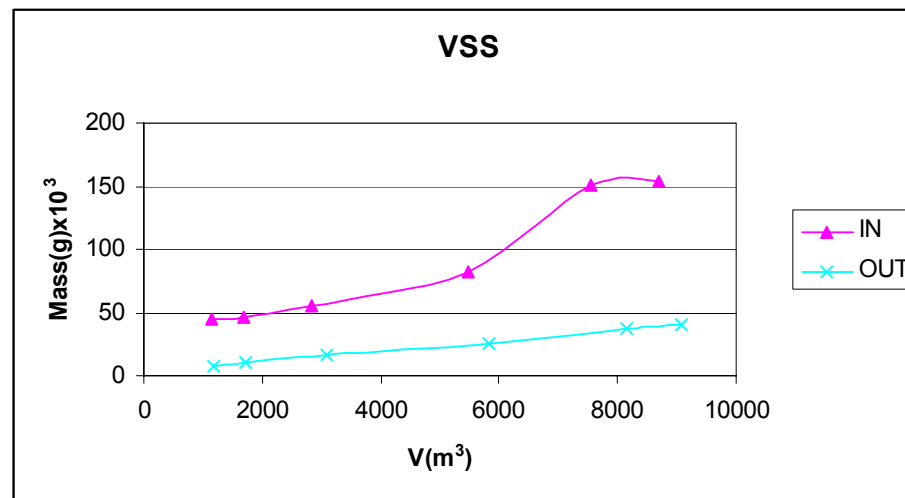
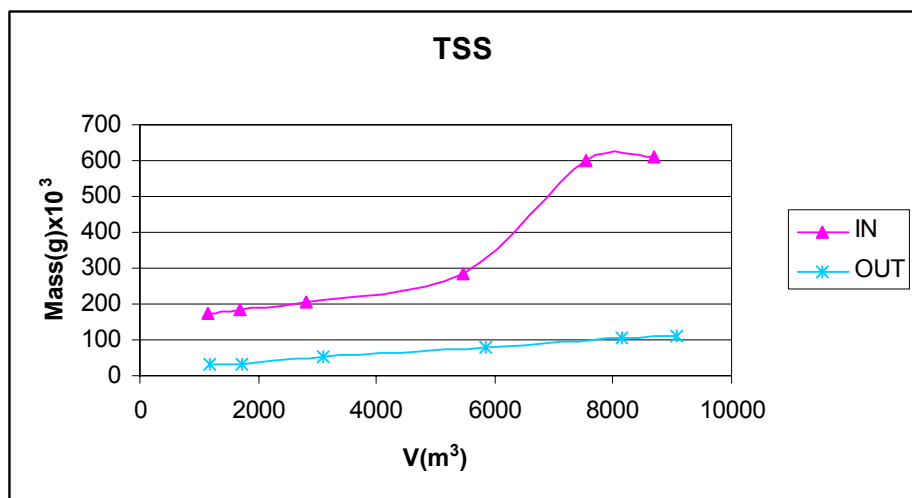
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### CUMULATIVE OUTLET

