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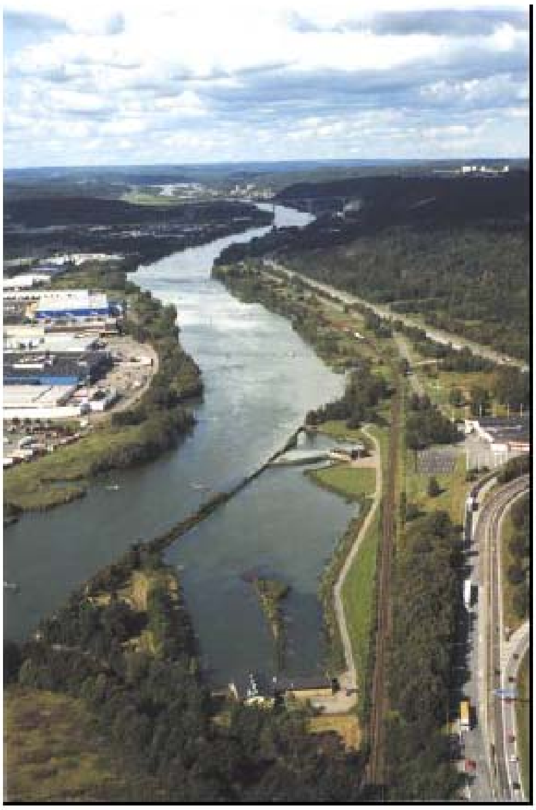

Raw Water Storage
Case study: Göteborg's Water Supply

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

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Cover: Photo of River Göta älv and the Lärjeholm raw water intake system

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Abstract

Göteborg has used the river Göta älv as the drinking water source since long ago. The reliability on this water supply was a matter of concern even for the first inhabitants in the city, which realized the necessity of a constant source of water of high quality. Nowadays, Göta älv still is providing water to the city, but is nowadays supported by the incorporation of Delsjöarna as a water reservoir for the city’s waterworks: Alelyckan and Lackarebäck.

Considering water quality, it is known that Göta älv has in general a relatively good water quality and, as this report confirmed, most of the parameters measured within the water control program does not overstep the old national guidelines given by SLVFS 1993:35, known as “gamla kungörelsen”. However there are a few parameters overstepping these guidelines. These parameters are *E. coli*, where the guideline establishes a maximum of 500 total colonies in 100 ml; oxygen, where the guideline allows a minimum of 50%, and Aluminium (acid dissolved aluminium) with a maximum of 0.1 mg/L Al^{+3} accepted. Water quality in the lakes is even better, since the pollutants, suspended sediments and microorganisms have time to settle (or die) during the reservoir storage in the lakes.

The capacity of the lake system Delsjöarna to diminishing the load of pollutants was evaluated using a water budget concept. It was found that under the period considered this capacity was not constant and was decreasing at the end of the period. The correlations between the continuously registered water quality parameters were evaluated by the Pearson’s correlation coefficient, thereby indicating different correlation patterns at the river (Lärjeholm) compared to Lackarebäck water treatment plant.

Further studies may be helpful to broaden the understanding of the load capacity of the lakes of Delsjöarna and how this capacity is reflected by different parameters. These studies should focus on the mechanisms behind the reduction of pollutants in the lakes.

Mellanlagring av råvatten
Fallstudie: Göteborgs dricksvattenförsörjning
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Sammanfattning

Göteborg har använt Göta älv som råvattentäkt sedan lång tid tillbaka. Redan stadens första innevånare insåg behovet av en obruten och säker vattenförsörjning. Nuförtiden försörjs staden med vatten från Göta älv som passerar Delsjöarna, vilka därigenom utgör som en vattenreservoar åt stadens vattenverk, Alelyckan och Lackarebäck.

Göta älv har vatten av ganska god kvalitet och i den här rapporten konstateras att de flesta parametrar inte överstred gränslinjer och riktlinjer angivna i livsmedelsverkets gamla kungörelse om dricksvatten, SLVFS 1993:35. Bara några enskilda parametrar överstred riktlinjerna: *E.coli*, där riktlinjerna anger maximalhalten 500 totala kolonier per 100 ml och aluminiuminnehåll (aluminium upplöst i syra) där maximalhalten är 0.1 mg/l Al^{+3}. Vattenkvaliteten i Delsjöarna är bättre än i älven, eftersom föroreningar, partiklar och mikroorganismer hinner sedimentera (eller avdödas) medan de befinner sig i sjöarna.

Delsjöarnas kapacitet att minska föroreningsbelastning har studerats med hjälp av balansberäkning av vattenbudget. Resultaten visar att reningskapacitetet under den period som studerades inte var konstant samt minskade mot slutet av perioden. Korrelationen mellan de kontinuerligt registrerade vattenkvalitetsparametrarna utvärderades med Pearsons korrelationskoefficient, något som indikerade olika korrelationsförhållanden i älven (Lärjeholm) jämfört med vid Lackarebäcks vattenverk.

Ytterligare studier skulle vara till hjälp för att bredda förståelsen om lagringskapaciteten i sjösystemet Delsjöarna och hur denna registreras genom olika parametrar. Dessa studier bör fokusera på de mekanismer som ligger bakom reduktionen av föroreningar i sjöarna.

