



STATENS GEOTEKNISKA INSTITUT
SWEDISH GEOTECHNICAL INSTITUTE



Impact of Climate Change on the Quality of
Urban and Coastal Waters - Diffuse Pollution (diPol)

Case site Göteborg, Sweden Urban groundwater impact

Thomas Rihm
Gunnel Göransson

Varia 633

LINKÖPING 2012

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European Union  The European Regional Development Fund

**The Interreg IVB
North Sea Region
Programme**



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1. Analysis results and procedures

PREFACE

This report is one part of the Interreg IVB North Sea Region Programme project “diPol” which aims at retaining sustainable and healthy urban and coastal waters despite potential adverse effects of climate change. The report describes an attempt to assess the impact of shallow urban groundwater on the Göta River estuary. It focuses on the present situation in order to assess the magnitude of the problem and to provide a bases for further research concerning the consequence of climate change with respect to pollution loads from the urban groundwater.

The study was financed by the Swedish Geotechnical Institute (SGI) and the EU Interreg IVB North Sea Region Programme. The authors would like to acknowledge Gryaab, the regional sewage works of the Göteborg region in Sweden, for the cooperation with respect to the analyzing of samples, Göteborg Vatten (the water management, Göteborg City) for their help with finding suitable sampling points, and Bengt Rosén (SGI) for reviewing the report.

August, 2012

SUMMARY

As the central parts of the Göteborg city to a large extent is built on filling materials from various origin, there may be a pollution potential emanating from earlier as well as on-going urban activities. Earlier investigations on groundwater observation wells in the city centre and in the outskirts of Göteborg have been used as well as earlier investigations on groundwater leaking into the stormwater pipe systems in periods of dry weather (drainage water). Complementary analyses of drainage water have been carried out and comparisons have been made between water from observation wells and drainage water. Comparisons have also been made with stormwater and treated sewage water. The pollution load from the different types of water has then been assessed.

The investigations indicate that the pollution load from the urban groundwater is not generally a great problem. Most of the pollutions from the city seems to emanate from precipitation, corrosion of building materials, and present anthropogenic activities, e.g. traffic, which are transported by the stormwater to the Göta River and its estuary. A good strategy to prevent the Göta River estuary from urban pollutants is to take further measures to reduce the pollutants in the stormwater.

1 INTRODUCTION

1.1 About the diPol project

This report is one part of the Interreg IVB North Sea Region Programme project with the acronym diPol (J-No 35-2-51-08). DiPol intends to make a contribution to retain sustainable and healthy urban and coastal waters despite potential adverse effects of climate change. European urban areas face a number of environmental problems such as air pollution, traffic volumes, scarcity of recreational areas, generation of large volumes of waste and waste water, and historical industrial legacies. Within the Water framework Directive (WFD, 2000) the water related problems are mapped and linked to their sources. However, the management options do not consider possible risks within a catchment area (from urban areas to coastal zones) under extreme conditions. Solutions need to be forward-looking and take into account future risks such as the impacts of climate change. They should also contribute to national, regional and global policies (Technical Report of the EC 2007-013). Education and awareness of the link between societal behaviour and development, environmental quality and economic development is necessary for the long-term mitigation of environment and climate related problems.

While direct consequences of climate change on urban development (e.g. flooding) have been addressed in a number of projects, secondary implications of increased urban runoff, higher contaminant loads in rivers during more frequent floods, the risks of rising groundwater levels in industrialized areas and of stronger rainfalls on the contamination of urban waters has received little attention until now. Ultimately the contaminated fresh water ends up in the coastal waters. Increased introduction of contaminants into surface waters in the coastal zone may counteract sustainable urban development (human health, quality of life, economic attraction) as well as European environmental strategies such as the WFD and the planned European Marine Strategy.

Within the diPol project, activities have been carried out at four case sites located at different areas of the river-coast continuum in the Northern Europe. The sites have been chosen exemplarily for areas that are affected to a different extent from continental impacts of climate change (increase of rainfall, rising groundwater levels, increased frequency of high and low river discharge) and coastal ones (sea level increase, storm surges). The sites are: (1) the inner Oslo-Fjord, Norway, which is an example for Northern European cities located at fjords with a high marine influence; (2) the Göta River near Göteborg, Sweden, which is an example for coastal cities located at the river mouth, with both marine and freshwater influence; (3) Wilhelmsburg near Hamburg, Germany, which is an example for urban areas influenced more by large rivers than by marine waters; (4) the Harrestrup stream and Kalveboderne Lagoon near Copenhagen, Denmark, which is an example for urban environments at small rivers with little marine influence.

The project consortium consist of nineteen partners, representing five countries, and with the Technical University Hamburg-Harburg (TUHH) as lead partner. More information can be found on the diPol web site: <http://www.tu-harburg.de/iue/dipol/home-copy-1.html>.

1.2 Aim and objectives

The work described in this report aimed to estimate the extent to which urban groundwater today affect urban surface and coastal waters and to provide a basis for further research needed in order to assess the impact of future climate change on these waters.

It is reasonable to believe that the city has a considerable impact on the urban water quality due to all activities that takes place within urban areas. It is reasonable to believe that all these activities have an impact also on the groundwater, as contaminants are infiltrated from various surfaces. In a study by Cato (2006) on sediment quality along the Göta River, it was found that the

content of pollutants in sediments in the Göta River is much lower upstream Göteborg than in the harbour area. This indicates that the city has a significant impact on the sediment and water quality in the estuary but also that most sedimentation occurs in the estuary. The pollutants originating from the city are considered to have many different diffuse sources. For example, a large part of the city is built on filling material of unknown origin which could also be a source of pollution.

This report describes an attempt to estimate the properties of the shallow ground water in the city of Göteborg and the present load of different compounds from the groundwater to the surface water.

2 METHODOLOGY

Shallow urban groundwater quality in the Göteborg city area have been studied by Mossmark (2003) and Norin (2004) among others. The urban groundwater quality has also been of interest when the contribution of pollutants from groundwater leaking into stormwater pipes has been estimated (Mattsson 1999). However, no attempts to assess the pollution load to the coastal waters from the urban groundwater have been found in the literature.

Estimating the pollution load from groundwater in an urbanized area presents itself with many difficulties and the information on the urban groundwater quality in the Göteborg city area is therefore scarce. The uppermost soil in the urbanized areas is often not natural but consists of filling in material which may differ considerably regarding hydraulic as well as chemical properties. In addition, underground constructions like stormwater and sewage water pipe systems influence the groundwater flow.

In order to avoid large number of monitoring wells for the monitoring of urban groundwater, sampling of water during dry periods from the stormwater pipe system has instead been used as a method. These pipes are in a large part of the city situated below the groundwater table and the water in these pipes during dry periods with little or no flow of surface runoff, is considered to represent the urban groundwater. In order to distinguish it from “true” groundwater observed in monitoring wells it is hereafter called *drainage water*. Based on this, the groundwater quality in the Göteborg city area have in this study been assessed by means of:

1. Analysis of previous studies on urban groundwater quality from the study site and analysis of existing data from monitoring programs regarding groundwater quality in general from the site.
2. Additional sampling and analyses of urban groundwater leaking into stormwater pipe system (*drainage water*). Sampling points were chosen to represent different type of urban pollution sources; urban highway (Gullbergsmotet), industrial/residential area (Järnbrott), residential area (Fiskebäck), area with mainly filling material (Gullbergsvassgatan) and industrial area with filling material (Hisingen).
3. Assessment of groundwater discharge based on precipitation and infiltration factors.

The additional water samples were analysed at ALS Laboratory Group, ALS Scandinavia AB, except high precision mercury analyses that were carried out by the Swedish environmental Research Institute (IVL). Results and methods used are related in appendix 1.

3 SITE DESCRIPTION

3.1 Study area

The system under study is the Göteborg city area and the major rivers/streams having their outflow in the Göteborg city area, and the harbour/estuary of Göteborg. Göteborg is situated on the south west coast of Sweden, a city of about 930 000 inhabitants in the metropolitan district, of which approximately 550 000 lives in the population centre. It is the second largest city in Sweden and the fifth largest city within the Nordic countries. The main river is the Göta River, that stretches from lake Vänern (lake volume: 153 km³) to the outlet at the city of Göteborg. The Göta River catchment downstream lake Vänern covers an area of about 3 000 km² and the river has a mean flow of 550 m³/s (Göta älvs vattenvårdsförbund, 2011). South of Kungälv, the river divides into two branches; the northern branch (the Nordre River) receives 3/4 of the total flow, whereas the remaining water passes Göteborg through the southern branch (still referred to as Göta River) (Göta älvs vattenvårdsförbund, 2011).

The southern branch divides the city in a northern part and a southern part and the main tributaries having their outflows in city centre area are the Sävån stream, Mölndas ån stream and the Kvillebäcken stream.

The city was founded in 1621 and has a long history of industrial activities (mainly ship yards, engineering industry and textile industry) and international Trade. The city is today the fifth largest in Scandinavia.

3.2 Topography

Göteborg is situated at the mouth of the Göta River. The elevation varies between sea level to somewhat more than 100 meters above the sea level. The landscape is cut through by a number of major fracture zones, of which the Göta River valley is the most important. The fracture zones have been carved out during several glaciations and formed valleys, filled with large quantities of sediments. The sediment thickness in the Göta River valley may exceed 100 meters in several areas.

3.3 Bedrock

The bedrock in the Göteborg area consists mainly of acidic igneous rock types such as granites, gneissic granites, granodiorites and tonalites (Lång 2009). North of the city centre is an enclave of metagreywacke.

3.4 Soil

The valleys in the Göteborg area normally have a thick soil layer consisting of clay underlain by a rather thin layer of till above the bedrock. Glacifluvial deposits of gravel, sand and silt found under the clay at some locations. The till and the glacial deposits constitute a confined aquifer. On higher ground the bedrock is often covered by a thin layer of till. At the highest points and at steep slopes outcrops of the bedrock can be seen. The till has in these areas been washed away and the material has sometimes been deposited as sandy sediments overlaying the clay at the valley sides. A schematic cross section of the geological properties of the Göta River valley is shown in Figure 1. In this part of the diPol project the urban groundwater in the filling material has been studied.

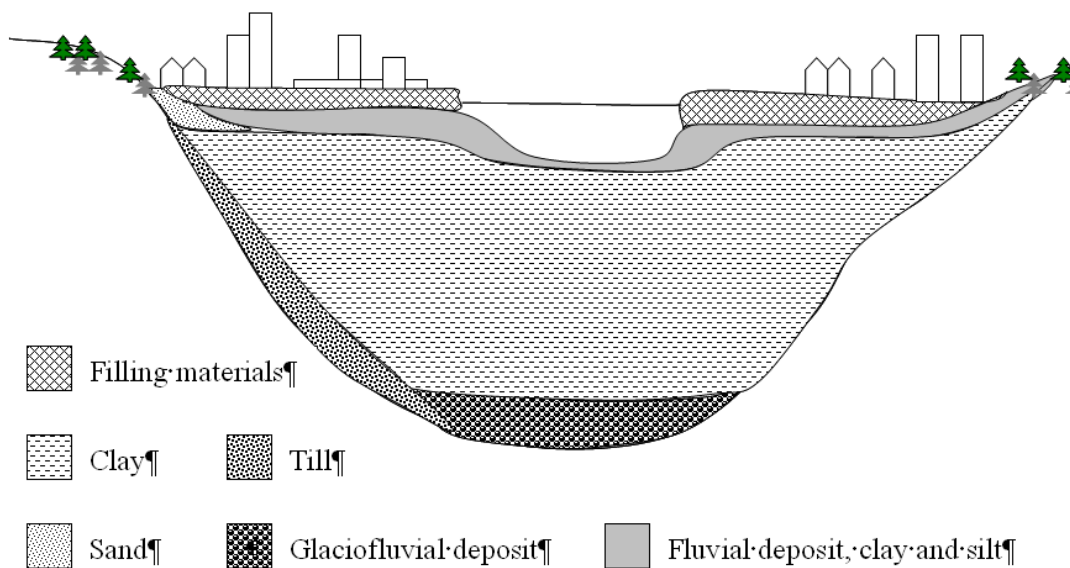


Figure 1. Schematic cross section of the geological properties of the Göta River valley. (after Hultén 1997).

3.5 Filling material

As in many other cities situated adjacent to rivers, the lower areas have commonly been filled with material to even out topographic differences. Such materials often originates from various sources, both natural and man-made. In Göteborg, the thickness of these fills varies from one to seven meters. This layer is rather heterogeneous however studies have shown that it mainly consists of sand and gravel located on top of natural soils (Hultén 1997). The filling material has a generally high hydraulic conductivity and is considered as an aquifer that is highly exposed to anthropogenic contamination (Mossmark 2003).

In older parts of the city there is often an old roadbed beneath the current streets, old houses have a foundation of wooden piles, and there is often a cultural layer on top of the clay layer (Hultén 1995). The cultural layer consists of organic household waste. Parts of old buildings are often found in the filling material. In a mixture containing these old features, there are new filling materials, utilities and foundation constructions. The upper part of the natural soil, which in most old parts of the city consists of clay, is often mixed with filling material.

The thickness of the filling material varies greatly within the city centre, as such material has been used to even out topographic differences and also to extend the harbour into the river. The thickest layer of filling material can be found closest to the river and is generally more than three meters in depth, in some locations as thick as seven meters. In the rest of the older parts of the city centre, the filling material is between 1.5 and 3.0 meters thick. In more newly constructed areas the thickness of the filling material is less than three meters (Mossmark 2003).

4 PREVIOUS INVESTIGATIONS OF GROUNDWATER QUALITY

4.1 Groundwater quality in shallow quaternary deposits above sea level

This section summarizes results from analyses of groundwater samples taken in natural quaternary deposits within the study site.

From the Swedish Geological Survey's groundwater database (SGU 2010), analyses results from samples taken from four wells in the Göteborg area was used. In this study. Some parameters have been sampled at many occasions (up to 40 occasions), while others only have been sampled at very few occasions. Mean concentrations for several parameters and for the four wells monitored during the years 1986-2005 are shown in Table 1. Mean of means and mean of medians are shown in Table 2. The locations of the wells are shown in Figure 2. Lång (2009) looked further into other investigations and gathered results from analyses made on groundwater samples from 20-200 wells (depending on parameter) in the Göteborg area, see Table 2. Mossmark (2003) reports mean concentration from three groundwater wells in a recreation area not far from the city centre. These results are also shown in Table 2. The locations of these wells are shown in Figure 3.

Table 1 Mean concentration in groundwater from four wells in the Göteborg area.