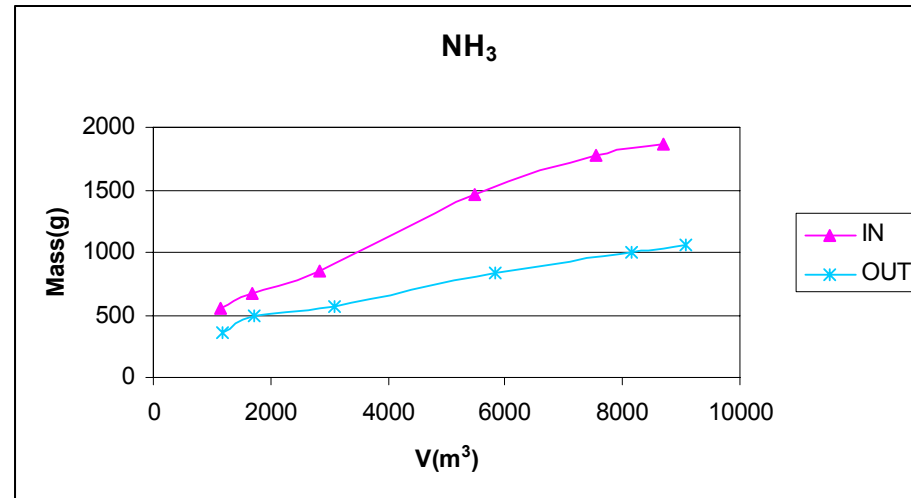
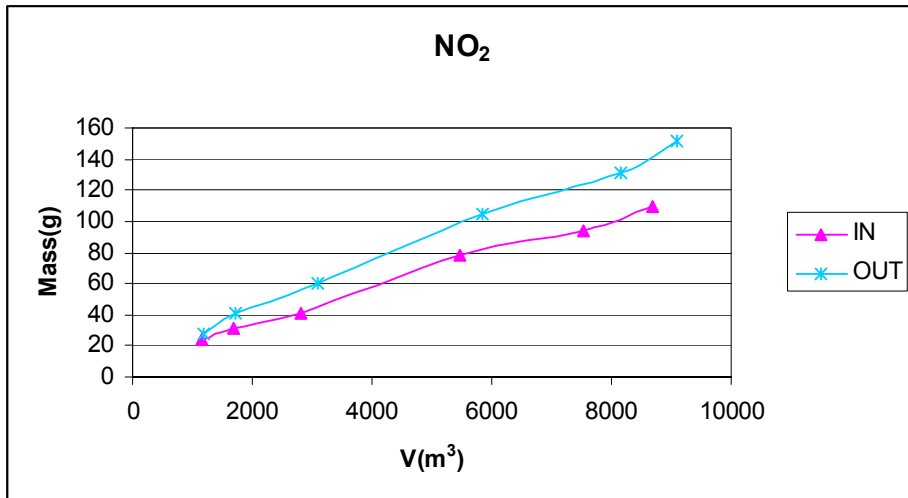
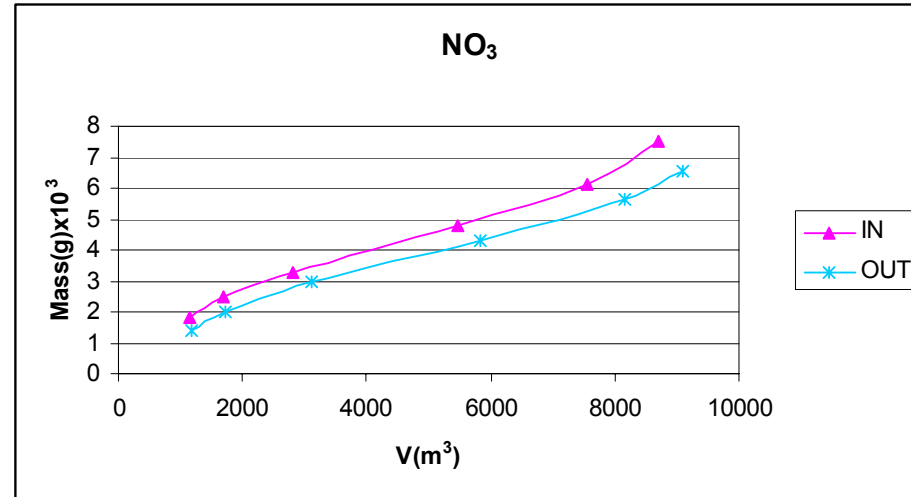
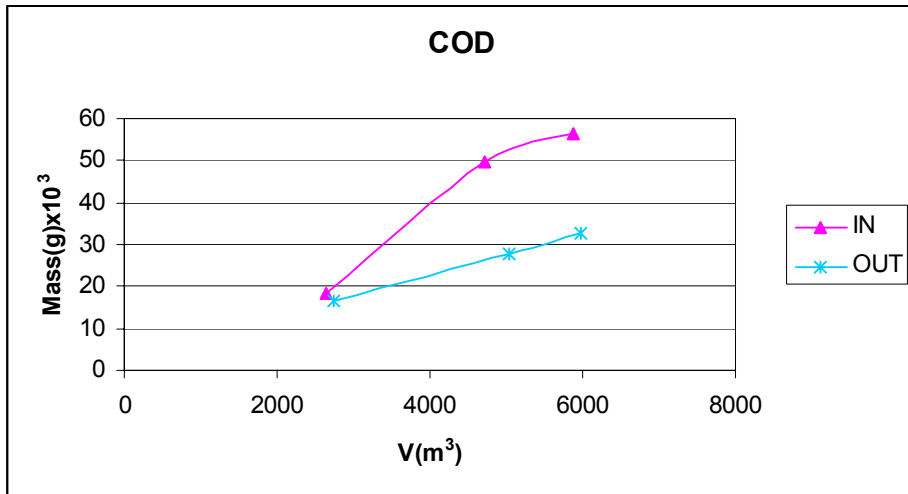
	M1	M1+M2	M1+M2+M3	M1+M2+M3+M4	M1+M2+M3+M4+M5	M1+M2+M3+M4+M5+M6
TSS	29018	33583	53859	76999	104298	109675
VSS	8097	11177	16383	25356	37968	40172
TOC	8341	12805	23282	44897	57639	65431
DOC	10246	13925	23612	51270	68734	75687
COD	-	-	-	16398	27958	32648
NO3-N	1418	2023	2982	4278	5619	6537
NO2-N	27	41	61	104	131	152
NH3-N	355	492	561	834	996	1061
Tot-N	2600	3370	9124	11611	13979	15292
PO4-P	402	539	1005	1131	1243	1288
Tot-P	615	840	1731	2004	2222	2297
Cl-	17730	26530	60780	104508	142926	171066
Zn <sub>t</sub>	106.76	164.16	281.15	598.76	896.03	1005.16
Zn <sub>d</sub>	28.05	44.45	73.04	153.18	202.04	221.88
Cu <sub>t</sub>	14.85	19.94	40.04	92.51	133.56	157.16
Cu <sub>d</sub>	13.16	18.55	32.51	65.46	81.44	89.43
Pb <sub>t</sub>	4.33	6.86	10.00	17.04	25.23	28.61
Pb <sub>d</sub>	0.73	1.07	1.90	3.21	4.09	4.45
Cd <sub>t</sub>	0.04	0.11	0.25	8.94	14.48	17.16
Cd <sub>d</sub>	0.06	0.08	0.13	0.34	0.61	0.75
Ni <sub>t</sub>	2.27	3.69	6.50	14.61	22.13	26.45
Ni <sub>d</sub>	1.75	2.57	4.77	11.47	17.73	19.76
Cr <sub>t</sub>	5.12	6.57	10.39	12.50	20.35	21.60
Cr <sub>d</sub>	3.43	4.13	5.85	8.33	10.25	11.02
Co <sub>t</sub>	0.80	1.00	2.05	3.01	3.97	4.28
Co <sub>d</sub>	0.28	0.40	0.76	1.21	1.55	1.68
Vol	V1 (m3)	V1+V2 (m3)	V1+V2+V3 (m3)	V1+V2+V3+V4 (m3)	V1+V2+V3+V4+V5 (m3)	V1+V2+V3+V4+V5+V6 (m3)
	1182	1732	3102	5835	8147	9085
Vol(onlyCOD)	-	-	-	2733	5045	5983