Acknowledgements

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Valeria Muñoz Mendel

Göteborg
July 2005

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1. Introduction

"Water is the driver of nature"
Leonardo da Vinci

1.1 Aim/hypothesis

The aim of this study is to explain the better raw water quality entering Lackarebäck waterworks, after passing through the Delsjö lakes, compared to the water from the River Göta älv. In order to achieve this aim, data from the period 2001-2004 were studied. Partial objectives of the work can be summarized as follows:

- To look after the differences in water quality between the river (Lärjeholm) and Lackarebäck waterworks.
- Identify those parameters that are significant or relevant in this water quality improvement between Lärjeholm and Lackarebäck.
- Verify if there is an interaction between the parameters measured, finding the ones that can possibly correlate with others.
- Assess the degree of vulnerability of the lakes if the water load is changed.

Two hypotheses or possible scenarios are formulated to develop the study.

Hypotheses/Scenarios	1. Delsjöarna are an effective reservoir in terms of reducing the amount of pollutants and bacteria 2. The reduction capacity is constant for the lakes.

On a first step, verification of the state of the system will be done at every place in the system considered. Then on a second step, correlations will be made between different parameters to verify their interrelationship and dependence on each other. Finally, in a third step, the reduction efficiency of the lakes will be estimated for the year 2001 to 2003 by water budget calculations. The results obtained will be compared and analyzed to verify the behaviour of the lakes and their compliance with the scenarios proposed.

1.2 About water

"There is nothing softer and weaker than water,
and yet there is nothing better for attacking hard and strong things.
For this reason there is no substitute for it."
Lao Tzu (c.550BC)

Water is and will continue to be the most important factor on earth's life. All life on earth depends on it and so does a wide range of economical activities. Unfortunately, water for drinking purposes is a limited resource in many parts of the world, threatened by pollution and increased demand as the world population continues to grow.

Water is a vital component of earth ecosystems, redistributing itself through natural cycles and thus helping climate control and the hydrologic cycle (Boyd, 2000). Figure 1 shows the hydrologic cycle.

The cycle begins with the evaporation of water from the ocean surface; the air lifted condenses forming clouds. Clouds can be transported and when the conditions promote it, water return to the earth in form of precipitation. The water that reaches the earth surface can evaporate back to the atmosphere or infiltrates the surface and become groundwater. Groundwater either seeps its way to the oceans, rivers, and streams, or is released back into the atmosphere through transpiration. The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.
Of all water on earth, 99.7 % is not usable by humans (Britannica online, 2005). This remaining 0.3% includes all types of freshwater that not always are available for consumption. Therefore water management has become a significant challenge for the authorities.

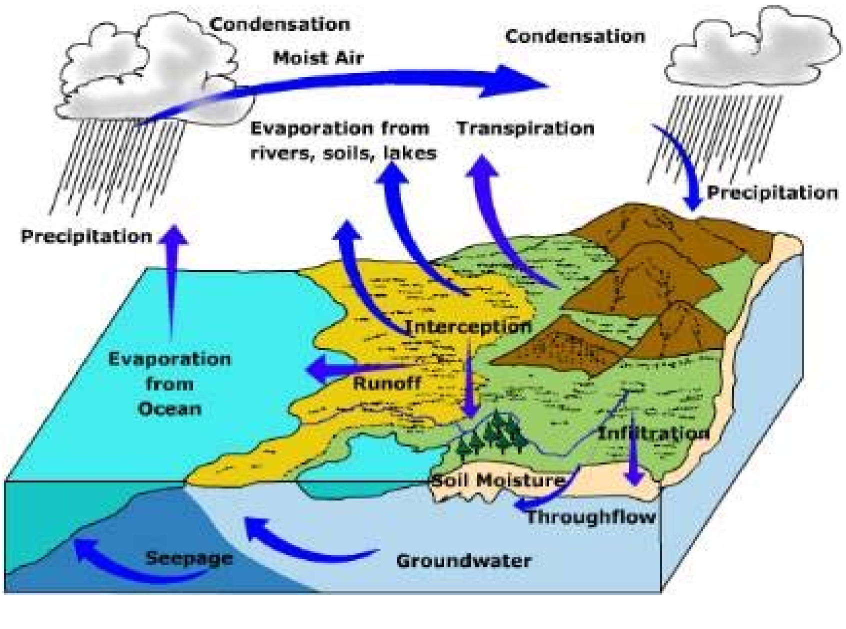


Figure 1: Hydrological Cycle (http://www.uwsp.edu).

Water Reservoirs

Reservoirs are by definition artificial water bodies created for specific purposes of water management (Wetzel, 2002), like water storage, flood control, generation of electrical energy and recreation. Historically, reservoirs have been the water supply of choice for areas that rely on surface water. Reservoirs differ from natural lake ecosystems even when they have many functional similarities in common, for a better understanding of this similarities/differences see Table 1. Waterworks operating natural and artificial water reservoirs are facing water quality degradation problems as can be deduced from the investigations done in the field, being eutrophication and particle sedimentation one of the subjects of major interest (Le Vaillant, 2000).