	SGU Brottkärr 20014-2008	SGU Härlanda 200014-2004	SGU Säve 20014-2034	SGU Torslanda 20014-2013
pH	4.8	4.7	6.5	5.6
Cond. (mS/m)	13.9	10.6	19.5	18.7
Alk. (mg HCO ₃ /l)	3.3	2.7	29	5.6
Acid (mg HCO ₃ /l)	0.74	0.91	0.61	0.90
SO ₄ (mg/l)	13.4	16.3	20.5	16.7
Cl (mg/l)	23	17	24	39
F (mg/l)	0.14	0.25	0.29	0.29
TOC (mg/l)	4.6	3.1	2.0	3.2
NO ₃ (mg/l)	0.2	0.24	3.6	0.24
NO ₂ (mg/l)	0.007	0.007		0.013
NH ₄ (mg/l)	0.12	0.14	0.16	0.08
Na (mg/l)	9.87	9.74	14.9	19.33
K (mg/l)	0.40	0.51	2.47	1.34
Ca (mg/l)	1.6	2.1	10.1	6.8
Mg (mg/l)	2.3	1.9	5.3	3.0
Fe (mg/l)	2.3	1.3	1.6	3.6
Mn (mg/l)	0.13	0.21		0.23
SiO ₂ (mg/l)	7.5	9.5	17.4	10.5
Al (µg/l)	2810	1530	1010	1490
Cd (µg/l)	0.24	0.25	0.13	0.13
Cr (µg/l)	0.18	0.56	0.17	0.66
Cu (µg/l)	3.10	3.15	4.61	3.22
Pb (µg/l)	16.7	5.1	2.0	2.6
Zn (µg/l)	58	27	37	26
As (µg/l)	0.88	0.48	0.55	0.97
Ni (µg/l)	1.17	1.44	0.77	3.06
Co (µg/l)	3.0	1.6	0.15	1.0

Table 2. Groundwater quality in groundwater wells in the Göteborg area (SGU 2010, Lång 2009 and Mossmark 2003). Bold figures represent the chosen background concentrations.

	SGU Mean of means from 4 wells (table 2)	SGU Mean of medians	Wells in sediments Median values (Lång 2009)	Wells in the berock Median values (Lång 2009)	Recreation area (mean) GB 193, 329 and 312 (Mossmark 2003)
pH	5.4	5.35	7.1	7.3	6.6
Cond. (mS/m)	15.7	14.4	24	37	23
Alk. (mg HCO ₃ /l)	10.2	9.5	78	107	42
Acid (mg HCO ₃ /l)	0.79				
SO ₄ (mg/l)	16.8	16			6.7
Cl (mg/l)	26	24	30	44	29
F (mg/l)	0.24	0.25			
TOC (mg/l)	3.2	3.7			
NO ₃ (mg/l)	1.1	1.0	1	1	
NO ₂ (mg/l)					
NH ₄ (mg/l)	0.12	0.05			9.1
Na (mg/l)	13.46	13.7	29	65	12
K (mg/l)	1.18	1.15	5.1	5.9	8.6
Ca (mg/l)	5.1	4.9	18	23	
Mg (mg/l)	3.1	3.1	4.6	5.4	
Fe (mg/l)	2.2	0.73	0.16	0.21	11
Mn (mg/l)	0.19	0.10	0.106	0.110	0.66
SiO ₂ (mg/l)	10.5				
Al (µg/l)	1710	696	20	10	7.5
Cd (µg/l)	0.19	0.12			0.07
Cr (µg/l)	0.39	0.27	0.7		0.17
Cu (µg/l)	3.52	1.28	25	50	2.5
Pb (µg/l)	6.6	1	0.75		0.1
Zn (µg/l)	37	22	32		147
As (µg/l)	0.72	0.83	0.2		
Ni (µg/l)	1.61	1.69	21		2.6
Co (µg/l)	1.4	1.27			4.3

As is seen in Table 2, the results from the wells in the SGU database, the values compiled by Lång (2009) and the ones from the recreation area (Mossmark 2003) show a fairly good correlation, although the values from the SGU database show lower values for pH, alkalinity, and ammonia. Typically, wells in coarse grained material have lower pH than wells in more fine grained material. Lång (2009) reports a pH mean of 6.4 for groundwater wells in backwash sediments. Low pH-values are not surprising considering the acidic bedrock from which the sediments are formed and the rather acid rain with an average pH level around 4.5 (Hansén 2002). The values given by Lång (2009) tend to be somewhat higher than the values from the SGU groundwater wells and the recreation area. This may be explained by the many wells located near the city centre in the compilation by Lång (2009).

A closer look into the SGU database (raw data is not made available in this report) reveals that the series of groundwater analyses from the SGU wells contain shorter periods of high concentrations of metals for which there seem to be no explanations. As a result the median values are often lower than the mean values.

As background concentrations, the mean of median concentration from the SGU database are chosen, with the exception of aluminum. The aluminum concentration seem to be out of line and the value 10 µg/l (bedrock, Table 1) is used instead. The chosen concentrations for the representation of background values are shown with bold figures in Table 2. These relatively low values are chosen as background values in order not to underestimate the influence of pollutants on the groundwater.



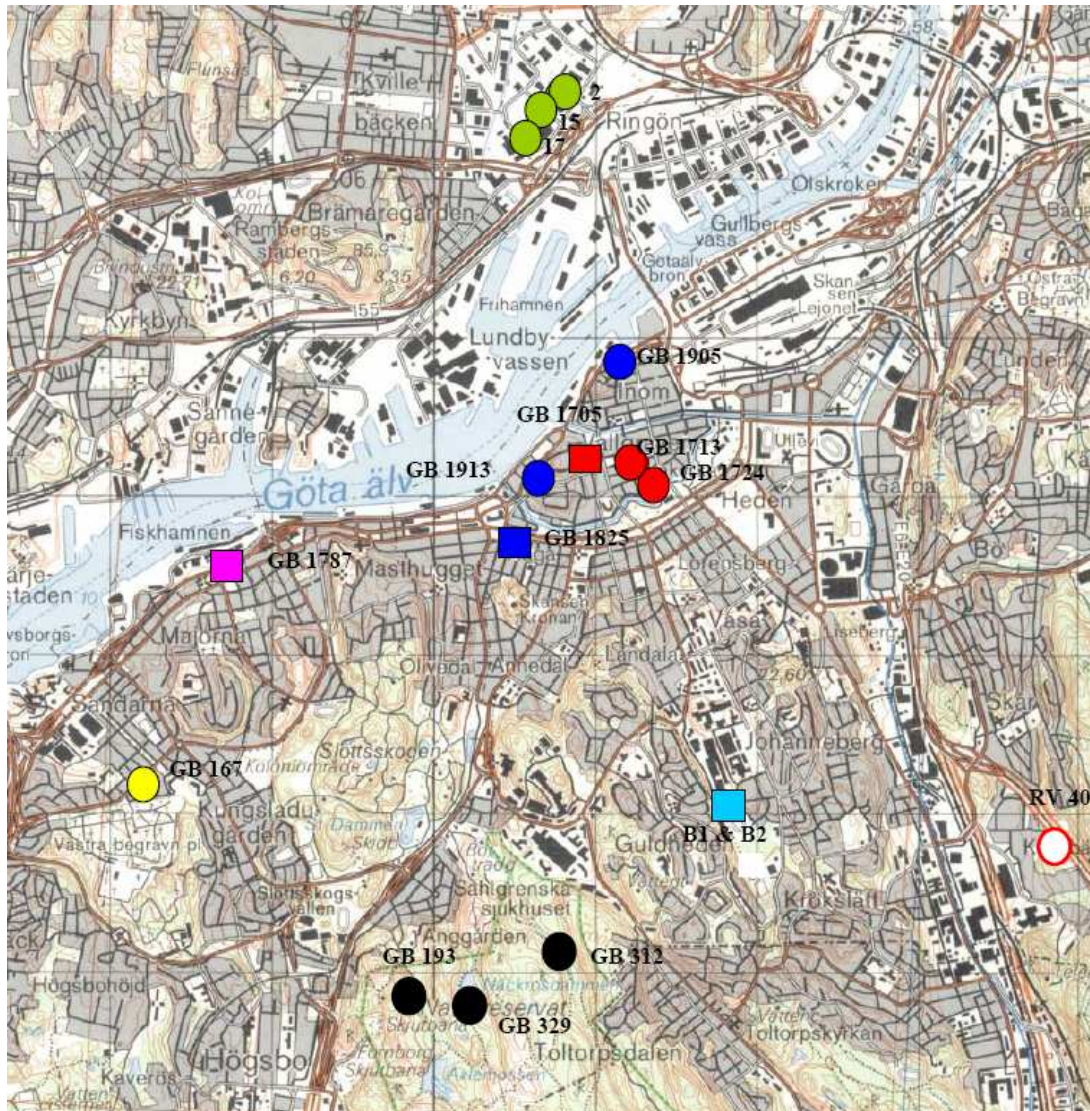
Figure 2. Location of SGU monitoring wells 20014-2008, 20014-2004, 20014-2013 and 20014-2034 (© Sveriges geologiska undersökning).

4.2 Groundwater quality in areas with filling material

4.2.1 Inorganic substances

Mossmark (2003) report on the results from analyses of groundwater samples taken in the centre or near the centre of the town. In his study he divided the wells into seven groups based on land use: urban forest (3 wells), industrial sites (3wells), urban highway (one well), major city streets (3 wells), residential area (one well), city centre with pedestrian shopping streets (3 wells), and urbanized wetland (2 wells). The locations of the wells are shown in Figure 3 and the results are shown in Table 3.

Mattsson (1999) report on the results from studies of water quality in stormwater pipes. Samples were taken during periods of little or no precipitation. The water in the pipes was considered as groundwater leaking into the pipes. The studies were carried out in three areas: an urban highway, an area with mixed industrial and residential buildings and a residential area. The results are also shown in Table 3.



- Urban Forest
- Industrial Site
- Urban highways
- Major city streets
- Residential neighbourhood
- City centre
- Urbanized wetland

Figure 3. Location of monitoring wells used by Mossmark (2003) and Norin (2004). Squares marks wells that were used for long-term analyses.

A review of nine Swedish studies of the base flow in stormwater pipes has recently been carried out by Arwidsson (2011). In this review, the base flow is defined as “the water present in stormwater ditches and stormwater pipes before and after a stormwater peak”, which should be very similar to “drainage water”. Medians from the nine studies are shown in Table 3.

Metal concentrations in water leaking in to the sewage water system (drainage and infiltration water, hereafter referred to as DI water) have also been calculated based on the relationship between different flow rates and corresponding metal concentrations at the Göteborg wastewater treatment plant (Balmer and Davidsson 2009). The average concentrations from the period 2004 – 2008 are shown in Table 3. The DI water amounts to nearly 50 % of the total flow to the wastewater treatment plant and Balmer and Davidsson (2009) concluded that, although the concentrations were low, the DI water seem to be a significant source of metals.

The results from Mossmark (2003), Mattsson (1999), Arwidsson (2011) and Balmer and Davidsson (2009) show a fairly good correlation, except for chromium and zinc, although the sampling was done with different strategies. The higher chromium concentration in the stormwater pipes could be due to the concrete in the pipes leaking chromium. Zinc may come from the well material. Some of the wells in the Mossmark study showed extremely high concentrations of zinc. The concentration of copper given by Balmer and Davidsson (2009) is also high in comparison with the other concentrations.

Table 3. Measured concentrations in groundwater from areas of different land uses. Water samples were taken from wells (Mossmark 2003) and from stormwater pipes (Mattsson 1999; Arwidsson 2011). Concentrations in DI water were calculated by Balmer and Davidsson (2009).

	Mossmark					Mattsson			Arwidsson	Balmer & Davidsson
	City centre	Urban highway	Major city street	Industrial site	Residential area	Urban highway	Industrial/residential area	Residential area	Mean of 9 studies in Sweden	DI water
pH	7.1	5.6	6.9	7.3	7.0	7.9	8.4	7.8		
Cond. (mS/m)	117	102	220	230	68	238	55	49		
Alk. (mg HCO ₃ /l)	142		280	304	196					
Acid (mg HCO ₃ /l)										
SO ₄ (mg/l)	32	11	35	126	2.0					
Cl (mg/l)	246	325	622	579	65					
F (mg/l)										
NH ₄ (mg/l)	4.4		42	5.3	9.1					
Na (mg/l)		36			20					
K (mg/l)	50	8.7	26	34	13					
Ca (mg/l)	71	8.9	106	194	86					
Mg (mg/l)	14	2.4	23	54	22					
Fe (mg/l)	0.13	184	2.5	0.9	2.7					
Mn (mg/l)	0.30	4.1	0.47	0.65	1.5					
Hg (µg/l)										0.095
Al (µg/l)	67	0.5	21	7.2	0.6					
Cd (µg/l)	0.03	0.2	0.43	0.10	0.3	0.11	0.09	0.50	0,05	0.12
Cr (µg/l)	0.2	0.2	0.67	0.93	0.3	8	4.1	2.0	1.4	3.0
Cu (µg/l)	3.5	3.2	4.5	6.3	3.2	7.1	9.7	5.1	6.6	40
Pb (µg/l)	0.7	0.2	0.2	0.5		0.29	1.6	0.36	1.4	2.3
Zn (µg/l)	187	655	4742	32	6180	20	45	31	24	43
Ni (µg/l)	6.9	35	15	32	15	6.8	6.5	2.6	3.1	3.2
Co (µg/l)	1.23	4.8	1.7	1.8	4.4					
Ba (µg/l)	28	21	110	76	17					
Sr (µg/l)	278	42	539	795	407					

4.2.2 Organic substances

Some of the wells used by Mossmark (2003) had previously been used by Carlsson and Johansson (2002) for the monitoring of some organic compounds. These results are shown in Table 4 and Table 5. In addition, analyses of nonyl phenoles and phthalates were carried out on groundwater from well GA 15, but concentrations above detection limit were only found for di-(2ethylhexyl)phthalate (11 µg/l, not shown in the tables).

Table 4. Chlorobenzenes, hydrocarbons, PCBs and PAHs for three wells in the city centre. ($\mu\text{g/l}$)(Carlsson and Johansson 2002). For well locations, see Figure 3.

Well	GB 1825	GA 15	GB 1913
Chloro benzenes	<1	<1	<1
Sum hydrocarbons	960	370	1400
Sum PCB	<1	<1	<1
Sum PAH	6	<3	4

Table 5. PAHs in wells GB1825 and GA 15 ($\mu\text{g/l}$) (Carlsson and Johansson 2002). For well locations, see Figure 3.