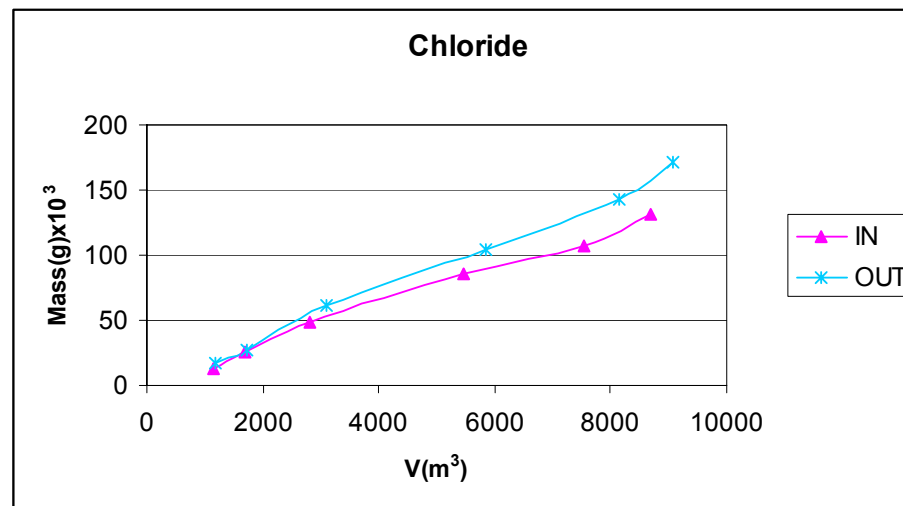
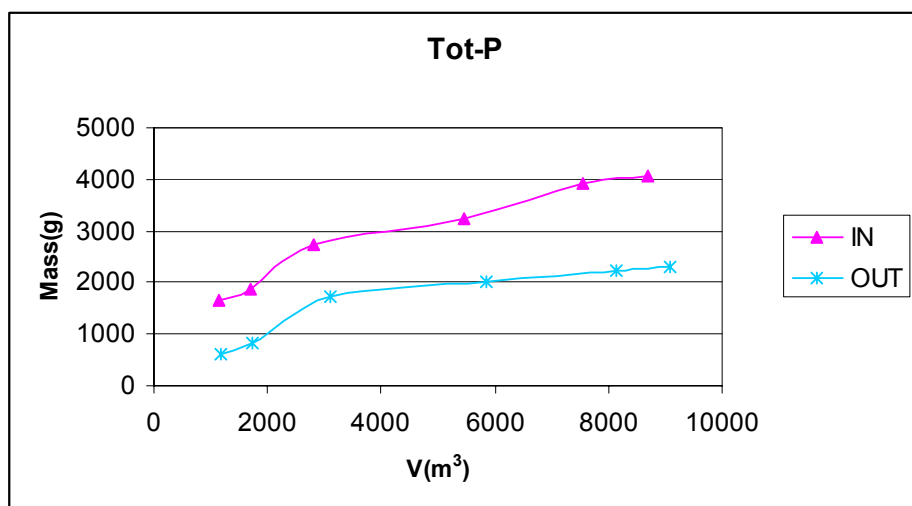
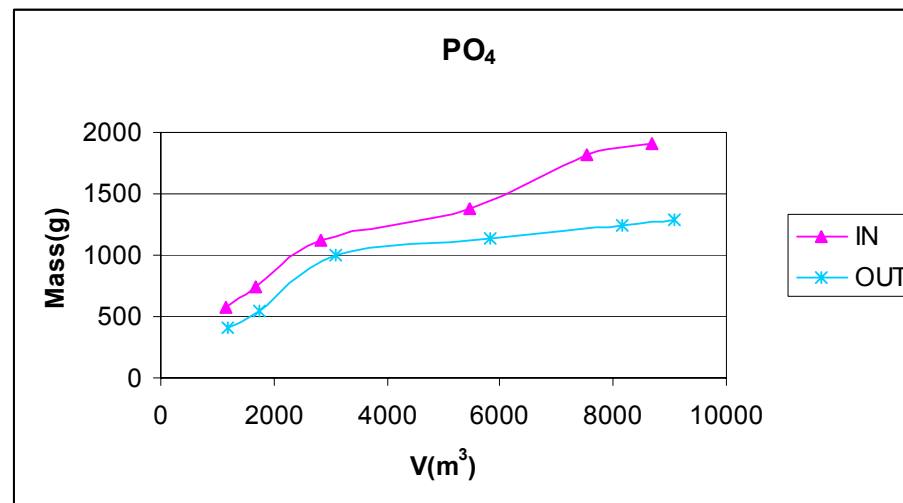
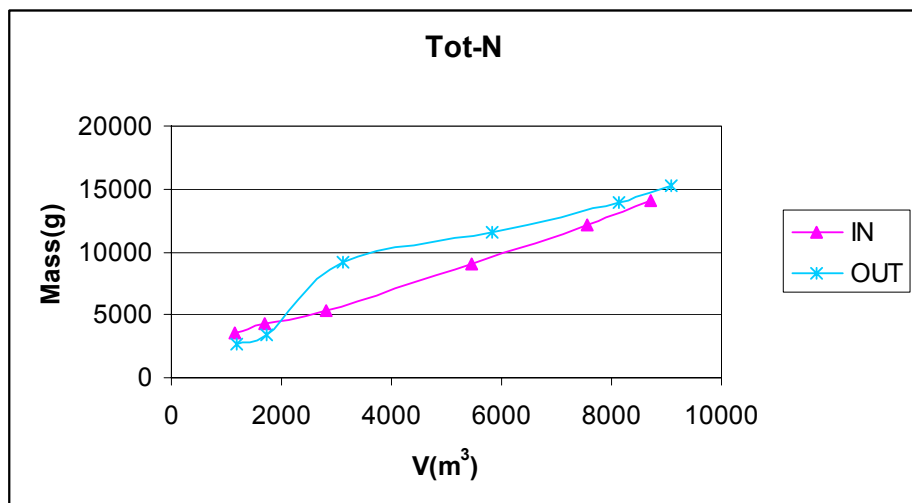