As increasing demand for water has begun to exceed available supplies in rapidly developing parts of the earth, water planners have begun to look at alternatives, such as new and alternative technologies. Among the emerging options are (USEPA, 2005):

a) Inter-basin transfers: a supply-and-demand concept that moves water from less populous areas where it's abundant, to growing communities struggling to keep up with rising demand.
b) Aquifer storage and recovery: a technology roughly equivalent to putting reservoirs underground. Treated water is pumped into an aquifer during the rainy season, to be recovered during dry periods.
c) Desalinization: the capturing and conversion of salt water into a potable water supply.
d) Reclaimed sewage water: is an effluent from sewage from wastewater treatment system. As a result of that treatment the effluent is suitable for beneficial use and is no longer considered wastewater.

Table 1: Comparative properties for reservoirs and natural lakes (Wetzel, 2002).

Properties	Reservoir	Natural Lake
Drainage basin	Usually narrow, elongated lake basin in base or drainage area; large area in comparison to lake area.	Circular, lake basin usually central; drainage area usually small in comparison to lake area.
Shape	Variable, ovoid to triangular	Circular to elliptical predominate
Shoreline development	Great, astatic	Relatively slow, stable.
Sediment Loading	Large with a large drainage basin area; flood plains large; deltas large, channelized, gradation rapid.	Low to very low; deltas small, broad gradation slow.
Deposition of sediments	High in riverine zone, decreasing exponentially down reservoir; greatest in old riverbed valley; highly variable seasonally.	Low, limited dispersal; relatively constant rates seasonally.
Sediment suspended in water (turbidity)	High, variable; high percentage of clay and silt particles; turbidity high.	Low to very low, turbidity low.
Water level fluctuations	Large, irregular	Small, stable.
Inflow	Most runoff to reservoir via river tributaries (high stream orders)	Runoff to lake via tributaries (often low stream orders) and diffuse sources.
Outflow (withdrawal)	Highly irregular with water use, withdrawals from surface layer or from hypolimnion.	Relatively stable; usually large surface water via surface outflow or shallow ground water.

Interbasin Water Transfer

Interbasin transfer has a long history as a means of addressing water scarcity in one region by transporting additional supplies from areas where water is more abundant (Cox, 1999). This system is also known as River Diversion, Interbasin Transfer or Interbasin Water Transfer (IBWT), and is widely used all over the world as can be deduced by all the studies carried out on the subject in England, India China, Germany, Spain, etc. (Ballestero, 2004). A summarized table with some of the IBWT projects in the world is given below (Table 2).

Problems associated with this procedure has been described in several studies (Diaz et al, 2002; Gibbins et al, 1998 and Xuejun et al, 2003) and they are mainly associated to environmental-geological problems: eutrophication, altered flow rates downstream the diversion, soil salinisation, rise of the groundwater table, etc. Such projects have the potential for serious ecological impacts, including introduction of nonindigenous organisms, changes in water quality and hydrologic regimes, and alteration of habitat (Meador, 1992). These problems are also highlighted by one communicate of the European Environmental Bureau (EEB, 2002), mentioning that there are factors that are highly time and/or spatial variable determining the availability of water: precipitation, evaporation, land cover, soil quality and geological structures.

As a result, water availability is extremely variable over space and time. Man-made, water storage and transfer schemes are able to change this natural availability to a certain extent, but inevitably have negative environmental implications. This occurs especially in the case of inter-basin water transfer because of its irreversible and unpredictable nature. Such schemes can destroy natural habitats, deteriorate hydromorphological conditions, needs a high input of energy and have negative effect on the quality of the water transferred. Water storage and long-distance or inter-basin transfer should therefore be seen only as a solution of last resort, where there are overriding public interests and no other possible local alternatives. More efficient water use, conservation, reallocation of water and prevention of water pollution should be the first local options.

Table 2: IWBT projects and their purpose (Water Quality Surveys – UNESCO, 1978).

Purpose	IBWT project
Urban drinking water supply	Rhone- Barcelona, France Spain LRC, Helsinki Metropolitan area (Finland), urban centers (Germany)
Drinking water supply and Irrigation	Ebro-Tarragona (Spain), Tajo-Segura (Spain)
Water supply: population, industry and agriculture	South Africa
Mainly irrigation and waterpower.	India, Bangladesh
Irrigation combined with drinking water and environmental rehabilitation.	Central Asia, Siberia (SIBARAL)
Navigation and environment. Mainly environmental improvement.	Rhine-Main- Danube, San Pedro River (Arizona), Snowy Mountains (Australia)

1.3Water Quality in Sweden

"Water should not be judged by its history,
but by its quality"
Dr. Lucas van Vuuren

Sweden is a rich country regarding water availability, with almost 100 000 lakes that account for 9% of the total area of the country according to a bulletin of The Swedish Water and Wastewater Association published in 2000 (VAV, 2002). The average river runoffs reach approximately 200km^3/year and according to the same bulletin only a 0.5% of the water theoretically available is extracted for municipal use. Other users, such as industry and farming, take account of approximately three times as much water as the municipal sector. But the quality of the raw water varies from one place to another and thus the drinking water treatment procedures needed.
Traditionally the local government or municipality administrate water supply and sanitation (stormwater management included) in a city or town. The municipality usually owns the facilities and responsible for the operation. In Sweden there are around 2000 public owned waterworks, of which 200 use surface water (VAV, 2000).