Well	GB 1825	GA15
naphtalene	0,029	<0.34
acenaphthylene	0.041	<0.25
acenaphthene	0	0.12
flourene	0.048	0.061
fenanthrene	0.088	0.092
anthracene	0.023	<0.13
fluoranthene	0.17	<0.30
pyrene	0.15	<0.37
benzo(a)anthracene	0.073	<0.07
chrycene	0.051	<0.16
benzo(b)fluoranthene	0.066	<0.27
benzo(k)fluoranthene	0.032	<0.05
benzo(a)phyrene	0.079	<0.26
dibenzo(ah)anthracene	0	<0.12
benzo(ghi)perylene	0.066	<0.04
indeno(123cd)pyrene	0.066	<0.06
Sum carcinogenic PAH	0.37	<0.05
Sum other PAH	0.61	0.27
Sum 16 EPA-PAH	0.98	0.27

Based on the studies by Carlsson and Johansson (2002) and Lindgren (1998), Norin (2004) suggested that the PAH composition given in Table 5 are indication on that the wear from rubber tyres probably is a main contributor to PAH in the shallow groundwater. As shown in Figure 4, there are high concentrations of, pyrene, fluoranthene and phenantrene, which is typically for the release of tyre rubber (Lindgren 1998). Analyses were also made on stormwater sampled during periods of little or no precipitation (Mattsson 1999), however the detection limit for these analyses were rather high (0.1 $\mu\text{g/l}$) and the concentrations of analysed substances were below detection limit.

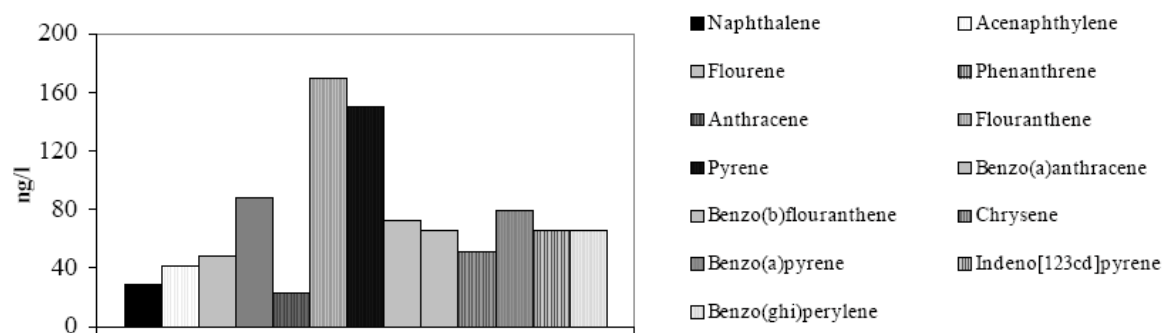


Figure 4. PAH distribution in shallow groundwater (well no. GB 1825, Norin 2004). The larger proportion of pyrene, flouranthene and phenanthrene typically indicates influence from rubber tyres (Norin, 2004).

4.3 Temporal variations

Studies on the seasonal variation in concentrations have been carried out by Mossmark (2003) and have been further discussed by Norin (2004). Mossmark concludes that the most significant variations in chemical composition of the groundwater were found to be caused by seasonal factors such as the use of de-icing chemicals (i.e. NaCl) and seasonal variation in groundwater recharge, depending on precipitation, evapotranspiration and surface run off, which led to fluctuations in the redox potential. Irrespective of the fact that deposition of de-icing chemicals is the only factor caused solely by anthropogenic activities, alteration of the balance of the hydrological cycle has occurred due to urbanization.

According to Norin (2004), periods with a large recharge rate stimulate a macro pore flow, which results in less ion exchange capacity. The urban soil structure permits macro pore flow to a greater extent than natural soils, due to the permeable filling material, pipes and underground buildings. Furthermore, when more water percolates through the vadose zone it is likely to dissolve sulphate that has precipitated during the previous dry period and thereby become more acidic before reaching the groundwater.

Periods with more acidic groundwater were brief in all of the locations, probably because the pH was neutralized by the extra high alkalinity caused by the composition of the filling material (Figure 5). The wells B1 and B2 described as urbanized wetland (see Figure 3) are situated further away from the city centre with less filling materials than the other wells which can explain lower pH values in these wells.

The alkalinity of groundwater remained relatively high even during acid pulses. According to Vinka and Årebäck (1994), this can be explained by the presence of aggressive carbon dioxide (CO_2) in groundwater. Bicarbonate (HCO_3^-) is retained in solution by an alteration of the equilibrium between bicarbonate and carbonic acid (H_2CO_3), which is caused by an increased concentration of aggressive carbon dioxide resulting from acid attacks on calcium carbonate (CaCO_3). Hydrogen ions (H^+) will remain mobilized, instead of being buffered by bicarbonate, which results in a lower pH value.

Norin (2004) also found a decreasing trend in lead content in the shallow groundwater from the year 1996 to 1999 (Figure 6). The decrease was especially significant for the three wells located along roads with moderate to heavy traffic (GB 1825, B1 and B2). Sales of leaded petrol were discontinued in Sweden in 1994, and the previous excess of lead in groundwater in the vicinity of roads should be reversed by now (Norin 2004).

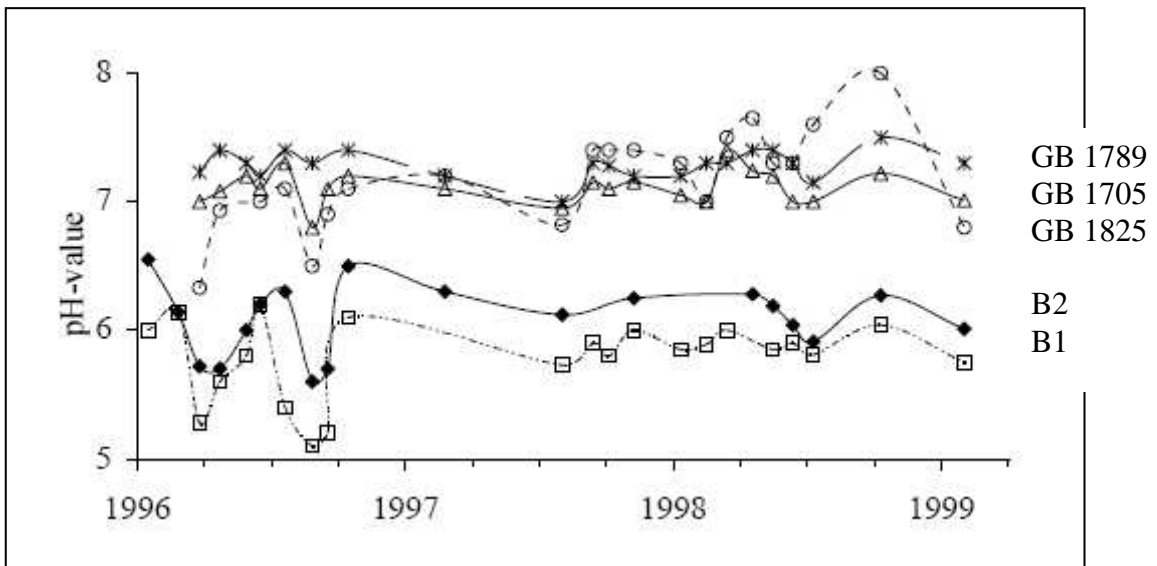
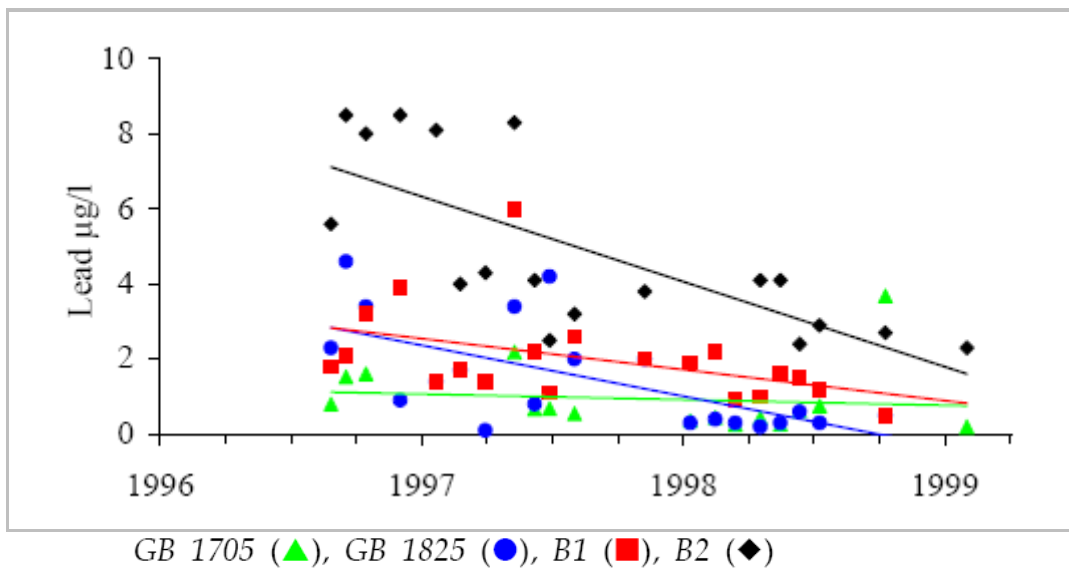


Figure 5. Seasonal changes of pH at five observation wells in the centre of Göteborg (Mossmark 2003).



GB 1705 (▲), GB 1825 (●), B1 (■), B2 (◆)

Figure 6. Lead concentrations (Norin 2004).

5 NEW INVESTIGATION ON URBAN GROUNDWATER QUALITY – ANALYSES ON DRAINAGE WATER

5.1 Sampling points

Sampling and analysis was carried out on water from stormwater pipes as described in the Methodology (section 2) and is hereafter referred to as drainage water.

Samples were taken from five locations, shown in Figure 7. These locations were chosen to represent different type of urban pollution sources (see Methodology). Three of these sampling points (Gullbergsmotet, Jämbrott and Fiskebäck) were also used by Mattsson (1999). Two new sampling points (Gullbergsvassgatan and Hisingen) were chosen to represent the shallow groundwater in the filling material near the city centre. The run off areas for the three sampling points near the town centre are shown in Figure 8.

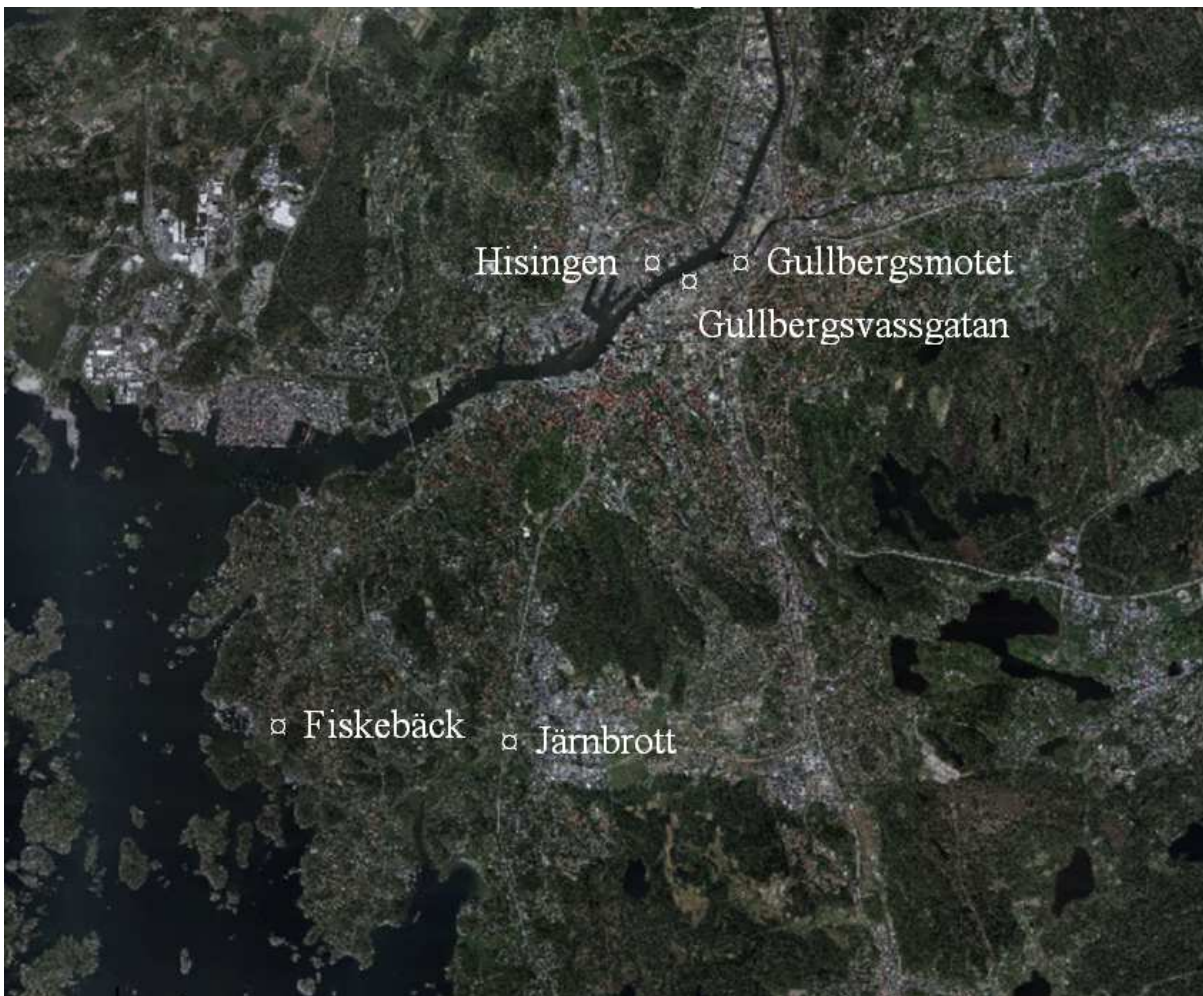


Figure 7. Sampling location for the sampling of drainage water in stormwater pipes.

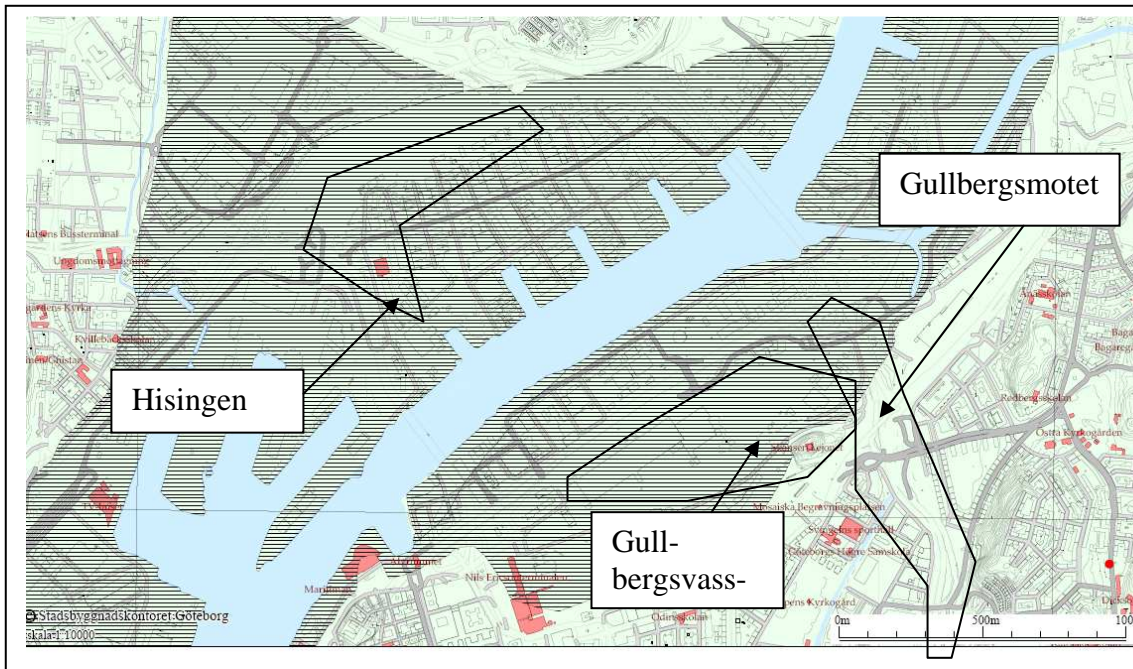


Figure 8. Run off areas for three of the sampling points. The sampling points are marked with arrows.