Appendix 6 - Pollutographs

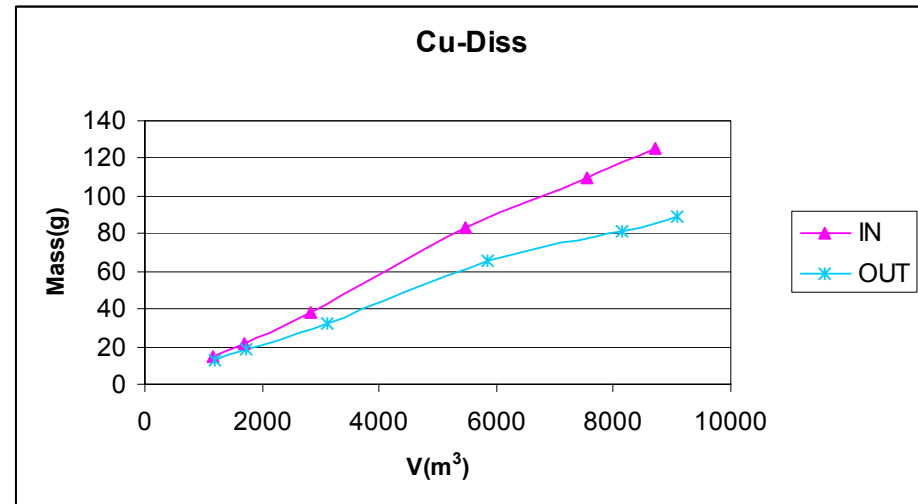
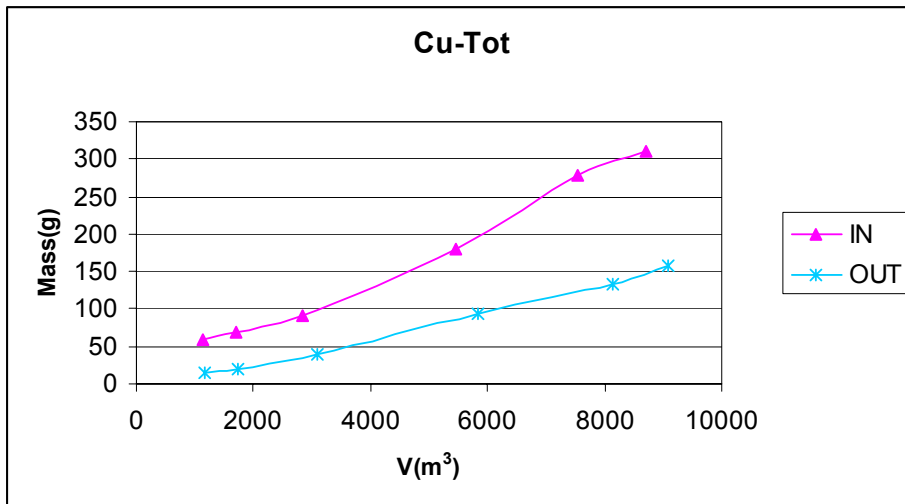
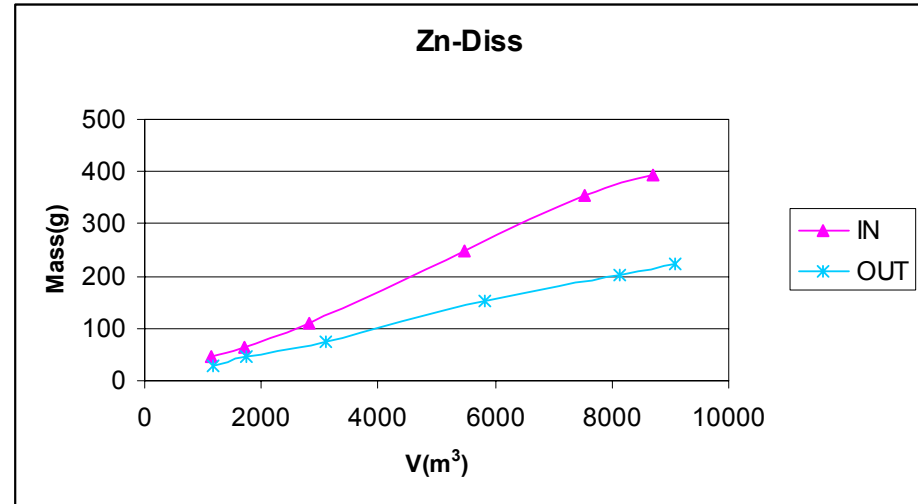
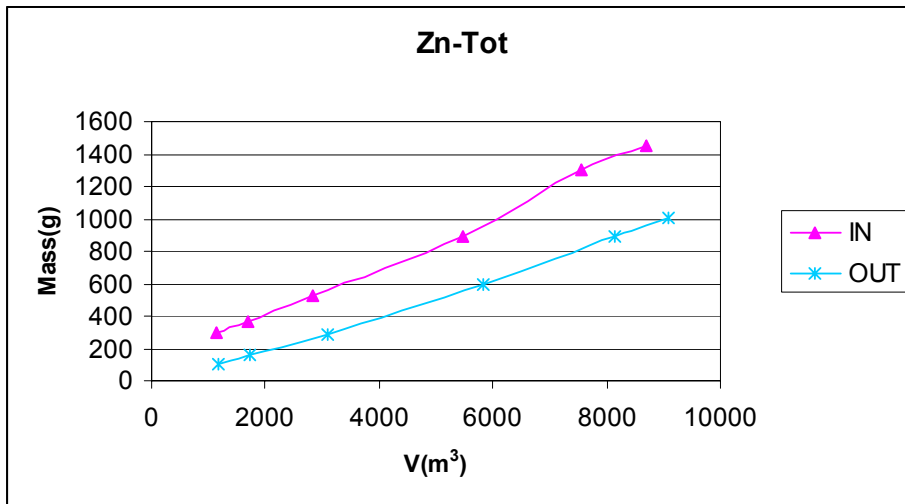