Drinking water quality is the responsibility of the Ministry of Agriculture (Jordbruksdepartamentet) with the National Food Administration (Livsmedelsverket) as the central supervising agency. The national food administration (Livsmedelsverket) is the central supervisory authority for matters relating to food, including drinking water in Sweden. Food and water control at the local level is the responsibility of the relevant municipal committee(s), usually the Environment and Health Protection Committee (Miljöförvaltningen). The County Administrations are responsible for co-ordinating food control within each county. Livsmedelsverket produces directions (föreskrifter) and public notices (kungörelser) to inform the local governments and municipalities what have been decided regarding laws and other important matters.

Water quality measurements are essential to data comparability and for decision-making and management related issues (Quevauviller, 2002). Any physical, chemical, or biological property that influences the use of water is a water quality variable (Boyd, 2000) and there are hundreds of them, but only few of them are of interest. The development of water quality standards was aimed to serve as a guideline mainly for protection of the water bodies from pollution.

Water monitoring is essential for the determination of state and trends in the quality of rivers, lakes and groundwaters (Quevauviller, 2002) and they often follow national or international/European requirements. In Sweden came into force the new Directions for Drinking Water: SLVFS 2001:30 on December 25th 2003, replacing the old directions of the SLVFS 1993:35. The new directive does not include guidelines or recommended values for surface raw water, so in the case of this study all the references are remitted to "den gamla kungörelse" i.e. SLVFS 1993:35 and are presented in Table 3.

Table 3: SLVFS 1993:35, directions and guidelines for surface waters.

Microorganisms, chemical substances and properties	**Unit**	**Guide Value**	**Limit Value** (mandatory)
E.coli	number/100ml	500	
Coliforms	number/100ml	5000	
Faecal Streptococci	number/100ml	1000	
Salmonella (min 1lt sample)	number/100ml	not shown	
Temperature	^{o}C	12	20
Odour	–	Strong	
Colour	–	50	100
COD_{Mn}	mg/l O_2	10	
pH	–	5.5-9.0	
Oxygen measured	% O_2	50	
Calcium	mg/l Ca	100	
Magnesium	mg/l Mg	30	
Sodium	mg/l Na	100	
Potassium	mg/l K	12	
Iron	mg/l Fe	1	
Manganese	mg/l Mn	0.3	
Aluminium, acid dissolved	mg/l Al	0.1	
Koppar	mg/l Cu	0.05	
Ammonium -nitrogen	mg/l N	0.05	
Nitrate-nitrogen	mg/l N	5	
Phosphate-phosphorus	mg/l P	0.05	
Fluorides	mg/l F		1.3
Chlorides	mg/l Cl		100
Sulphates	mg/ SO_4		100
Phenols	mg/l	0.001	0.005
Antimony	mg/l Sb		0.01
Arsenic	mg/l As		0.01
Barium	mg/l Ba		1
Lead	mg/l Pb		0.01
Boron	mg/l B	1	
Cyanide, available	mg/l CN		0.05
Cadmium	mg/l Cd	0.0001	0.001
Chromium	mg/l Cr	0.01	0.05
Mercury	mg/l Hg	0.0001	0.001
Nickel	mg/l Ni	0.01	0.05
Selenium	mg/l Se		0.01
Silver	mg/l Ag		0.01
Zinc	mg/l Zn		1
Pesticides	–	must not be measurable	
Hydrocarbons, in emulsion or dissolved	mg/l		0.2
Polycyclic aromatic hydrocarbons	mg/l		0.0002
Active surface ions	mg/l	0.2	

1.4 Literature Review

Water Analysis

" In one drop of water
are found all the secrets
of all oceans"
Khalil Gibran

The environmental parameters present in all types of water are numerous, and therefore will not be introduced here. However, a brief description will be given of the parameters highlighted by the normative known as SLVFS 1993:35 and adapted mainly from Boyd (2000), Quevauviller (2002) and Fresenius (1988).

a) Physical chemical analysis

In practice, laboratories responsible for environment monitoring select the target elements to be analysed and that are included in the regulations. Water is one of our most important provisions and therefore should undergo strict quality requirements. Raw water in Göteborg and drinking water produced at the waterworks are controlled regarding their bacteriological and physical-chemical parameters with an extensive sampling programme. This programme resulted from cooperation between the waterworks and Göteborg's Miljöförvaltningen. Physical-chemical analyses are resumed in Tables 4, 5 and 6 and are in principle carried out by the certified laboratory at the waterworks according to their own control programme.

Table 4: Physical Chemical Analysis Measured to Göteborg's raw water.