Gullbergsmotet (urban highway)

A sample was taken from a pumping station situated on the south side of the Göta River, near the entrance to the Tingstad tunnel under the river (Figure 8). The area next to the river consists of filling material. The inlet to the pumping station is several meters below the see level. The pumps were run manually to lower the water table under the level of the inlet pipe, and a sample could be taken from a free falling flow as can be seen in Figure 9. The flow was estimated to 1.5 to 2 litres per second.



Figure 9. Inlet pipe at the pumping station at Gullbergsmotet. A sample was taken from the free falling flow. (Photo: SGI).

Järnbrott (industrial/residential area)

At the time for the study carried out by Mattsson (1999), the stormwater pipes ended in a small stream leading to the sea south of the Göteborg centre. Today, a construction is built to dam up the water in order to lead it to a pond in where pollutants can precipitate before they reach the stream (Figure 10). The construction also facilitate an overflow of water to the stream in case of extreme flow rates. The construction made it difficult to do the sampling as planned for, however there was a small leakage under the bottom of the construction and water from this leakage could be sampled. Due to the arrangements the water flow could not be estimated.



Figure 10. Sampling point at Järnbrott (photo: SGI).

Fiskebäck (residential area)

The sample was taken from inside a 1500 mm stormwater pipe at the same location as the sample from the study by Mattsson (1999).

Gullbergsvassgatan (area with filling material)

A sample was taken from a pumping station (Figure 11) in much the same way as at Gullbergsmotet. This pumping station is however much smaller and the flow was estimated to only 0.03 litres per second. The sampling point is located near railroad tracks in the east and large areas for container traffic in the west.



Figure 11. The pumping station at Gullbergsvassgatan (photo: SGI).

Hisingen (industrial area with filling material)

A drainage water sample was taken from an 800 mm stormwater pipe.

5.2 Results

5.2.1 Metals

Analyses were made both on filtered samples (0.45 μm) and on unfiltered samples after digestion. The filtered samples had, not surprisingly, lower concentrations, but, with the exception for Pb, Al and Fe, the difference between the filtered and the unfiltered samples were not dramatic. It is unclear if the analyses made 1992 were filtered or not, but the concentrations seem to be lower for most metals 2010, even if the concentration from 1992 are compared with the unfiltered samples from 2010. The samples from “Hisingen” have somewhat higher concentrations than the other samples, but otherwise there are no clear distinction between areas with different land uses.

Analyses results concerning metals are shown in Table 6. In addition, mercury was analysed with a high resolution method. The results are shown in Table 7. Some of the results is also illustrated with diagrams (Figure 12). The result indicates the following:

- The concentrations of metals have decreased since the 1992 measurements with the exception of copper.
- The metal concentrations 2010 do not differ much from the background values with the exception of copper.
- The concentrations in filtered and unfiltered samples are in the same order of magnitude with the exception of iron, aluminium and lead.
- The samples from Hisingen 2010 seem to have higher concentrations than the other samples from 2010, otherwise there seem to be no significant differences between areas with different land use.

Table 6. Metal concentrations in stormwater pipes during a dry period (drainage water) in June 2010. Concentrations from 1992 (Mattsson) are shown for comparison.

ELEMENT	SAM- PLE	Gullbergsmotet (GM)			Gullbergsvass- gatan (GVG)		Järnbrott (J)			Fiskebäck (F)			Hisingen (H)	
		92-01	10-06	10-06	10-06	10-06	92-01	10-06	10-06	92-01	10-06	10-06	10-06	10-06
filtrering 0.45µm; digestion			yes	no	yes	no		yes	no		yes	no	yes	no
Ca	mg/l	79.7	84.7	182	185	54.8	54.1	45.5	46.6	34.9	35.4			
Fe	mg/l	0.0064	1.36	0.0087	24.8	0.0337	0.807	0.0338	0.411	0.146	4.06			
K	mg/l	19.2	21.3	15.8	17	7.09	7.41	6.18	7.06	6.3	7.5			
Mg	mg/l	22.9	24.6	15.6	16.3	9.09	9.53	8.77	9.56	6.44	7.12			
Na	mg/l	305	339	277	291	102	105	54.8	57.2	137	137			
Si	mg/l	6.91		12.2		5.45		6.6		14.3				
Al	µg/l	5.92	488	<0.2	<50	4.72	140	30.7	259	36.1	812			
As	µg/l	1.3	2.21	<0.6	1.65	0.349	1.19	1.38	1.19	3.91	6.34			
Ba	µg/l	54.9	69.5	175	288	31.5	37.5	21	26.8	4.28	34.4			
Cd	µg/l	0.11	0.0349	<0.05	<0.002	<0.05	0.09	0.019	<0.05	0.06	0.0272	<0.05	0.0296	0.0854
Co	µg/l		0.252	0.496	0.131	0.201		0.096	0.317	0.104	0.297	0.28	0.652	
Cr	µg/l	8	0.166	<0.9	0.195	<0.9	4.1	0.165	<0.9	2	0.223	<0.9	0.392	1.82
Cu	µg/l	7.1	6.97	5.3	0.105	1.22	9.7	6.57	9.67	5.1	5.92	6.21	8.18	15.4
Hg	µg/l	<0.002	<0.02	<0.002	<0.02	<0.002	<0.002	<0.02	<0.02	<0.002	<0.02	0.0022	<0.02	
Mn	µg/l	205	257	1240	1340	2.91	100	21.5	40.6	130	204			
Mo	µg/l	2.93	2.77	1.08	1.11	2.25	2.22	3.19	3.17	1.19	1.27			
Ni	µg/l	6.8	1.18	1.69	0.384	<0.6	6.5	1.87	2.36	2.6	1.41	1.64	1.1	2.55
P	µg/l		22.7		2.34			19.7		141		19400		
Pb	µg/l	0.29	0.0133	0.768	<0.01	<0.6	1.6	0.0266	0.79	0.36	0.0243	<0.6	0.0421	3.55
Sr	µg/l		310		534			173		160		68		
Zn	µg/l	20	6.26	13	1.42	4.68	45	13.5	21.7	31	9.55	18.1	9.28	44.7
Sb	µg/l		0.605	0.613	0.413	0.619		0.525	0.548	0.303	0.348	0.682	1.06	
B	µg/l		208	225	170	182		62	67.8	116	127	209	209	
Sn	µg/l		<0.05	<0.5	0.297	<0.5		<0.05	<0.5	<0.05	1.13	0.0639	0.701	
Ag	µg/l		<0.05	<0.5	<0.05	<0.5		<0.05	<0.5	<0.05	<0.5	<0.05	<0.5	
Bi	µg/l		<0.005	<0.05	<0.005	<0.05		<0.005	<0.05	<0.005	<0.05	<0.005	0.335	

*From Mattsson 1992

Table 7. Mercury concentrations from high resolution analysis.

		Gullbergsmotet	Gullbergsvassgatan	Järnbrott	Fiskebäck	Hisingen
Hg	ng/l	2.6	1.2	2.9	3.3	9.4

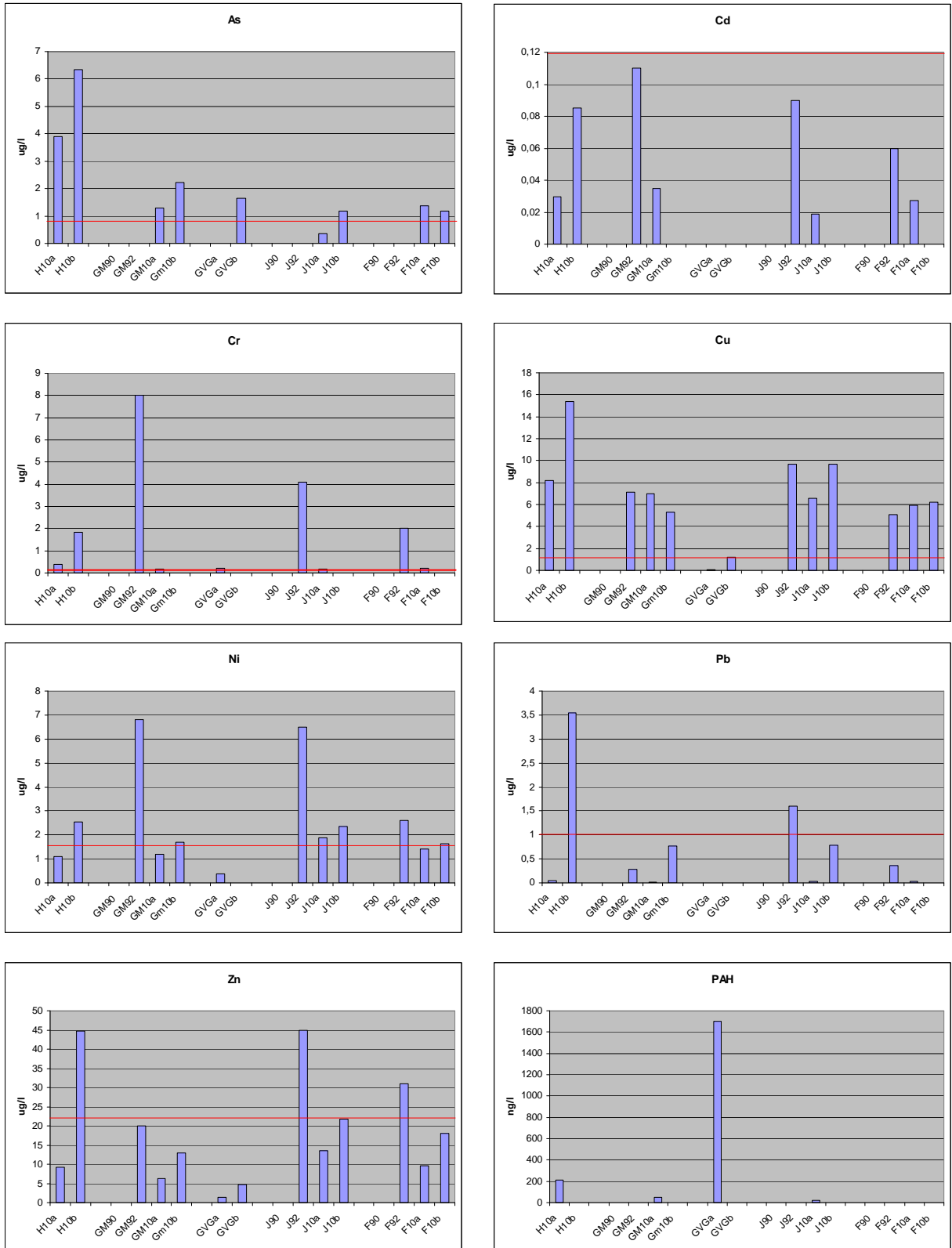


Figure 12. Diagrams for some metals and PAH. Abbreviations: H =Hisingen, GM = Gullbergsmotet, GVG = Gullbergsvassgatan, J = Järnbrott and F = Fiskebäck. The number indicates the sampling year. a = filtered, b = unfiltered. Red line = background values from Table 2.

5.2.2 Physical parameters and nutrients

In Table 8, physical parameters and nutrients from this complementary sampling in 2010 is compared with the results from the 1990 and the 1999 sampling occasions. Again the sample from Hisingen shows highest concentrations. It can be noted that both the samples from Gullbergsvassgatans pumping station and from Hisingen show high amounts of suspended solids. In the case of Gullbergsvassgatan a major part of the suspended solids consists of Fe (there is a huge difference in concentrations between filtered and unfiltered samples, see table 5), while for Hisingen the major part seems to consist of organic substances.

Table 8. Physical parameters and nutrients.

		Gullbergsmotet			Gullbergsvassgatan	Järnbrott			Fiskebäck			Hisingen
ELEMENT	SAMPLE	90-09	92-01	10-06	10-06	90-09	92-01	10-06	90-09	92-01	10-06	10-06
pH		7.9	7.9	8.1	7.3	8.4	8.4	7.5	8	7.8	8	8
conductivity	mS/m	226	238	220	234	41	55	88.7	26	49	58.8	81.9
alkalinity	mg HCO ₃ /l			240	502			150			160	290
ammonium	mg/l			0.394	2.29			0.347			0.451	<0.050
nitrate	mg/l			7.17	2.22			5.8			941	<2.00
chloride	mg/l			639	612			174			751	105
CODCr	mg/l	30	34	25	33	24	20	22	9	22	23	116
DOC	mg/l			5.97	10.6			6.58			6.4	24.2
TOC	mg/l			7.79	10.7			6.92			6.51	26.5
N-tot	mg/l	2.9	2.3	2.2	2.1		1.4	2.39	1	2.3	3.26	2.17
P-tot	mg/l	0.085	0.06	0.071	0.159	0.22	0.12	0.065	0.23	0.15	0.149	35.3
suspended solids	mg/l	5.5	7	7.2	51.7	6	63	<5.0	<1	<5	<5.0	65.4
alkalinity	mg HCO ₃ /l											

5.2.3 Tin organic substances and phthalates

Remarkably, monobutyltin was found in all samples. Dibutyltin and tributyltin was found at Gullbergsvassgatan and Hisingen. Tributyltin was also found at Fiskebäck. Phthalates were found in the sample from Hisingen. In the other samples the concentrations were below the detection limit. The concentrations of tin organic substances and phthalates are shown in Table 9.

Table 9. Tin organic compounds and phthalates.