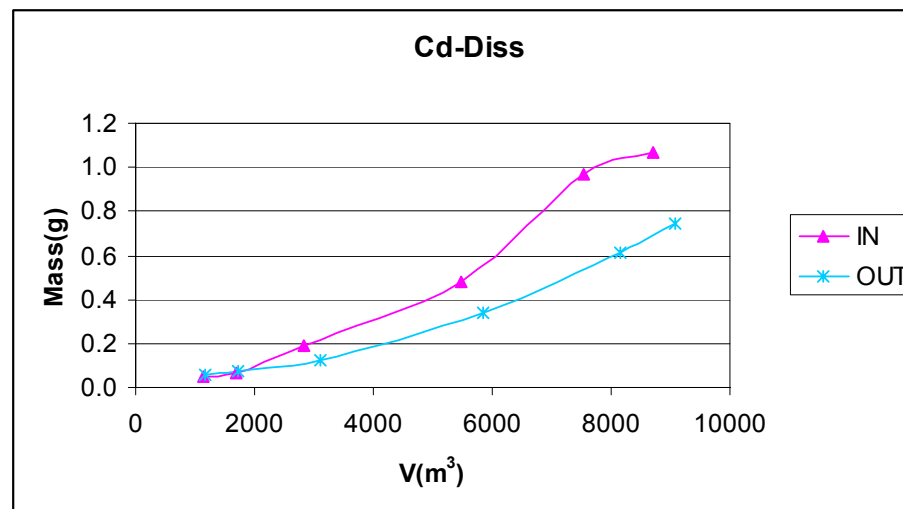
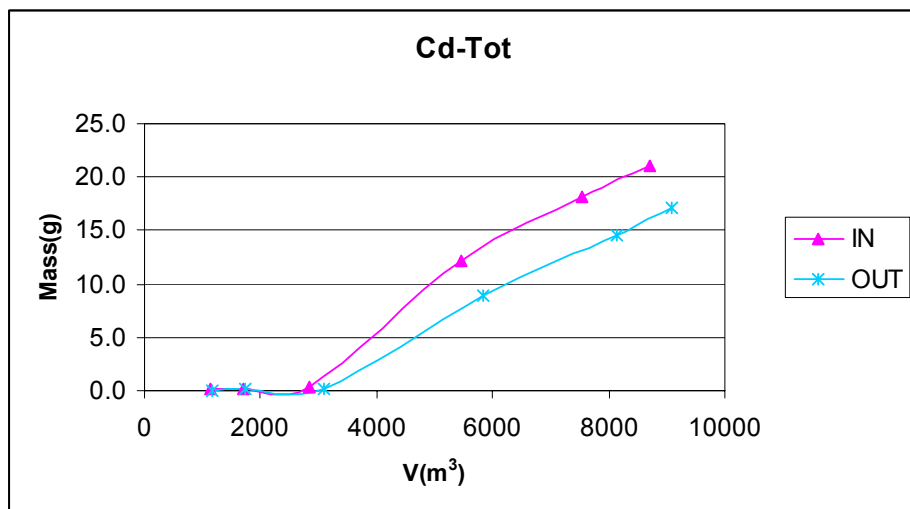
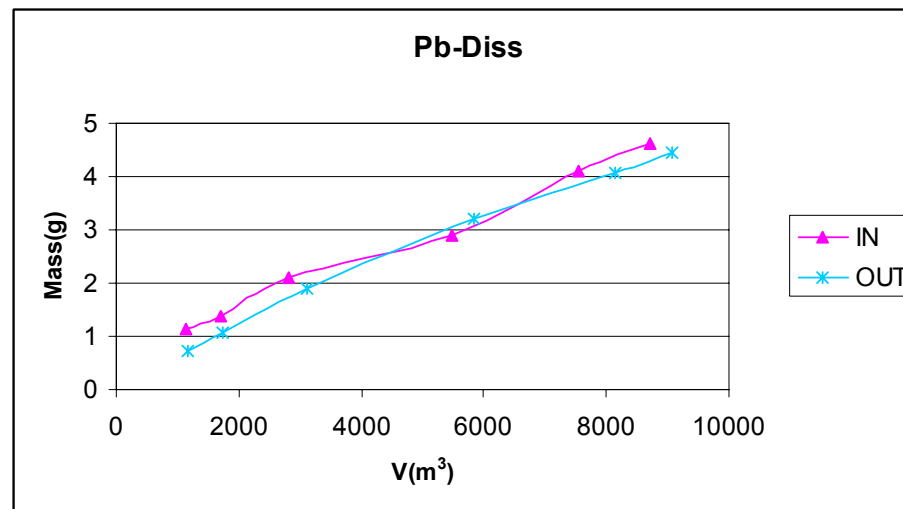
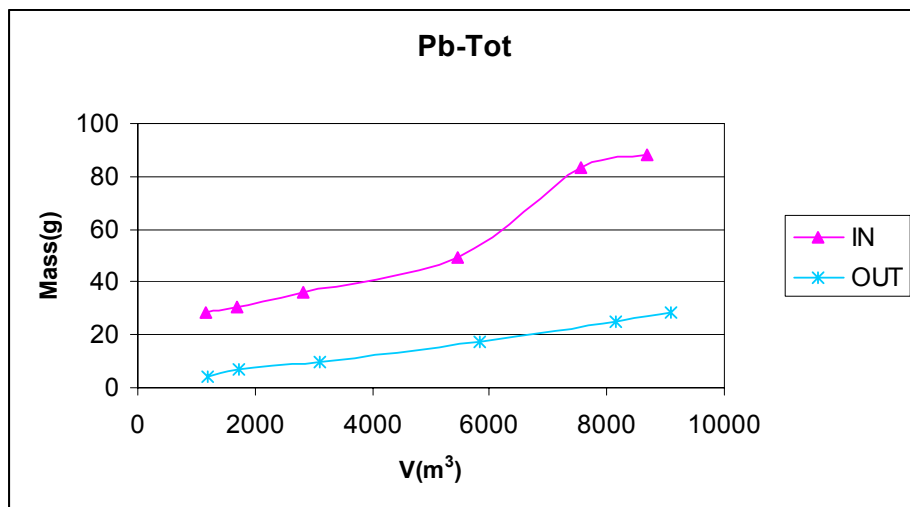
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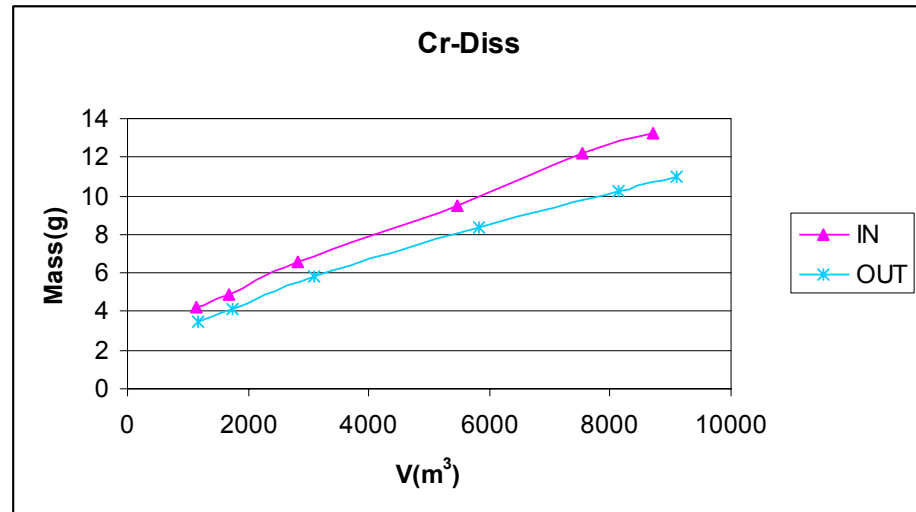
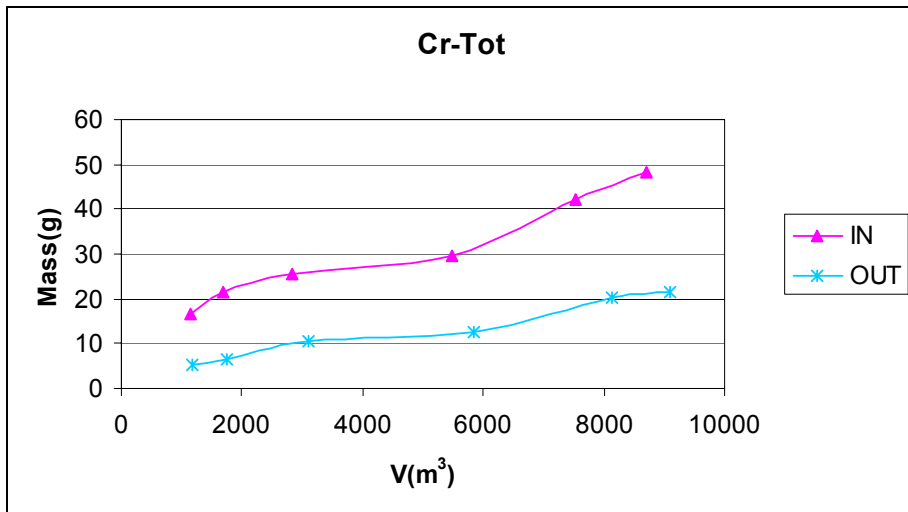
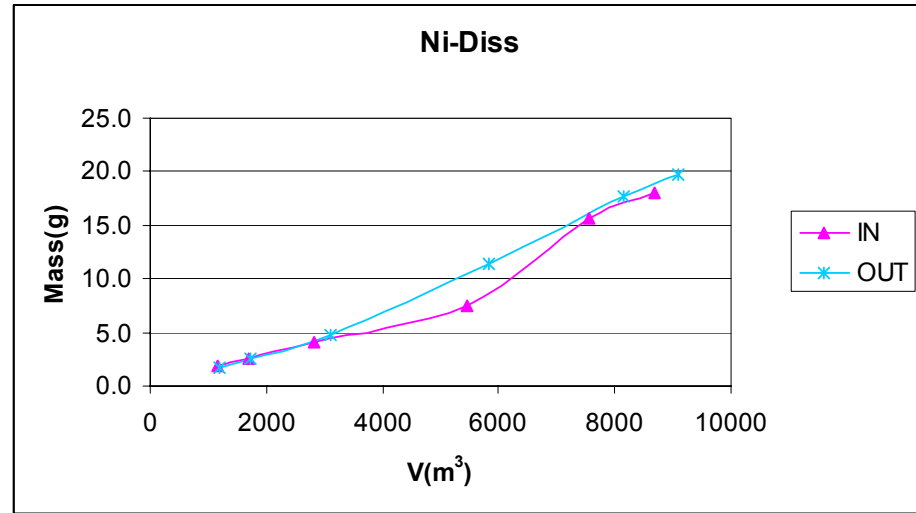
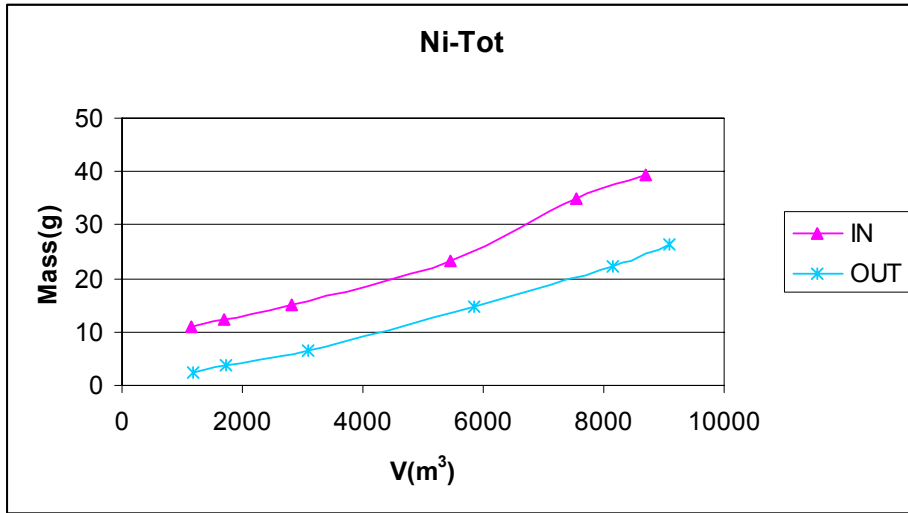