Parameter	Units	Comments
Turbidity	FNU	Tubidity is caused by suspended or colloidally dissolved inorganic and /or organic susbstances. Appart form sludge particles, silic acid, ferric and aluminium hydroxide, organic colloids, bacteria and plancton are possible.
Colour	mg Pt	Natural waters have color resulting from suspended and dissolved substances. Colouring gives information on possible contamination.
Odour	-	Can be product of contamination and/or decomposition of organic materials. As a rule water should be odorless and there is a scale to quantify it: very weak, weak, distinct, strong, very strong
pH	-	The pH is an index of the intensity of hydrogen ions and is a master variable because many reactions that control water quality are pH dependant. Normal waters contain acids and bases and biological processes tend to increase either acidity or basicity. The interactions between these opposing compounds and processes determine pH.
COD	mgL^{-1} O_2	Chemical oxygen demand is a measure of the oxygen demand of the organic matter in a sample giving a rapid way to asses BOD (biological oxigen demand). COD also may be used as an index of the concentration of organic matter in water samples.
Oxygen	% O_2	Dissolved oxygen gives information about the health of a water ecosystem.A decrease in the dissolved oxygen levels is usually an indication of an influx of some type of organic pollutant.

Table 5: Trace Elements frequently analysed in water samples

Element	Symbol	Origin and uses
Antimony	Sb	Metalloid used in association with Pb and Sn to increse their hardness and in the form of salts as catalysts fro rubber vulcanization. Moderate toxicity.
Arsenic	As	Largely present in the biosphere, principally in the form of AS_2S_2 or As_2S_3. This element is used in metallurgy (alloys), electronics (semiconductors), tanning industry, paint formulations, glass coloration, etc. Naturally has low water concentrations because it is not present in most soils and the mineral forms are not soluble.
Barium	Ba	Element found in the nature in the form of sulphates and carbonate. Widely used in industry.
Boron	B	Boron occurs in soils as borosilicates and borates that dissolve easily. It uses are sveral: antiseptic, glass and ceramic industries, paints and cosmetics. It is frequently found in urban and industrial waste-waters.
Cadmium	Cd	It is rare in geological deposits and occur mainly in carbonate and hydroxide forms. Is used in the polymer and nuclear industries and in galvanoplasty. It is associated with a bone decalcification toxic syndrome.
Chromium	Cr	Relatively common element in earth's crust, existing at low concentrations in several oxidation states. Widely used in the industry as colouring agent, tanning agent, anticorrosion agent.
Copper	Cu	Element found in the nature in form of native copper ores, oxides or sulphides. Among its uses are alloys and as fungicide (copper salts). Widely used by its thermal and conductivity properties. Appart from industrial pollution, water pipes corrosion is a source for copper in water.
Cyanide	CN	CN in waters are the result of pollution, generally industrial waste-water.Highly toxic depending on the the associated cation and the posibilitie of release of cyanhidric acid.
Fluoride	F	Fluoride is highly electronegative and therefore a powerful oxidizing agent. This is why it is not found as free element but as a gas (F_2) and organic and mineral fluorides. It is widely used in the industry (fertilizers,catalysts, insecticides, etc).
Lead	Pb	Lead occur in several minerals in earth's crust. Frequently used in the industry and thus the pollution sources are diverse.
Mercury	Hg	Has a low abundance in geological formations and can be naturally released (evaporation, erosion, vulcanic eruptions). Geological contamination explains its presence in in some industrial wastes.the metal is used inelectric apparatus, control instruments, marine paints and some fungicides.
Nickel	Ni	Frequently founded silicates and pyrites. Nickel is the main constituent of numerous alloys.
Selenium	Se	Occurs in the earth's crust as elemental Se, ferric selenite and calcium selenite. Used as colouring agent, in glass and textil industries, metallurgy, rubber and chemical industries, pharmaceutical industry, etc.
Silver	Ag	Used in the metal plating and photographic processing industries.
Zinc	Zn	Element present in rocks in form of sulphides. Zn uses includes alloys, galvanizationn, pigments, etc.

Table 6: Major elements frequently analysed in water samples.

Element	Symbol	Origin and uses
Aluminium	Al	Widespread on earth (as aluminosilicates) is not a major constituent of water, but at low pHs becomes toxic element
Calcium	Ca	Another widespread element on earth, mainly as carbonates. Exists in water in the hydrogencarbonates form and, in lesser amounts as sulphates, chlorides, etc. Their presence in pipelines may cause depositions or incrustations of carbonates.
Chloride	Cl^-	Chloride concentrations in waters are very variable according to soil leaching, pollution (road treatment during winter), seawater infiltration in grounwater levels, etc. May lead to unwanted flavour in water and produce corrosion.
Magnesium	Mg	Abundant on earth's crust as magnesium salts (carbonates) that are highly soluble in water. As calcium, constitutes a significant element of water hardness.
Nitrogen	N	Nitrogen (N_2) is an important constituent of the atmosphere and plays an essential rol in the biospere thanks to the reversible changes of its mineral (ammonium, nitrites, and nitrates) and organic (aminoacids and proteins) forms. Ammonium nitrogen, both as ionized and non-ionized forms, indicates a degradation process of organic matter. Ammonia is rapidly transformed into nitrites and nitrates through oxidation processes.

b) Microbiological Analysis

Water plays an essential role in supporting life and thus it also has, if contaminated, great potential for transmitting a wide variety of diseases and illnesses (Tebbutt, 1998). Infections are mainly caused by viruses, bacteria or parasites (protozoa or worms). Water-related diseases are often associated to the contamination of water by human faeces or urine following an infection cycle (Figure 2). The cycle begins when the pathogenic organism is reaching the water, which is then consumed by a person who does not have immunity to the disease.