ELEMENT	SAMPLE	Gullbergsmotet 10-06-17	Gullbergsvassgatan 10-06-17	Järnbrott 10-06-17	Fiskebäck 10-06-17	Hisingen 10-06-17
monobutyltin	ng/l	46	15	50	26	50
dibutyltin	ng/l	<1.0	2	<1.0	<1.0	2.5
tributyltin	ng/l	<1.0	2.7	<1.0	4.1	1.4
tetrabutyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
monooctyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
dioctyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
tricyklohexyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
monophenyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
diphenyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
triphenyltin	ng/l	<1.0	<1.0	<1.0	<1.0	<1.0
dimethylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	<0.60
diethylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	2.59
di-n-propylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	<0.60
di-n-butylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	1.73
di-isobutylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	2.06
di-pentylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	<0.60
di-n-octylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	<0.60
di-(2-ethylhexyl)phthalat	µg/l	<1.3	<1.3	<1.3	<1.3	19.2
butylbensylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	0.83
di-cyclohexylphthalat	µg/l	<0.60	<0.60	<0.60	<0.60	<0.60

5.2.4 Polyaromatic hydrocarbons (PAH)

The water samples from the five sampling points were analysed at the Swedish Environmental Research Institute. To benefit from low detection limits, the samples were analysed with a non accredited method "A20". Water samples were liquid / liquid extracted with pentane and concentrated before being purified and fractionated on silica gel. The analysis was performed with high-resolution liquid chromatography (HPLC) and fluorescence detector. The results are shown in Table 10 and Figure 13 and 14. Canadian guidelines for the protection of aquatic life are shown for comparison.

Table 10. PAHs ($\mu\text{g/l}$) in drainage water samples from the five sampling points and guidelines for the protection of aquatic life (Canadian Council of Ministers of the Environment, CCME 2007).

	Gullbergsmotet	Gullbergsvassgatan	Järnbrott	Fiskebäck	Hisingen	CCME
naphthalene	0.0031	0.050	<0.0029	<0.0029	0.015	1.1
acenaphthulene						
acenaphthene	0.012	0.960	0.0011	<0.00029	0.031	5.8
fluorene	0.0055	0.160	0.0027	0.00038	0.024	3.0
fenanthrene	0.007	0.071	0.0026	<0.0009	0.040	0.4
anthracene	0.001	0.052	0.0024	0.000026	0.0035	0.012
fluoranthene	0.009	0.250	0.0033	0.00051	0.033	0.04
pyrene	0.0086	0.150	0.0061	0.00064	0.031	0.025
benzo(a)anthracene	0.00073	0.0045	0.00028	0.00015	0.0017	0.018
chrycene	0.0013	0.0052	0.0014	0.00022	0.0082	
benzo(b)fluoranthene	0.0013	0.0018	0.0013	0.00019	0.0053	
benzo(k)fluoranthene	0.00044	0.00062	0.00039	<0.000038	0.0019	
benzo(a)phyrene	0.00079	0.00093	0.00064	<0.000077	0.0023	0.015
dibenzo(ah)anthracene	0.00026	0.00044	0.00053	<0.000096	0.0010	
benzo(ghi)perylene	0.00125	0.0013	0.00029	<0.00029	0.0072	
indeno(123cd)pyrene	<0.00069	<0.00067	<0.00067	<0.00067	0.0025	
Sum carcinogenic PAH						
Sum other PAH						
Sum PAH	0.052	1.70	0.023	0.0021	0.210	

The concentrations are generally lower than the ones given by Carlsson and Johansson (2002) (Table 4) and in the same order of magnitude or lower than the ones given in Table 5. The highest concentrations were found at Gullbergsvassgatan and Hisingen where at least some of the concentrations exceeded the Canadian guidelines. The concentrations at Fiskebäck, the residential area, were very low. As seen from Figure 13 and 14, the concentrations at Gullbergsvassgatan were much higher and are shown in Figure 14. The PAHs at Gullbergsvassgatan could probably originate from the railroad yard in the area. The characteristics of leaching behaviour of old railroad ties impregnated with creosote are shown in Figure 15, illustrating that it is mostly the more dense compounds that are left for leakage.

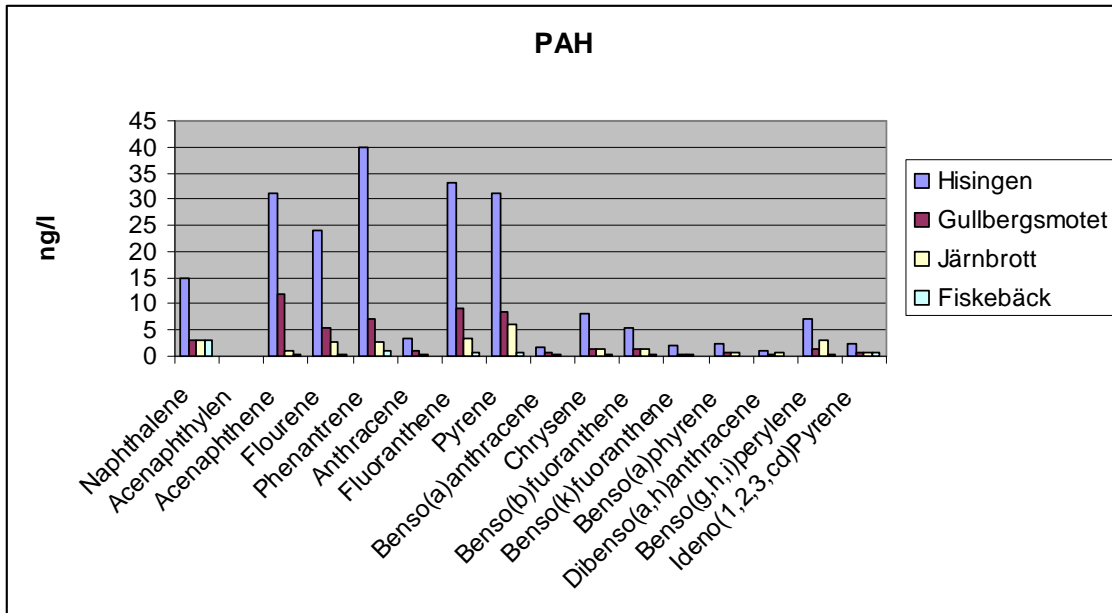


Figure 13. Concentrations of individual PAH at Hisingen, Gullbergsmotet, Järnbrott and Fiskebäck.

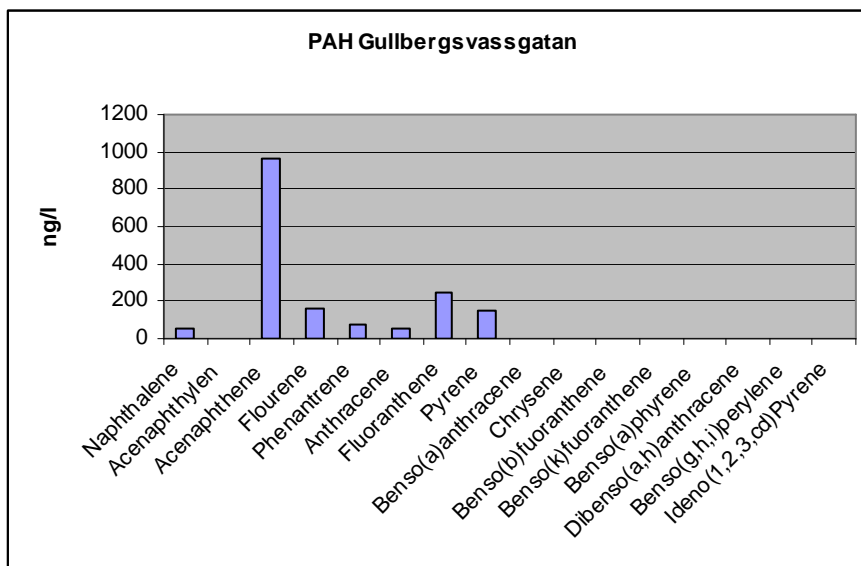


Figure 14. PAH concentrations at Gullbergsvassgatan.

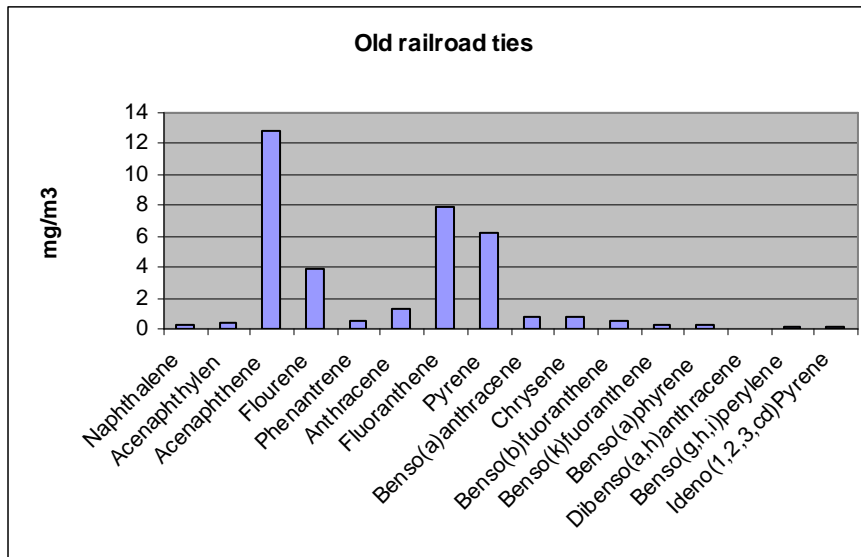


Figure 15. Surface leaching characteristics for old railroad ties impregnated with creosote (Andersson-Sköld et al. 2008).

6 COMPARISON OF WATER QUALITY

The results can give us a clue concerning the degree of pollution of the ground water in the city compared with the background concentrations given in Table 2. As a very rough estimate the compounds in the groundwater have been divided into five groups as shown in Table 11. The table shows that of the metals it is only copper that to a large extent occurs in drainage water from the filling material compared to what is found in groundwaters from background soils.

Table 11 Concentrations in drainage water (filtered samples) within the city compared with background values.

Group	Compounds
Concentrations less than 50 % of background values	Cd, Co, Pb, Zn
Concentrations 50 – 150 % of background values	Fe, Cr, Ni,
Concentrations 1,5 – 3 times background values	Mg, Al, As,
Concentrations 3 – 10 times background values	K, Cu, Mn, conductivity
Concentrations > 10 times background values	Ca, Na, alkalinity

Pollutant standard concentrations in stormwater was calculated by Alm et al. (2010). The calculations were based on long-term sampling over several years, using sampling proportional to the flow. The concentrations, expressed as mean concentrations, are shown in Table 12. As can be seen from the table, the concentrations of metals in the urban groundwater and the drainage water are lower than the concentrations in the stormwater.

Table 12. Calculated standard concentrations in stormwater (Alm et al. 2010), measured concentrations in drainage water (this study, in bold letters), Mattsson (1999), and measured concentrations in urban groundwater (Mossmark 2003).

Land use		P	N	As	Pb	Cu	Zn	Cd	Cr	Ni	Hg	SS	PAH 16	BaP***
		mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	µg/l	µg/l
Back-ground values	From table 2			0.8	1	1.3	22	0.12	0.27	1.7				
Road (5 000 vpd*)	Stormwater (a)	0.14	1.7	2.4	14	31	62	0.24	1	1.2	0.06	79	0.67	0.03
Road (15 000 vpd*)	Stormwater (a)	0.2	2	2.4	21	59	116	0.3	2.6	2.5	0.06	95	1.1	0.035
Road (30 000 vpd*)	Drainage water (GM 2010)	0.02		1.3	0.013	6.9	6.3	0.035	0.17	1.18	0.0026		0.052	0.0008
	Drainage water (GM 1992) (c)				0.29	7.1	20	0.11	8	6.8				
	Stormwater (a)	0.24	2.4	2.4	31	72	197	0.44	5	4.4	0.06	115	1.5	0.042
	Groundwater (b)				0.2	3.2	655	0.2	0.2	35				
Parking area	Stormwater (a)	0.1	1.1	2.4	30	40	140	0.45	15	4	0.05	140	1.7	0.06
Villa area	Stormwater (a)	0.2	1.4	3	10	20	80	0.5	4	6	0015	45	0.6	0.05
Terrace / row house area	Drainage water (F 2010)	0.14		1.4	0.024	5.9	9.6	0.027	0.22	1.4	0.0033		0.0021	0.00007
	Drainage water (F 1992) (c)				0.36	5.1	31	0.5	2	2.6				
	Stormwater (a)	0.25	1.5	3	12	25	85	0.6	6	7	0.02	45	0.6	0.05
Residential area	Drainage water (J 2010)	0.02		0.35	0.027	6.6	13.5	0.019	0.17	1.9	0.0029		0.023	0.0006
	Drainage water (J 1992) (c)				1.6	9.7	45	0.09	4.1	6.5				
	Stormwater (a)	0.3	1.6	3	15	30	100	0.7	12	9	0.025	70	0.6	0.05
	Groundwater (b)					3.2	6180	0.3	0.2	15				
Holiday house area	Stormwater	0.2	3.3	3.3	5	20	80	0.5	2	5	0.015	50	0.3	0.03
Small summer house area	Stormwater (a)	0.15	5	3.3	5	15	50	0.2	0.2	1	0.012	38	0	0
City area	Stormwater (a)	0.28	1.9	2.4	20	22	140	1	5	8.5	0.05	100	0.6	0.1
	Groundwater (b)				0.7	3.5	187	0.03		6.9				
Industrial	Drainage water (GVG 2010)	0.0023		0.6	0.01	0.1	1.4	0.002	0.2	0.38	0.0012		1.7	0.0023
	Drainage water (H 2010)	19		3.9	0.042	8.2	9.3	0.029	0.39	1.1	0.0094		0.21	0.0009
	Stormwater (a)	0.3	1.8	4	30	45	270	1.5	14	16	0.07	100	1	0.15
	Groundwater (b)				0.5	6.3	32	0.1	0.93	32				
Park	Stormwater (a)	0.12	1.2	4	6	15	25	0.3	3	2	0.02	49	0	0
Seas**	Stormwater (a)	0.032	1.5	0.3	3	5	30	0.11	0.17	0.4	0.01	0	1.9	0.01
Woodland	Stormwater (a)	0.035	0.75	4	6	6.5	15	0.2	0.5	0.5	0.005	34	0	0
Farming area	Stormwater (a)	0.22	5.3	4	9	14	20	0.1	1	0.5	0.005	100	0	0
Grass area	Stormwater (a)	0.2	1	4	6	15	30	0.3	2	0.5	0.005	45	0	0
Wetland	Stormwater (a)	0.05	0.9	4	6	7.5	13	0.15	0.15	0.5	0.005	16	0	0

a (Alm et al. 2010), b (Mossmark 2003), c (Mattsson 1999)

*vpd=average daily traffic, vehicles per day

** Atmospheric deposition

*** BaP=benzo(a)pyrene

7 ASSESSMENT OF POLLUTION LOAD FROM GROUNDWATER TO SURFACE WATER

The Göteborg city area amounts to about 198 km², of which 58 km² (30 %) refers to impervious areas and 140 km² (70 %) refers to green spaces (SCB 2010). The infiltration area for groundwater recharge is hence set to 70 % of the total area. Mean annual precipitation during the statistical period 1961-1990 amounted to 758 mm and the mean temperature to 7.7 degrees. A rough estimate of the evapotranspiration can be calculated with Tams formula:

$$E = 221.5 + 29T$$

where E is the evapotranspiration and T the mean temperature. The annual evapotranspiration in the Göteborg area can be calculated to 445 mm and the annual recharge of groundwater to approximately 300 mm. Within the Göteborg city, the annual groundwater recharge can be estimated to $198 \cdot 10^6 \text{ m}^2 \cdot 70 \% \cdot 0.3 \text{ m} = 41 \cdot 10^6 \text{ m}^3$. If the runoff coefficient is set to 0.85 (which is the value used by Alm et al. (2010) for roads and parking lots) for the impervious surfaces, the annual amount of stormwater can be calculated to $198 \cdot 10^6 \text{ m}^2 \cdot 30 \% \cdot 0.758 \text{ m} \cdot 0.85 = 38 \cdot 10^6 \text{ m}^3$.