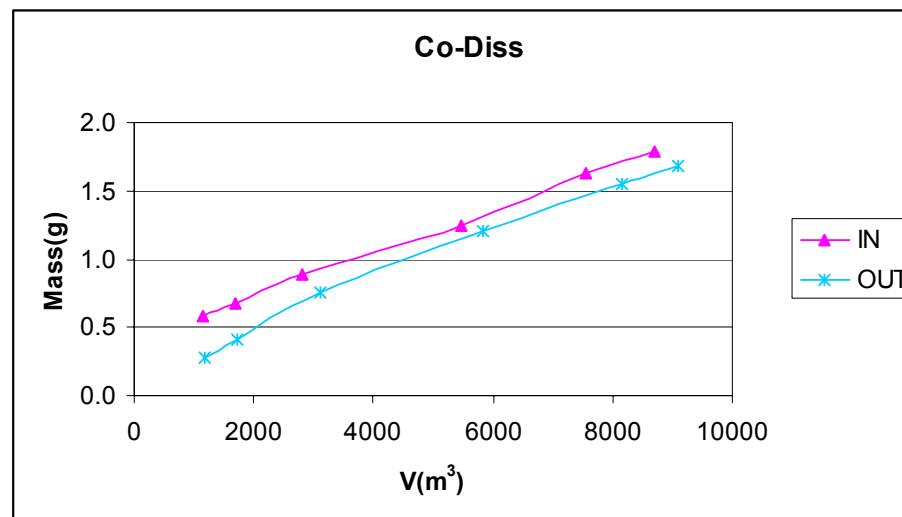
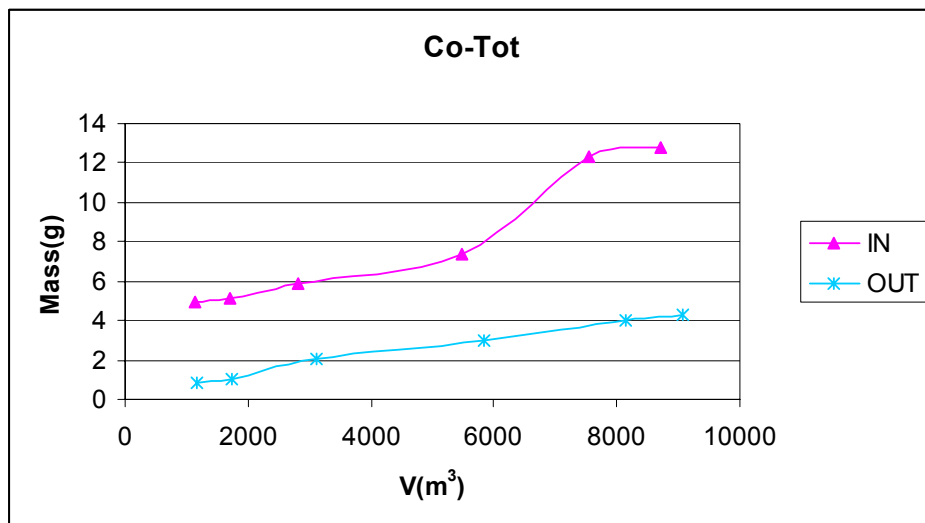
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**Appendix 7 - Environmental quality criteria in lakes and watercourses.***Table 7.1. pH*