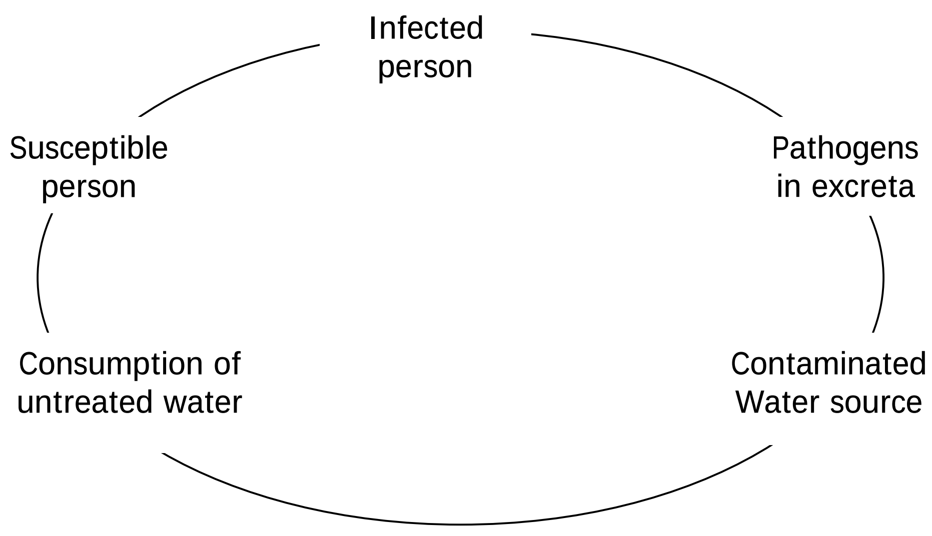


Figure 2: Classical waterborne disease infection cycle (Tebbut, 1998).

Microbiological analysis of water is used to monitor the microbiological quality and safety of water used as drinking water (Mason, 2002, Fresenius, 1988). Since it is difficult to assess the entire biota present in a sampling area due to the diversity of analysis and the time restrictions a monitoring programme is necessary. This programme must be focused on those organisms that are most likely to provide the information required easily and representatively. These microorganisms, which are not necessarily pathogens, are denominated indicator organisms. Reliance is thereby placed on relatively simple and more rapid bacteriological tests (Quevauviller, 2002) that could lead to identification of the possible type and sources of contamination. Using indicator organisms is a well-established practise in assessing drinking water quality (WHO, 2004). Ideally, the criteria for the indicators are that they should not be pathogens themselves and should:

1. be universally present in faeces of humans and animals in large numbers;
2. not multiply in natural waters;
3. persist in water in a similar manner to faecal pathogens;
4. be present in higher numbers than faecal pathogens;
5. respond to treatment processes in a similar fashion to faecal pathogens; and
6. be readily detected by simple, inexpensive methods.

The organisms most commonly used as indicators of faecal contamination in water are classified as follows:

a. Primary Indicators: those organisms used as indicators of faecal contamination. In this category are included the members of the coliform group, particularly *E. coli*.
b. Secondary Indicators: those organisms that are analysed when results of coliform tests are positive. This category includes faecal streptococci and *Clostridium perfringens*. These microbes occur normally in faeces, though in much smaller numbers than *E. coli*. Thus, the presence of secondary indicators confirms faecal contamination.

Among these indicator organisms are the coliform bacteria and the reason for their selection is because the coliform bacteria are relatively simple to identify, are present in much larger numbers than the more dangerous pathogens, and react to the natural environment and treatment processes in a manner and degree similar to pathogens (Boyd, 2002). Among coliform bacteria it is possible to distinguish total coliforms, faecal coliforms and *E.coli*. Figure 3 shows a schematic representation of the repartition of the coliform bacteria.

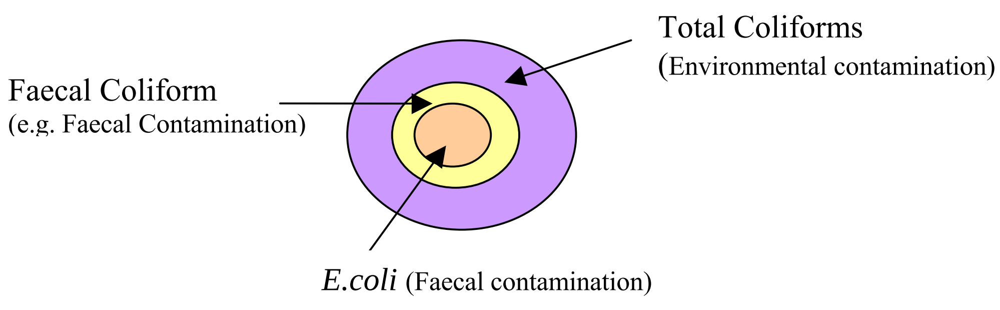


Figure 3: Repartition of the coliform bacteria (Office of Drinking Water, Washington State, 2004)

Table 7 describes the different organisms considered indicators in water analysis to confirm water pollution (Tomar, 1999).