However, 39 km² of the Göteborg city have a combined stormwater and sewage water system (Jansson 2011) where both types of water is lead to the sewage water treatment plant. The actual annual amount of stormwater lead directly to the river, the tributaries or the estuary is hence $(198 \text{ km}^2 - 39 \text{ km}^2) \cdot 30 \% \cdot 10^6 \cdot 0.76 \text{ m} \cdot 0.85 = 31 \cdot 10^6 \text{ m}^3$.

Between year 2001-2010 the annual mean water flow in Göta River varied from 145 m³/s to 235 m³/s (Göteborgs vattenvårdsförbund 2010). The 10-year mean amounts to 170 m³/s, or $5.3 \cdot 10^9 \text{ m}^3/\text{year}$.

Measured mean concentrations in the drainage water 2010 are given in Table 13. Results are given for both filtered samples and unfiltered and digested samples. The concentrations are compared with mean concentrations for stormwater from the same types of areas (road 30000 vpd, terracehouse area, residential area and industrial area) given in Table 12. Comparisons are also made with background concentration and concentrations in Göta River at Alelyckan fresh water intake.

The pollution load given in Table 13 are calculated from the concentrations and corresponding water flows. Table 13 indicates that leakage of metals from the filling material is not generally a great problem. Only for copper and arsenic the leakage is significantly higher than for natural soils surrounding Göteborg. The main contribution of metals and PAH to the Göta River from the city seems to emanate from the stormwater. However the huge volume of water also make the Göta River an important contributor to the total load to the estuary.

Table 13. Concentrations in various waters ($\mu\text{g/l}$).

	Back-ground values	Drainage water filtered (this study)	Drainage water unfiltered digested (this study)	Stormwater baseflow (1)	Storm water (2)	Treated sewage water (3)	Göta River (4)
As	0.8	1.51	2.51		3.1		0.28
Pb	1	0.023	1.26	1.4	22	0.24	0.35
Cu	1.3	5.5	7.56	6.6	43	9.2	1.33
Zn	22	8	20.4	24	160	11	3.7
Cd	0.12	0.022	0.06	0.05	0.8	0.01	0.009
Cr	0.27	0.23	1.1	1.4	6.8	0.82	0.34
Ni	1.7	1.12	1.77	3.1	9.1	4.1	0.76
Hg		0.0039			0.044	0.02	0.00159
PAH 16		0.4			0.93		
BaP		0.0008			0.07		

(1)Arwidsson 2011. Stormwater baseflow is defined as the water present in storm water ditches and storm water pipes after a storm water peak.

(2)Alm et al. 2010

(3)GRYAAB 2011

(4)Göta älvs Vattenvårdsförbund 2011

Table 14. Pollution load from various waters to the estuary (kg/year).

Elements	Transport (kg/year)					
	Background values (provided the drainage water would have had the same concentrations as the background values)	Drainage water filtered (this study)	Drainage water unfiltered digested (this study)	Storm-water	Treated sewage water (1)	Göta River at Alelyckan
Water m ³ /s	1.3	1.3	1.3	1	3.7	170
water, million m ³ /year	41	41	41	31	118	5300
As	32.8	61.91	102.91	95	88	1484
Pb	41	0.94	51.66	680	34	1855
Cu	53.3	225.5	309.96	1300	1122	7049
Zn	902	328	836.4	5100	1445	19610
Cd	4.92	0.90	2.46	25	1.4	47.7
Cr	11.07	9.43	45.1	210	100	1802
Ni	69.7	45.9	72.57	280	488	4028
Hg		0.16		1.4	2	8.43
PAH 16		16.4		29	12	
BaP		0.03		2.2		

(1)GRYAAB 2011

8 DISCUSSION

In this part of the diPol-project we have focused on the contribution from urban shallow groundwater to the overall water quality in the estuary. Samples were taken from stormwater pipes during periods of little or no precipitation in order to obtain representative samples for large areas without having a large number of monitoring wells. This approach provides some uncertainties though as sewage water or drinking water from leaking pipes systems may leak into the storm water pipes. The pipe material itself may contribute to pollutants, and solution

and desorption of pollutants from sediments within the pipe system may be other sources of error.

Comparisons have been made with earlier analyses from stormwater pipes and from monitoring wells within the Göteborg area. The correlations are in most cases fair, that is to say within the same order of magnitude. Taking samples of drainage water is therefore considered to be a useful method to estimate the concentrations of pollutants in shallow urban groundwater. Comparisons have also been made with earlier analyses from observation wells in natural soil in the outskirts of Göteborg. In most cases it has not been able to gain information on data concerning the observation wells such as exact location, soil material and depth. It is also unclear whether the samples have been filtered or digested before analyses.

It can also be discussed whether groundwater is best represented by filtered or unfiltered samples. In the case of groundwater, particles larger than 0.45 μm are often regarded as artefacts caused by the sampling technique. On the other hand the environment in the pipe system may lead to precipitation of metals and filtering may lead to an underestimation of the metal content. Regardless of if filtered or unfiltered samples are used for the transport calculations, the stormwater seems to be the largest contributor of metals and PAH from the city to the surface water.

Although low background concentrations were chosen in order not to underestimate pollution this project indicates that leaking of pollutants from the filling material in the city is not generally a major problem. Only for copper and arsenic the leakage is significantly higher than for natural soils surrounding Göteborg

Only a few new samples were taken in this study and it has not been possible to account for seasonal variations of the water quality. More samples and analyses are hence needed to confirm the results. In addition, there are great needs for long time observations from well documented sampling points and analyses techniques.

9 CONCLUSIONS

Taking samples from drainage water (stormwater pipes during periods with little or no precipitation) is considered to be a useful method to estimate the concentrations of pollutants in shallow urban groundwater, although there are several sources of error. A good knowledge of the stormwater pipe system is required and suitable sampling points can be hard to find.

This project indicates that leaking of pollutants from the filling material in the city is not a major problem. Only for copper and arsenic the leakage is significantly higher than for natural soils surrounding Göteborg. This should however not be a pretext to reduce the remediation of contaminated sites which may have significantly higher amounts of pollutants than the investigated areas.

The main contribution of metals and PAH to the Göta River from the city seems to emanate from the stormwater. Thus, a good strategy to prevent pollution of the Göta River estuary from the city is to take further measures to reduce the pollutants in the stormwater, preferably by action at the pollution sources, traffic and air pollution. However, more thorough investigations are needed to confirm the above conclusions.

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APPENDIX

Analysis results and procedures

Projekt
 Bestnr
 Registrerad **2010-06-23**
 Utfärdad **2010-07-07**

SGI
Thomas Rihm

Chalmers Vasa Hus 5
412 96 Göteborg

Analys av vatten

Er beteckning	GM					
	2010-06-17					
Labnummer	O10323384					
Parameter	Resultat	Osäkerhet (\pm)	Enhet	Metod	Utf	Sign
filtrering 0,45 μ m; metaller*	JA			1	1	AKR
Ca	79.7	9.6	mg/l	2	E	AKR
Fe	0.0064	0.0012	mg/l	2	H	AKR
K	19.2	2.3	mg/l	2	E	AKR
Mg	22.9	2.8	mg/l	2	E	AKR
Na	305	41	mg/l	2	E	AKR
Si	6.91	1.01	mg/l	2	E	AKR
Al	5.92	1.17	μ g/l	2	H	AKR
As	1.30	0.24	μ g/l	2	H	AKR
Ba	54.9	6.7	μ g/l	2	E	AKR
Cd	0.0349	0.0062	μ g/l	2	H	AKR
Co	0.252	0.071	μ g/l	2	H	AKR
Cr	0.166	0.147	μ g/l	2	H	AKR
Cu	6.97	1.19	μ g/l	2	H	AKR
Hg	<0.002		μ g/l	2	F	AKR
Mn	205	25	μ g/l	2	E	AKR
Mo	2.93	0.52	μ g/l	2	H	AKR
Ni	1.18	0.32	μ g/l	2	H	AKR
P	22.7	4.4	μ g/l	2	H	AKR
Pb	0.0133	0.0086	μ g/l	2	H	AKR
Sr	310	39	μ g/l	2	E	AKR
Zn	6.26	1.15	μ g/l	2	H	AKR
Sb	0.605	0.136	μ g/l	3	H	AKR
B	208	32	μ g/l	3	E	AKR
Sn	<0.05		μ g/l	3	H	AKR
Ag	<0.05		μ g/l	3	H	AKR
Bi*	<0.005		μ g/l	3	S	AKR
monobutyltenn	46		ng/l	4	2	ANFR
dibutyltenn	<1.0		ng/l	4	2	ANFR
tributyltenn	<1.0		ng/l	4	2	ANFR
tetrabutyltenn	<1.0		ng/l	4	2	ANFR
monooktyltenn	<1.0		ng/l	4	2	ANFR
dioktyltenn	<1.0		ng/l	4	2	ANFR
tricyklohexyltenn	<1.0		ng/l	4	2	ANFR
monofenyltenn	<1.0		ng/l	4	2	ANFR
difenyltenn	<1.0		ng/l	4	2	ANFR
trifenyltenn	<1.0		ng/l	4	2	ANFR
dimetylftalat	<0.60		μ g/l	5	3	AKR
dietylftalat	<0.60		μ g/l	5	3	AKR
di-n-propylftalat	<0.60		μ g/l	5	3	AKR
di-n-butylftalat	<0.60		μ g/l	5	3	AKR
di-isobutylftalat	<0.60		μ g/l	5	3	AKR
di-pentylftalat	<0.60		μ g/l	5	3	AKR
di-n-oktylftalat	<0.60		μ g/l	5	3	AKR



Er beteckning	GM 2010-06-17					
Labnummer	O10323384					
Parameter	Resultat	Osäkerhet (\pm)	Enhet	Metod	Utf	Sign
di-(2-etylhexyl)ftalat	<1.3		$\mu\text{g/l}$	5	3	AKR
butylbensylftalat	<0.60		$\mu\text{g/l}$	5	3	AKR
di-cyklohexylftalat	<0.60		$\mu\text{g/l}$	5	3	AKR
pH	8.1			6	0	JOTA
konduktivitet	220		mS/m	7	0	JOTA
alkalinitet	240		mg HCO ₃ /l	8	0	JOTA
ammonium	0.394	0.079	mg/l	9	3	AKR
nitrat	7.17	1.43	mg/l	10	3	AKR
klorid	639	128	mg/l	11	3	AKR
CODCr	25.0	7.5	mg/l	12	3	AKR
DOC	5.97	1.19	mg/l	13	3	AKR
TOC	7.79	1.56	mg/l	14	3	AKR
N-tot	2.20	0.66	mg/l	15	3	AKR
P-tot	0.071	0.014	mg/l	16	3	AKR
suspenderad substans	7.2	1.4	mg/l	17	3	AKR

Er beteckning	GVG					
	2010-06-17					
Labnummer	O10323385					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
filtrering 0,45µm; metaller*	JA			1	1	AKR
Ca	182	22	mg/l	2	E	AKR
Fe	0.0087	0.0016	mg/l	2	H	AKR
K	15.8	1.9	mg/l	2	E	AKR
Mg	15.6	1.9	mg/l	2	E	AKR
Na	277	37	mg/l	2	E	AKR
Si	12.2	1.8	mg/l	2	E	AKR
Al	<0.2		µg/l	2	H	AKR
As	<0.6		µg/l	2	H	AKR
Ba	175	21	µg/l	2	E	AKR
Cd	<0.002		µg/l	2	H	AKR
Co	0.131	0.032	µg/l	2	H	AKR
Cr	0.195	0.039	µg/l	2	H	AKR
Cu	0.105	0.028	µg/l	2	H	AKR
Hg	<0.002		µg/l	2	F	AKR
Mn	1240	219	µg/l	2	H	AKR
Mo	1.08	0.20	µg/l	2	H	AKR
Ni	0.384	0.091	µg/l	2	H	AKR
P	2.34	0.74	µg/l	2	H	AKR
Pb	<0.01		µg/l	2	H	AKR
Sr	534	66	µg/l	2	E	AKR
Zn	1.42	0.30	µg/l	2	H	AKR
Sb	0.413	0.091	µg/l	3	H	AKR
B	170	26	µg/l	3	E	AKR
Sn	0.297	0.082	µg/l	3	H	AKR
Ag	<0.05		µg/l	3	H	AKR
Bi*	<0.005		µg/l	3	S	AKR
monobutyltenn	15		ng/l	4	2	ANFR
dibutyltenn	2.0		ng/l	4	2	ANFR
tributyltenn	2.7		ng/l	4	2	ANFR
tetrabutyltenn	<1.0		ng/l	4	2	ANFR
monooktyltenn	<1.0		ng/l	4	2	ANFR
dioktyltenn	<1.0		ng/l	4	2	ANFR
tricyklohexyltenn	<1.0		ng/l	4	2	ANFR
monofenyltenn	<1.0		ng/l	4	2	ANFR
difenyltenn	<1.0		ng/l	4	2	ANFR
trifenyltenn	<1.0		ng/l	4	2	ANFR
dimetylftalat	<0.60		µg/l	5	3	AKR
dietylftalat	<0.60		µg/l	5	3	AKR
di-n-propylftalat	<0.60		µg/l	5	3	AKR
di-n-butylftalat	<0.60		µg/l	5	3	AKR
di-isobutylftalat	<0.60		µg/l	5	3	AKR
di-pentylftalat	<0.60		µg/l	5	3	AKR
di-n-oktylftalat	<0.60		µg/l	5	3	AKR
di-(2-etylhexyl)ftalat	<1.3		µg/l	5	3	AKR
butylbensylftalat	<0.60		µg/l	5	3	AKR
di-cyklohexylftalat	<0.60		µg/l	5	3	AKR
pH	7.3			6	O	JOTA
konduktivitet	234		mS/m	7	O	JOTA
alkalinitet*	502		mg HCO3/l	18	2	CL
ammonium	2.29	0.458	mg/l	9	3	AKR
nitrat	2.22	0.44	mg/l	10	3	AKR
klorid	612	122	mg/l	11	3	AKR