<b>Class</b>	<b>pH</b>	<b>pH value</b>
<b>1</b>	Almost neutral	> 6.8
<b>2</b>	Mildly acid	6.5-6.8
<b>3</b>	Moderately acid	6.2-6.5
<b>4</b>	Acid	5.6-6.2
<b>5</b>	Very acid	< 5.6

*Table 7.2. Dissolved oxygen*

<b>Oxygen</b>		
<b>Class</b>	<b>Level</b>	<b>Minimum oxygen level during year (mg/l)</b>
<b>1</b>	Abundant	> 7
<b>2</b>	Moderate	5-7
<b>3</b>	Low	3-5
<b>4</b>	Very low	1-3
<b>5</b>	Entirely or nearly depleted	< 1

*Table 7.3. TOC and COD*

<b>Organic matter</b>		
<b>Class</b>	<b>Level</b>	<b>Level of TOC or COD<sub>Mn</sub> (mg/l)</b>
<b>1</b>	Very low	< 4
<b>2</b>	Low	4-8
<b>3</b>	Moderately high	8-12
<b>4</b>	High	12-16
<b>5</b>	Very high	>16

TOC = total organic carbon

COD = chemical oxygen demand



Table 7.4. Phosphorus

## Phosphorus in lakes

Class	Level	Total phosphorus conc.(µg P/l)		Description
		May-Oct.	August	
1	Low	< 12.5	<12.5	Oligotrophic
2	Moderately high	12.5-25	12.5-23	Mesotrophic
3	High	25-50	23-45	Eutrophic
4	Very high	50-100	45-96	
5	Extremely high	> 100	Unspecified	Hypertrophic

source: naturvårdsverket

Table 7.5. Nitrogen

## Nitrogen in lakes

Class	Level	Total nitrogen conc.(µg N/l)
		May-Oct.
1	Low	< 300
2	Moderately high	300-625
3	High	625-1250
4	Very high	1250-5000
5	Extremely high	> 5000

Source: Naturvårdsverket

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Table 7.6. Environmental quality criteria for metals in lakes and watercourses.

Metals in water					
	Class 1	Class 2	Class 3	Class 4	Class 5
Concentration	Very low	Low	Moderately high	High	Very high
	µg/l				
<b>Arsenic</b>	< 0.4	0.4-5	5-15	15-75	> 75
<b>Cadmium</b>	< 0.01	0.01-0.1	0.1-0.3	0.3-1.5	> 1.5
<b>Chromium</b>	< 0.3	0.3-5	5-15	15-75	> 75
<b>Copper</b>	< 0.5*	0.5-3*	3-9*	9-45	> 45
<b>Nickel</b>	< 0.7	0.7-15	15-45	45-225	> 225
<b>Lead</b>	< 0.2	0.2-1	1-3	3-15	> 15
<b>Zinc</b>	< 5	5-20	20-60	60-300	> 300
	Risk of biological effects				
	None or very little	Little	Primarily in acidic water and in soft water with low concentrations of humus and nutrients	Increased risk	High risk even with brief exposure

*Classification of heavy metals levels in water (Swedish EPA)*

## Appendix 8 - Reference Values for Metals in Water and Deviations

*Table 8.1. Deviations from reference values – metal concentrations in water*

Class	Extent of deviation	As	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
		Measured level/Reference value								
1	No deviation	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2	Slight	1-2	1-8	1-8	1-2	1-2	1-2	1-8	1-3	1-3
3	Significant	2-5	8-15	8-15	2-6	2-4	2-4	8-15	3-8	3-8
4	Large	5-9	15-30	15-30	6-11	4-7	4-8	15-30	8-13	8-13
5	Very large	> 9	> 30	> 30	> 11	> 7	> 8	> 30	> 13	> 13

Source: Swedish EPA homepage, 2004

*Table 8.2. Reference values*

	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	V	Zn
<b>Smaller watercourses</b>	<b>µg/l</b>									
Reference value	0.06	0.002	0.35	0.1	0.3	0.001	0.3	0.02	0.06	1
Background: Northern Sweden	0.06	0.003	0.03	0.1	0.3	0.002	0.3	0.04	0.06	0.9
Background: Southern Sweden	0.3	0.016	0.06	0.2	0.5	0.004	0.4	0.24	0.2	2.0
<b>Lakes</b>	<b>µg/l</b>									
Reference value	0.2	0.005	0.03	0.05	0.3	0.001	0.2	0.05	0.1	1
Background: Northern Sweden	0.2	0.009	0.03	0.05	0.3	0.002	0.2	0.11	0.1	0.9
Background: Southern Sweden	0.3	0.016	0.06	0.2	0.5	0.004	0.4	0.24	0.2	2.0

Source: Swedish EPA homepage, 2004

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### Appendix 9 - Assessment of pollution levels for PAH