Table 7: Primary and secondary indicators of faecal contamination in water

Indicator	Organisms	Characteristics
Primary	Coliform bacteria	Aerobic and facultative anaerobic, Gram -, non spore forming rods that ferment lactose with the production of acid gas within 24h to 48h at 37°C, when grown in a medium containing bile salts. The total coliform group includes: E*nterobacteriaceae* family, *Escherichia, Klesbisella, Citrobactor* and Enterobacter. Out of these genera, *Escherichia* (*E.coli* species) appears to be the most common indicator of faecal contamination.
Primary	Faecal Coliform	Coliform organisms that are thermotolerant coliforms and ferment lactose at 44°C within 24h.
Primary	*Escherichia coli*	*E.coli* is one of the species of coliform bacteria that constitute the larger proportion of the normal intestinal flora of humans and other warm-blooded animals in comparison with any other organisms.
Secondary	Faecal streptococci	Gram + cocci that form pairs or chains and grow in a medium containing that concentration of sodium azide that is inhibitory to coliform organisms and most other gram - bacteria. They grow at 45°C, serving as good secondary indicators
Secondary	Enterococci	Two strains of faecal streptococci (*S. faecalis* and *S. faecium*, which are normally, present in man and various animals.

Total coliform bacteria are commonly found in the environment (e.g., soil or vegetation) and are generally harmless. If only total coliform bacteria are detected in drinking water, the origin is probably environmental and not faecal. The term “total coliforms” refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics (UNEP/WHO, 1996). The group includes thermotolerant coliforms and bacteria of faecal origin, as well as some bacteria that may be isolated from environmental sources. Thus the presence of total coliforms may or may not indicate faecal contamination.

Faecal coliform bacteria are a sub-group of the total coliform group (USEPA, 2004). They appear in great quantities in the intestines and faeces of humans and animals. The presence of faecal coliform in a drinking water sample normally indicates fresh faecal contamination – meaning that there is a greater risk that other pathogens also are present than if only total coliform bacteria is detected.

The term “faecal coliform” has been used in water microbiology to denote coliform organisms, growing at +44 or +44.5 ºC and ferment lactose to produce acid and gas (UNEP/WHO, 1996). In practice, some organisms with these characteristics may not be of faecal origin and the term “thermotolerant coliform” is therefore more correct and is also a commonly used term.

Usually, more than 95 % of the thermotolerant coliforms isolated from water are the *E. coli*, which is a sub-group of the faecal coliform group (USEPA, 2004). Most *E. coli* are harmless and are found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, may cause illness. The presence of *E. coli* in a drinking water sample almost always indicates recent faecal contamination – meaning that there is a greater risk that other pathogens are present. Most outbreaks have been related to food contamination, caused by a specific strain of *E. coli* known as O157:H7 or EHEC (USEPA, 2004). Boiling or treating contaminated drinking water with a disinfectant (like chlorine) destroys all forms of *E. coli*, including O157:H7.

Intestinal enterococci are a subgroup of the larger group of organisms defined as faecal streptococci, comprising species of the genus Streptococcus. Faecal streptococci including intestinal enterococci have been isolated from the faeces of warm-blooded animals (UNEP/WHO, 1996).
Faecal streptococci are considered to have certain advantages over the coliform and faecal coliform bacteria as indicators (Maier-Gerba, 2002):

a) They rarely multiply in water.
b) They are more resistant to environmental stress and chlorination than coliforms.
c) They generally persist longer in the environment.

It is therefore possible to isolate faecal streptococci from water that contains few or no thermotolerant coliforms as, for example, when the source of contamination is distant in either time or space from the sampling point.

The subgroup intestinal enterococcus consists of the species *Enterococcus faecalis*, *E. faecium*, *E. durans*, and *E. hirae* (UNEP/WHO, 1996). This group was separated from the rest of the faecal streptococci because they are relatively specific for faecal pollution (see Figure 4). Enterococci are extremely resistant and can survive under conditions lethal for most other microorganisms and therefore are also used as indicator microorganism for water quality.

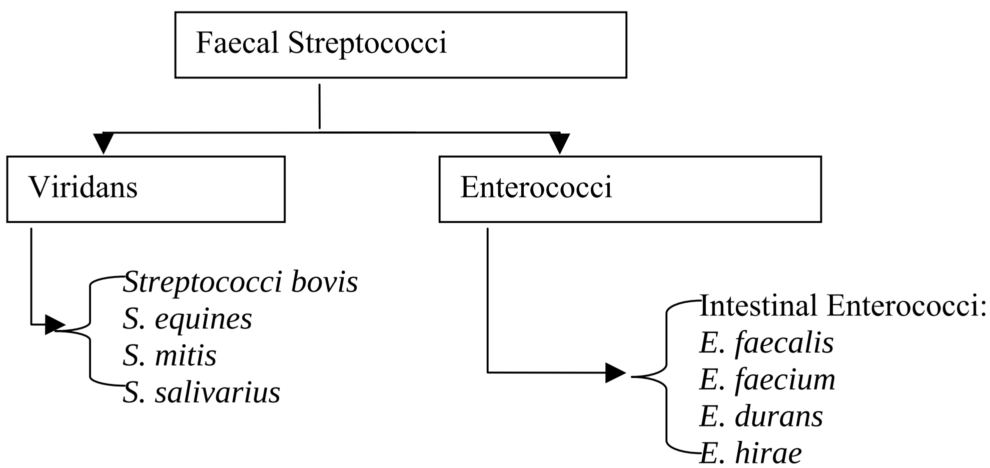


Figure 4: Faecal streptococci and some of its sub-groups (Maier, 2002).