Er beteckning	GVG 2010-06-17					
Labnummer	O10323385					
Parameter	Resultat	Osäkerhet (\pm)	Enhet	Metod	Utf	Sign
CODCr	33.0	9.9	mg/l	12	3	AKR
DOC	10.6	2.12	mg/l	13	3	AKR
TOC	10.7	2.14	mg/l	14	3	AKR
N-tot	2.10	0.63	mg/l	15	3	AKR
P-tot	0.159	0.032	mg/l	16	3	AKR
suspenderad substans	51.7	10.3	mg/l	17	3	AKR
As: Förhöjd rapporteringsgräns pga kloridstörning						

Er beteckning	Järnbrott 2010-06-17					
Labnummer	O10323386					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
filtrering 0,45µm; metaller*	JA			1	1	AKR
Ca	54.8	6.6	mg/l	2	E	AKR
Fe	0.0337	0.0059	mg/l	2	H	AKR
K	7.09	0.89	mg/l	2	E	AKR
Mg	9.09	1.12	mg/l	2	E	AKR
Na	102	14	mg/l	2	E	AKR
Si	5.45	0.79	mg/l	2	E	AKR
Al	4.72	0.99	µg/l	2	H	AKR
As	0.349	0.084	µg/l	2	H	AKR
Ba	31.5	3.9	µg/l	2	E	AKR
Cd	0.0190	0.0049	µg/l	2	H	AKR
Co	0.0960	0.0200	µg/l	2	H	AKR
Cr	0.165	0.036	µg/l	2	H	AKR
Cu	6.57	1.13	µg/l	2	H	AKR
Hg	<0.002		µg/l	2	F	AKR
Mn	2.91	0.53	µg/l	2	H	AKR
Mo	2.25	0.40	µg/l	2	H	AKR
Ni	1.87	0.36	µg/l	2	H	AKR
P	19.7	3.7	µg/l	2	H	AKR
Pb	0.0266	0.0097	µg/l	2	H	AKR
Sr	173	21	µg/l	2	E	AKR
Zn	13.5	2.5	µg/l	2	H	AKR
Sb	0.525	0.125	µg/l	3	H	AKR
B	62.0	11.0	µg/l	3	E	AKR
Sn	<0.05		µg/l	3	H	AKR
Ag	<0.05		µg/l	3	H	AKR
Bi*	<0.005		µg/l	3	S	AKR
monobutyltenn	50		ng/l	4	2	ANFR
dibutyltenn	<1.0		ng/l	4	2	ANFR
tributyltenn	<1.0		ng/l	4	2	ANFR
tetrabutyltenn	<1.0		ng/l	4	2	ANFR
monooktyltenn	<1.0		ng/l	4	2	ANFR
dioktyltenn	<1.0		ng/l	4	2	ANFR
tricyklohexyltenn	<1.0		ng/l	4	2	ANFR
monofenyltenn	<1.0		ng/l	4	2	ANFR
difenyltenn	<1.0		ng/l	4	2	ANFR
trifenyltenn	<1.0		ng/l	4	2	ANFR
dimetylftalat	<0.60		µg/l	5	3	AKR
dietylftalat	<0.60		µg/l	5	3	AKR
di-n-propylftalat	<0.60		µg/l	5	3	AKR
di-n-butylftalat	<0.60		µg/l	5	3	AKR
di-isobutylftalat	<0.60		µg/l	5	3	AKR
di-pentylftalat	<0.60		µg/l	5	3	AKR
di-n-oktylftalat	<0.60		µg/l	5	3	AKR
di-(2-etylhexyl)ftalat	<1.3		µg/l	5	3	AKR
butylbensylftalat	<0.60		µg/l	5	3	AKR
di-cyklohexylftalat	<0.60		µg/l	5	3	AKR
pH	7.5			6	O	JOTA
konduktivitet	88.7		mS/m	7	O	JOTA
alkalinitet	150		mg HCO ₃ /l	8	O	JOTA
ammonium	0.347	0.069	mg/l	9	3	AKR
nitrat	5.80	1.16	mg/l	10	3	AKR
klorid	174	34.8	mg/l	11	3	AKR



Er beteckning	Järnbrott 2010-06-17					
Labnummer	O10323386					
Parameter	Resultat	Osäkerhet (\pm)	Enhet	Metod	Utf	Sign
CODCr	22.0	6.6	mg/l	12	3	AKR
DOC	6.58	1.32	mg/l	13	3	AKR
TOC	6.92	1.38	mg/l	14	3	AKR
N-tot	2.39	0.72	mg/l	15	3	AKR
P-tot	0.065	0.013	mg/l	16	3	AKR
suspenderad substans	<5.0		mg/l	17	3	AKR

Er beteckning	F					
	2010-06-17					
Labnummer	O10323387					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
filtrering 0,45µm; metaller*	JA			1	1	AKR
Ca	45.5	5.4	mg/l	2	E	AKR
Fe	0.0338	0.0059	mg/l	2	H	AKR
K	6.18	0.76	mg/l	2	E	AKR
Mg	8.77	1.08	mg/l	2	E	AKR
Na	54.8	7.3	mg/l	2	E	AKR
Si	6.60	0.96	mg/l	2	E	AKR
Al	30.7	5.2	µg/l	2	H	AKR
As	1.38	0.25	µg/l	2	H	AKR
Ba	21.0	2.6	µg/l	2	E	AKR
Cd	0.0272	0.0049	µg/l	2	H	AKR
Co	0.104	0.021	µg/l	2	H	AKR
Cr	0.223	0.043	µg/l	2	H	AKR
Cu	5.92	1.02	µg/l	2	H	AKR
Hg	<0.002		µg/l	2	F	AKR
Mn	21.5	3.8	µg/l	2	H	AKR
Mo	3.19	0.56	µg/l	2	H	AKR
Ni	1.41	0.24	µg/l	2	H	AKR
P	141	26	µg/l	2	H	AKR
Pb	0.0243	0.0094	µg/l	2	H	AKR
Sr	160	20	µg/l	2	E	AKR
Zn	9.55	1.75	µg/l	2	H	AKR
Sb	0.303	0.067	µg/l	3	H	AKR
B	116	18	µg/l	3	E	AKR
Sn	<0.05		µg/l	3	H	AKR
Ag	<0.05		µg/l	3	H	AKR
Bi*	<0.005		µg/l	3	S	AKR
monobutyltenn	26		ng/l	4	2	ANFR
dibutyltenn	<1.0		ng/l	4	2	ANFR
tributyltenn	4.1		ng/l	4	2	ANFR
tetrabutyltenn	<1.0		ng/l	4	2	ANFR
monooktyltenn	<1.0		ng/l	4	2	ANFR
dioktyltenn	<1.0		ng/l	4	2	ANFR
tricyklohexyltenn	<1.0		ng/l	4	2	ANFR
monofenyltenn	<1.0		ng/l	4	2	ANFR
difenyltenn	<1.0		ng/l	4	2	ANFR
trifenyltenn	<1.0		ng/l	4	2	ANFR
dimetylfatalat	<0.60		µg/l	5	3	AKR
dietylfatalat	<0.60		µg/l	5	3	AKR
di-n-propylfatalat	<0.60		µg/l	5	3	AKR
di-n-butylfatalat	<0.60		µg/l	5	3	AKR
di-isobutylfatalat	<0.60		µg/l	5	3	AKR
di-pentylfatalat	<0.60		µg/l	5	3	AKR
di-n-oktylfatalat	<0.60		µg/l	5	3	AKR
di-(2-etylhexyl)fatalat	<1.3		µg/l	5	3	AKR
butylbensylfatalat	<0.60		µg/l	5	3	AKR
di-cyklohexylfatalat	<0.60		µg/l	5	3	AKR
pH	8.0			6	O	JOTA
konduktivitet	58.8		mS/m	7	O	JOTA
alkalinitet	160		mg HCO ₃ /l	8	O	JOTA
ammonium	0.451	0.090	mg/l	9	3	AKR
nitrat	9.41	1.88	mg/l	10	3	AKR
klorid	75.1	15.0	mg/l	11	3	AKR



Er beteckning	F 2010-06-17					
Labnummer	O10323387					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
CODCr	23.0	6.9	mg/l	12	3	AKR
DOC	6.40	1.28	mg/l	13	3	AKR
TOC	6.51	1.30	mg/l	14	3	AKR
N-tot	3.26	0.98	mg/l	15	3	AKR
P-tot	0.149	0.030	mg/l	16	3	AKR
suspenderad substans	<5.0		mg/l	17	3	AKR

Er beteckning	H 2010-06-17					
Labnummer	O10323388					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
filtrering 0,45µm; metaller*	JA			1	1	AKR
Ca	34.9	4.2	mg/l	2	E	AKR
Fe	0.146	0.019	mg/l	2	E	AKR
K	6.30	0.97	mg/l	2	E	AKR
Mg	6.44	0.80	mg/l	2	E	AKR
Na	137	18	mg/l	2	E	AKR
Si	14.3	2.1	mg/l	2	E	AKR
Al	36.1	6.1	µg/l	2	H	AKR
As	3.91	0.67	µg/l	2	H	AKR
Ba	4.28	0.74	µg/l	2	H	AKR
Cd	0.0296	0.0052	µg/l	2	H	AKR
Co	0.280	0.065	µg/l	2	H	AKR
Cr	0.392	0.070	µg/l	2	H	AKR
Cu	8.18	1.40	µg/l	2	H	AKR
Hg	0.0022	0.0007	µg/l	2	F	AKR
Mn	130	16	µg/l	2	E	AKR
Mo	1.19	0.21	µg/l	2	H	AKR
Ni	1.10	0.20	µg/l	2	H	AKR
P	19400	2380	µg/l	2	E	AKR
Pb	0.0421	0.0110	µg/l	2	H	AKR
Sr	68.0	8.5	µg/l	2	E	AKR
Zn	9.28	1.88	µg/l	2	H	AKR
Sb	0.682	0.150	µg/l	3	H	AKR
B	209	32	µg/l	3	E	AKR
Sn	0.0639	0.0411	µg/l	3	H	AKR
Ag	<0.05		µg/l	3	H	AKR
Bi*	<0.005		µg/l	3	S	AKR
monobutyltenn	50		ng/l	4	2	ANFR
dibutyltenn	2.5		ng/l	4	2	ANFR
tributyltenn	1.4		ng/l	4	2	ANFR
tetrabutyltenn	<1.0		ng/l	4	2	ANFR
monooktyltenn	<1.0		ng/l	4	2	ANFR
dioktyltenn	<1.0		ng/l	4	2	ANFR
tricyklohexyltenn	<1.0		ng/l	4	2	ANFR
monofenyltenn	<1.0		ng/l	4	2	ANFR
difenyltenn	<1.0		ng/l	4	2	ANFR
trifenyltenn	<1.0		ng/l	4	2	ANFR
dimetylfталат	<0.60		µg/l	5	3	AKR
dietylfталат	2.59	0.91	µg/l	5	3	AKR
di-n-propylfталат	<0.60		µg/l	5	3	AKR
di-n-butylfталат	1.73	0.60	µg/l	5	3	AKR
di-isobutylfталат	2.06	0.72	µg/l	5	3	AKR
di-pentylfталат	<0.60		µg/l	5	3	AKR
di-n-oktylfталат	<0.60		µg/l	5	3	AKR
di-(2-etylhexyl)fталат	19.2	6.7	µg/l	5	3	AKR
butylbensylfталат	0.83	0.29	µg/l	5	3	AKR
di-cyklohexylfталат	<0.60		µg/l	5	3	AKR
pH	8.0			6	O	JOTA
konduktivitet	81.9		mS/m	7	O	JOTA
alkalinitet	290		mg HCO3/l	8	O	KABJ
ammonium	<0.050		mg/l	9	3	AKR
nitrat	<2.00		mg/l	10	3	AKR
klorid	105	21.0	mg/l	11	3	AKR



Er beteckning	H 2010-06-17					
Labnummer	O10323388					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
CODCr	116	34.8	mg/l	12	3	AKR
DOC	24.2	4.84	mg/l	13	3	AKR
TOC	26.5	5.30	mg/l	14	3	AKR
N-tot	2.17	0.65	mg/l	15	3	AKR
P-tot	35.3	7.05	mg/l	16	3	AKR
suspenderad substans	65.4	13.1	mg/l	17	3	AKR

Er beteckning	GM. 2010-06-17					
Labnummer	O10323389					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
Ca	84.7	9.0	mg/l	19	E	AKR
Fe	1.36	0.12	mg/l	19	E	AKR
K	21.3	1.8	mg/l	19	E	AKR
Mg	24.6	2.2	mg/l	19	E	AKR
Na	339	29	mg/l	19	E	AKR
Al	488	65	µg/l	19	E	AKR
As	2.21	0.87	µg/l	19	H	AKR
Ba	69.5	6.0	µg/l	19	E	AKR
Cd	<0.05		µg/l	19	H	AKR
Co	0.496	0.149	µg/l	19	H	AKR
Cr	<0.9		µg/l	19	H	AKR
Cu	5.30	1.30	µg/l	19	H	AKR
Hg	<0.02		µg/l	19	F	AKR
Mn	257	24	µg/l	19	E	AKR
Ni	1.69	0.55	µg/l	19	H	AKR
Pb	0.768	0.231	µg/l	19	H	AKR
Zn	13.0	4.8	µg/l	19	H	AKR
Sb	0.613	0.175	µg/l	3	H	AKR
Mo	2.77	1.02	µg/l	3	H	AKR
B	225	22	µg/l	3	E	AKR
Sn	<0.5		µg/l	3	H	AKR
Ag	<0.5		µg/l	3	H	AKR
Bi*	<0.05		µg/l	3	S	AKR

Er beteckning	GVG. 2010-06-17					
Labnummer	O10323390					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
Ca	185	20	mg/l	19	E	AKR
Fe	24.8	2.2	mg/l	19	E	AKR
K	17.0	1.4	mg/l	19	E	AKR
Mg	16.3	1.5	mg/l	19	E	AKR
Na	291	25	mg/l	19	E	AKR
Al	<50		µg/l	19	H	AKR
As	1.65	0.78	µg/l	19	H	AKR
Ba	288	23	µg/l	19	E	AKR
Cd	<0.05		µg/l	19	H	AKR
Co	0.201	0.218	µg/l	19	H	AKR
Cr	<0.9		µg/l	19	H	AKR
Cu	1.22	0.68	µg/l	19	H	AKR
Hg	<0.02		µg/l	19	F	AKR
Mn	1340	123	µg/l	19	E	AKR
Ni	<0.6		µg/l	19	H	AKR
Pb	<0.6		µg/l	19	H	AKR
Zn	4.68	3.40	µg/l	19	H	AKR
Sb	0.619	0.196	µg/l	3	H	AKR
Mo	1.11	0.91	µg/l	3	H	AKR
B	182	19	µg/l	3	E	AKR
Sn	<0.5		µg/l	3	H	AKR
Ag	<0.5		µg/l	3	H	AKR
Bi*	<0.05		µg/l	3	S	AKR