Table 9.1. Assessment of conditions (based on reference values for polluted groundwater)

Classification	Level for Carcinogen PAH ( $\mu\text{g/l}$ )	Level for Others PAHs ( $\mu\text{g/l}$ )
Less serious	< 0.2	< 10
Reasonable serious	0.2 - 0.6	10 - 30
Serious	0.6 - 2.0	30 - 100
Very serious	> 2.0	> 100

Source: Swedish EPA homepage, 2004

Table 9.2. Reference values (Riktvärden) for polluted groundwater (gas station area)

Compound	Reference value ( $\mu\text{g/l}$ )
Carcinogens PAH	0.2
Other PAH	10

Source: Swedish EPA homepage, 2004

Table 9.3. Reference values (Riktvärden) for polluted soil

Compound	Reference value (mg/kg dried substance)
Carcinogens PAH	0.3
Other PAH	20

Source: Swedish EPA homepage, 2004

### Appendix 10 - Removal Efficiency by Storm Events.

<b>REMOVAL</b>	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5-6	<b>TOTAL</b>
<b>TSS</b>	84%	35%	34%	70%	90%	<b>83%</b>
<b>VSS</b>	82%	-70%	56%	66%	79%	<b>75%</b>
<b>TOC</b>	20%	-17%	1%	-10%	-19%	<b>-7%</b>
<b>DOC</b>	0%	-10%	5%	-15%	-11%	<b>-8%</b>
<b>COD</b>	-	-	-	14%	58%	<b>45%</b>
<b>NO3-N</b>	25%	8%	0%	18%	17%	<b>17%</b>
<b>NO2-N</b>	-10%	-86%	-75%	-14%	-48%	<b>-34%</b>
<b>NH3-N</b>	38%	-14%	69%	57%	44%	<b>45%</b>
<b>Tot-N</b>	29%	-8%	-320%	35%	26%	<b>-4%</b>
<b>PO4-P</b>	32%	22%	-3%	54%	70%	<b>35%</b>
<b>Tot-P</b>	64%	0%	16%	44%	66%	<b>46%</b>
<b>Cl<sup>-</sup></b>	-36%	30%	-19%	-14%	-43%	<b>-24%</b>
<b>Zn<sub>t</sub></b>	66%	15%	38%	15%	28%	<b>34%</b>
<b>Cu<sub>t</sub></b>	76%	43%	31%	44%	51%	<b>52%</b>
<b>Pb<sub>t</sub></b>	85%	-42%	54%	48%	70%	<b>69%</b>
<b>Cd<sub>t</sub></b>	79%	-367%	47%	27%	6%	<b>22%</b>
<b>Ni<sub>t</sub></b>	80%	1%	14%	3%	28%	<b>36%</b>
<b>Cr<sub>t</sub></b>	70%	71%	23%	48%	51%	<b>57%</b>
<b>Co<sub>t</sub></b>	84%	14%	-18%	38%	77%	<b>68%</b>
<b>Zn<sub>d</sub></b>	41%	6%	50%	44%	54%	<b>46%</b>
<b>Cu<sub>d</sub></b>	16%	17%	32%	29%	42%	<b>32%</b>
<b>Pb<sub>d</sub></b>	37%	-27%	5%	-67%	29%	<b>8%</b>
<b>Cd<sub>d</sub></b>	-25%	25%	64%	27%	32%	<b>39%</b>
<b>Ni<sub>d</sub></b>	9%	-16%	-21%	-92%	21%	<b>-5%</b>
<b>Cr<sub>d</sub></b>	21%	0%	15%	18%	28%	<b>21%</b>
<b>Co<sub>d</sub></b>	53%	-48%	-38%	-18%	7%	<b>9.6%</b>

$$R_{i \text{ event}} = (C_i^{\text{in}} - C_i^{\text{out}}) / C_i^{\text{in}},$$

$$R_{\text{Total}} = ((\Sigma M^{\text{in}} / \Sigma V^{\text{in}}) - (\Sigma M^{\text{out}} / \Sigma V^{\text{out}})) / (\Sigma M^{\text{in}} / \Sigma V^{\text{in}})$$

8. Appendicies

**Appendix 11 - Residence Time Data**

**Stormwater volumes per storm event**

	<u>Inflow</u>	<u>Outflow</u>	V <sub>Tot-600</sub>
Prev. storm			
6/11/2004	1148	1182	582
6/12/2004	546	550	
6/15/2004	1130	1370	770
6/20/2004	2645	2733	2133
2004-06-22A	2076	1599	
2004-06-22B		713	1712
6/23/2004	1154	938	338
Sum	8699	9085	

<b>IN (6.5 l/s)</b>		<b>UT (5 l/s)</b>						<u>T<sub>Res, dyn.</sub>(h)</u>	<u>T<sub>Res, dry.</sub>(d)</u>
<u>Start</u>	<u>Stop</u>	<u>Start</u>	T <sub>600</sub>	T <sub>Vtot-600</sub>	<u>Stop</u>	<u>T<sub>Res1</sub></u>	<u>T<sub>Res2</sub></u>		
	04/06/10 06:00								
04/06/11 16:25	04/06/11 23:54	04/06/11 16:38	04/06/11 19:08	04/06/11 19:02	04/06/12 05:24	2.50	10.37	- 6.4	- 1.4
04/06/12 05:49	04/06/12 12:31	04/06/12 06:00	-	-	04/06/12 14:38			-	0.2
04/06/15 04:24	04/06/15 12:42	04/06/15 06:18	04/06/15 08:30	04/06/15 09:10	04/06/15 21:32	2.20	12.37	7.3	2.7
04/06/19 07:36	04/06/20 11:56	04/06/19 07:56	04/06/19 13:38	04/06/20 01:56	04/06/20 19:28	5.70	17.53	11.6	3.8
04/06/22 06:00	04/06/23 00:55	04/06/22 06:24	04/06/22 08:56						
				04/06/22 17:12	04/06/23 06:34	2.53	13.37		
04/06/23 06:01	04/06/24 04:29	04/06/23 14:44	04/06/24 00:02	04/06/23 22:22	04/06/24 09:18	9.30	10.93	9.0	1.8

**Appendix 12 - Photos from the site**



*In clockwise direction: Ditch, pond 1, pond 2, pond 3, author at the overflow chamber upstream the ditch inlet.*

## 8. Appendices