Er beteckning	Järnbrott. 2010-06-17					
Labnummer	O10323391					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
Ca	54.1	5.8	mg/l	19	E	AKR
Fe	0.807	0.074	mg/l	19	E	AKR
K	7.41	0.65	mg/l	19	E	AKR
Mg	9.53	0.85	mg/l	19	E	AKR
Na	105	9	mg/l	19	E	AKR
Al	140	26	µg/l	19	H	AKR
As	1.19	0.71	µg/l	19	H	AKR
Ba	37.5	3.8	µg/l	19	E	AKR
Cd	<0.05		µg/l	19	H	AKR
Co	0.317	0.143	µg/l	19	H	AKR
Cr	<0.9		µg/l	19	H	AKR
Cu	9.67	2.30	µg/l	19	H	AKR
Hg	<0.02		µg/l	19	F	AKR
Mn	100	9	µg/l	19	E	AKR
Ni	2.36	0.97	µg/l	19	H	AKR
Pb	0.790	0.235	µg/l	19	H	AKR
Zn	21.7	5.3	µg/l	19	H	AKR
Sb	0.548	0.194	µg/l	3	H	AKR
Mo	2.22	0.97	µg/l	3	H	AKR
B	67.8	12.2	µg/l	3	E	AKR
Sn	<0.5		µg/l	3	H	AKR
Ag	<0.5		µg/l	3	H	AKR
Bi*	<0.05		µg/l	3	S	AKR

Er beteckning	F. 2010-06-17					
Labnummer	O10323392					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
Ca	46.6	5.0	mg/l	19	E	AKR
Fe	0.411	0.078	mg/l	19	H	AKR
K	7.06	0.62	mg/l	19	E	AKR
Mg	9.56	0.86	mg/l	19	E	AKR
Na	57.2	5.0	mg/l	19	E	AKR
Al	259	45	µg/l	19	E	AKR
As	1.19	0.71	µg/l	19	H	AKR
Ba	26.8	3.2	µg/l	19	E	AKR
Cd	<0.05		µg/l	19	H	AKR
Co	0.297	0.221	µg/l	19	H	AKR
Cr	<0.9		µg/l	19	H	AKR
Cu	6.21	1.30	µg/l	19	H	AKR
Hg	<0.02		µg/l	19	F	AKR
Mn	40.6	4.0	µg/l	19	E	AKR
Ni	1.64	0.89	µg/l	19	H	AKR
Pb	<0.6		µg/l	19	H	AKR
Zn	18.1	4.7	µg/l	19	H	AKR
Sb	0.348	0.160	µg/l	3	H	AKR
Mo	3.17	1.05	µg/l	3	H	AKR
B	127	15	µg/l	3	E	AKR
Sn	1.13	1.00	µg/l	3	H	AKR
Ag	<0.5		µg/l	3	H	AKR
Bi*	<0.05		µg/l	3	S	AKR

Er beteckning	H. 2010-06-17					
Labnummer	O10323393					
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
Ca	35.4	3.8	mg/l	19	E	AKR
Fe	4.06	0.37	mg/l	19	E	AKR
K	7.50	0.66	mg/l	19	E	AKR
Mg	7.12	0.64	mg/l	19	E	AKR
Na	137	12	mg/l	19	E	AKR
Al	812	81	µg/l	19	E	AKR
As	6.34	1.81	µg/l	19	H	AKR
Ba	34.4	3.6	µg/l	19	E	AKR
Cd	0.0854	0.0375	µg/l	19	H	AKR
Co	0.652	0.171	µg/l	19	H	AKR
Cr	1.82	0.45	µg/l	19	H	AKR
Cu	15.4	2.9	µg/l	19	H	AKR
Hg	<0.02		µg/l	19	F	AKR
Mn	204	19	µg/l	19	E	AKR
Ni	2.55	0.88	µg/l	19	H	AKR
Pb	3.55	0.63	µg/l	19	H	AKR
Zn	14.7	8.7	µg/l	19	H	AKR
Sb	1.06	0.27	µg/l	3	H	AKR
Mo	1.27	0.92	µg/l	3	H	AKR
B	209	21	µg/l	3	E	AKR
Sn	0.701	0.975	µg/l	3	H	AKR
Ag	<0.5		µg/l	3	H	AKR
Bi*	0.335		µg/l	3	S	AKR

* efter parameternamn indikerar icke ackrediterad analys.

	Metod
1	Filtrering; 0,45 µm
2	<p>Bestämning av metaller utan föregående uppslutning. Provet har surgjorts med 1 ml salpetersyra (Suprapur) per 100 ml. Detta gäller dock ej prov som varit surgjort vid ankomst till laboratoriet. Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SFMS).</p> <p>Analys av Hg med AFS har skett enligt SS-EN 13506 (modifierad). Vid analys av W har provet ej surgjorts. Vid analys av Se har provet uppslutits med HCl i autoklav. Om S har analyserats så har provet först stabiliserats med H₂O₂.</p>
3	Tillägg av metaller till befintligt paket.
4	<p>Paket OV-19A. Bestämning av tennorganiska föreningar enligt metod DIN EN ISO 17353 (F13). Mätning utförs med GC-FPD.</p>
5	<p>Paket OV-4. Bestämning av ftalater, enligt metod baserad på EPA 8061, 3510. Extraktion med diklormetan, därefter svavelborttagning med kvicksilver. Mätning utförs med GC-MS.</p>
6	<p>Bestämning av pH enligt SS 028122 utg 2 modifierad pH vid 25±2°C bestäms potentiometriskt med pH-meter och temperaturkompensering.</p> <p>Mätosäkerhet (k=2): Renvatten: ±0.14 vid pH 6.87 Avloppsvatten: ±0.14 vid pH 6.87</p>
7	<p>Bestämning av Konduktivitet enligt SS-EN 27888 utg 1 Direkt bestämning av vattnets elektriska ledningsförmåga vid 25°C.</p> <p>Mätosäkerhet (k=2): Renvatten: ±7% vid 14.7 mS/m och ±7% vid 141 mS/m Avloppsvatten: ±9% vid 14.7 mS/m och ±9% vid 141 mS/m</p>
8	<p>Bestämning av alkalinitet enligt SS-EN ISO 9963-2 utg 1 Provet titreras med saltsyra under avdrivande av koldioxid till slutpunkten pH 5.4.</p> <p>Mätosäkerhet (k=2): Renvatten: ±12% vid 24 mg/l eller 0.4 mekv/l och ±8% vid 220 mg/l eller 3.7 mekv/l</p>
9	<p>Bestämning av ammonium med FIA och spektrofotometrisk detektor enligt CSN ISO 11732. Filtrering av grumlige prover ingår i metoden.</p>
10	<p>Bestämning av nitrat med jonkromatografi enligt metod baserad på CSN ISO 10304-1&2. Filtrering av grumlige prover ingår i metoden.</p>
11	<p>Bestämning av klorid med jonkromatografi enligt CSN ISO 10304-1&2.</p> <p>Filtrering av grumlige prover ingår i metoden.</p>
12	Bestämning av COD _{Cr} enligt metod CSN ISO 15705.

13	Bestämning av DOC enligt metod baserad på CSN EN 1484.
14	Bestämning av TOC enligt metod baserad på CSN EN 1484.
15	Bestämning av totalkväve, N-tot, enligt EN 12260. Bestämning av kväve med IR detektion.
16	Bestämning av totalfosfor, P-tot, med spektrofotometri enligt CSN EN ISO 6878.
17	Bestämning av suspenderande ämnen. Metoden är baserad på CSN EN 872. Filtrering utförs med glasfiberfilter; porstorlek 1,5 µm.
18	Bestämning av alkalinitet enligt DIN EN ISO 9963.
19	Bestämning av metaller. Upplösning och analys av vattenprov, 12 ml prov och 1,2 ml HNO ₃ (suprapur) har behandlats i autoklav. Vid analys av Ag har upplösning skett med HCl i mikrovågsugn. För Se har upplösning skett med HCl i autoklav vid 120°C i 30 minuter För W är provet upplöst med HNO ₃ och HF. Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SFMS). Analys av Hg med AFS har skett enligt SS-EN 13506 (modifierad).

	Godkännare
AKR	Anna-Karin Revell, Kemist
ANFR	Andreas Fredman, Kemist
CL	Camilla Lundeborg, Kemist
JOTA	Joanna Tagai, Kemist
KABJ	Karin Björk, Kemist

	Utf ¹
E	Mätningen utförd med ICP-AES För mätningen svarar ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, som är av SWEDAC ackrediterat laboratorium (Reg.nr. 2030).
F	Mätningen utförd med AFS För mätningen svarar ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, som är av SWEDAC ackrediterat laboratorium (Reg.nr. 2030).
H	Mätningen utförd med ICP-SFMS För mätningen svarar ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, som är av SWEDAC ackrediterat laboratorium (Reg.nr. 2030).
O	För mätningen svarar ALS Scandinavia AB, Box 511, 183 25 Täby som är av det svenska ackrediteringsorganet SWEDAC ackrediterat laboratorium (Reg.nr. 2030).
S	Mätningen utförd med ICP-SFMS För mätningen svarar ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, som är av SWEDAC ackrediterat

¹ Utförande teknisk enhet (inom ALS Scandinavia) eller anlitat laboratorium (underleverantör).

	laboratorium (Reg.nr. 2030).
1	För mätningen svarar ALS Scandinavia AB, Aurorum 10, 977 75 Luleå, som är av SWEDAC ackrediterat laboratorium (Reg.nr. 2030).
2	För mätningen svarar GBA, Flensburger Straße 15, 25421 Pinneberg, Tyskland, som är av det tyska ackrediteringsorganet DAR ackrediterat laboratorium (Reg.nr. DAC-P-0040-97-10). DAR är signatär till ett MLA inom EA, samma MLA som SWEDAC är signatär till. Laboratorierna finns lokaliserade på följande adresser: Flensburger Straße 15, 25421 Pinneberg, Daimlerring 37, 31135 Hildesheim, Brekelbaumstraße 1, 31789 Hameln, Wiedehopfstraße 30, 45892 Gelsenkirchen, Meißner Ring 3, 09599 Freiberg, Goldtschmidtstraße 5, 21073 Hamburg. Kontakta ALS Täby för ytterligare information.
3	För mätningen svarar ALS Laboratory Group, Na Harfê 9/336, 190 00, Prag 9, Tjeckien, som är av det tjeckiska ackrediteringsorganet CAI ackrediterat laboratorium (Reg.nr. 1163). CAI är signatär till ett MLA inom EA, samma MLA som SWEDAC är signatär till. Laboratorierna finns lokaliserade i; Prag, Na Harfê 9/336, 190 00, Praha 9, Ceska Lipa, Bendlova 1687/7, 470 03 Ceska Lipa, Pardubice, V Raji 906, 530 02 Pardubice. Kontakta ALS Täby för ytterligare information.

Mätosäkerheten anges som en utvidgad osäkerhet (enligt definitionen i "Guide to the Expression of Uncertainty in Measurement", ISO, Geneva, Switzerland 1993) beräknad med täckningsfaktor lika med 2 vilket ger en konfidensnivå på ungefär 95%.

Mätosäkerhet från underleverantör anges oftast som en utvidgad osäkerhet beräknad med täckningsfaktor 2. För ytterligare information kontakta laboratoriet.

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller endast det identifierade, mottagna och provade materialet. Beträffande laboratoriets ansvar i samband med uppdrag, se aktuell produktkatalog eller vår webbplats www.alsglobal.se

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Statens Geotekniska Institut
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ANALYSUPPDRAG

Uppdrag nr: AG2010-3763

Inkom datum: 2010-06-17

Analysdatum: 2010-08-25

Uppdragets omfattning: Bestämning av polycykliska aromatiska kolväten(PAH) i 5 st vattenprover enligt metod A20 men med låghaltsbestämning

ANALYSRESULTAT:

Resultat: Tabell 1

Göteborg, 2010-08-31
IVL Svenska Miljöinstitutet AB



Erika Rehngrén
Analytisk kemist



Annika Potter
Analytisk kemist

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1(2)

Tabell 1. Resultat

Kund ID	F	GM	GVG
Lab ID	3763-1	3763-2	3763-3
Provvolum(L)	1.0	1.0	1.0
	ng/L	ng/L	ng/L
Naphthalene	<2.9	3.1	50
Acenaphthene	<0.29	12	960
Fluorene	0.38	5.5	160
Phenantrene	<0.90*	7.0	71
Anthracene	0.026	1.0	52
Fluoranthene	0.51	9.0	250
Pyrene	0.64	8.6	150
Benso(a)anthracene	0.15	0.73	4.5
Chrysene	0.22	1.3	5.2
Benso(b)fluoranthene	0.19	1.3	1.8
Benso(k)fluoranthene	<0.038	0.44	0.62
Benso(a)pyrene	<0.077	0.79	0.93
Dibenso(a,h)anthracene	<0.096	0.26	0.44
Benso(g,h,i)perylene	<0.29	1.5	1.3
Indeno(1,2,3-cd)pyrene	<0.67	<0.69	<0.67
Summa analyserad PAH	2.1	52	1700

Kund ID	H	Järnbrott
Lab ID	3763-4	3763-5
Provvolum(L)	1.0	1.0
	ng/L	ng/L
Naphthalene	15	<2.9
Acenaphthene	31	1.1
Fluorene	24	2.7
Phenantrene	40	2.6
Anthracene	3.5	0.24
Fluoranthene	33	3.3
Pyrene	31	6.1
Benso(a)anthracene	1.7	0.28
Chrysene	8.2	1.4
Benso(b)fluoranthene	5.3	1.3
Benso(k)fluoranthene	1.9	0.39
Benso(a)pyrene	2.3	0.64
Dibenso(a,h)anthracene	1.0	0.53
Benso(g,h,i)perylene	7.2	2.9
Indeno(1,2,3-cd)pyrene	2.5	<0.67
Summa analyserad PAH	210	23

* Förhöjd kvantifieringsgräns pga störning

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Uppdrag: AG2010-3769
Inkom datum: 2010-06-17
Analysdatum: 2010-08-24
Uppdragets omfattning: Bestämning av totalkvicksilver i vatten (metod A9).

ANALYSRESULTAT

Provmärkning	Provtagningsdatum	Hgtot (ng/L)	Mätosäkerhet (\pm ng/L)	Anm.
F	i.u	3.3	0.2	
GM	i.u	2.6	0.1	
GVG	i.u	1.2	0.1	
H	i.u	9.4	0.5	
Järnbrö	i.u	2.9	0.2	

Mätområde: 0.1-1000 ng/L
Osäkerheten är angiven enligt 95% konfidensintervall.

Göteborg 2010-11-04

IVL Svenska Miljöinstitutet AB

Ulla Hageström
Analytisk kemist

Camilla Hällinder Ehrencrona
Kvalitetsansvarig

Denna rapport får endast återges i sin helhet, om inte utfärdande laboratorium i förväg skriftligen godkänt annat.

Sidan 1 av 1



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