1.5 Göteborg's water supply

"Water sustains all "
Thales of Milletus, 600 BC

Göteborg is the second largest city of Sweden, with important industrial and commercial activities. Located in the southwestern coast, its port is the most important of Scandinavia. The Swedish King Gustav Adolf, the second, founded the city in the beginning of the 17th century, becoming soon an important trade centre with the help of Dutchmen, Englishmen, Germans and Scotsmen. Figure 5 shows the geographical location of Göteborg.

Historically human settlements were established in the nearby of rivers, where their inhabitants would find the necessary water supply for their activities. Göteborg is not the exception. Already in the city's early years, the water supply was based on the river Göta älv and the inhabitants fetched water both from the channels through the city (Adamson, 1987) and the river until the water deteriorated to such an extreme that it became necessary to build a 5 km wooden pipeline from Kallebäck spring to the city centre inaugurated on November 1787(Pettersson, 1987). The city continued to grow and Kallebäck spring did not satisfy the water requirements from the population any longer. In 1871 were replaced by the first waterworks: a slow filtration system that used water from the Delsjö lakes. This "Delsjöarna" waterworks no longer could provide the necessary water quantity to the city so in 1894 it was necessary to go back to the Göta älv as a source for raw water.

Alelyckan waterworks was also implemented with slow filtration system that later on was replaced by a new system known as sand infiltration. Chemical precipitation in the water treatment was started up in 1949. Alelyckan was the first waterworks in Göteborg and is today producing about half the total volume of potable water delivered to the city. Processes here include pH adjustment with lime, flocculation with aluminium sulphate, sedimentation, intermediate chlorination, filtration and adsorption with active coal.

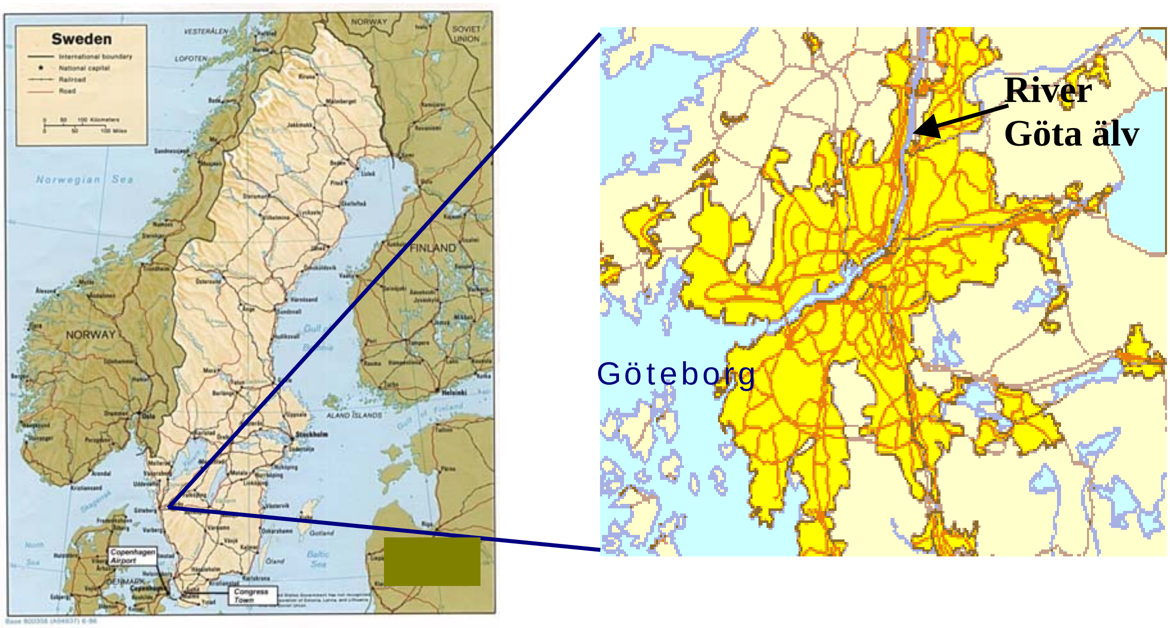


Figure 5: Göteborg's location and city map

In 1960 it was estimated that the actual production would never reach the water demand from the city in the future, so it was necessary to ideate a new system to ensure the water supply. Lackarebäck waterworks was therefore built in 1968 to complement the production of Alelyckan and to secure the water supply for the city. The processes include alkalinity raising and pH adjustment with lime, flocculation with aluminium sulphate, adsorption with activated coal, pH adjustment and alkalinity raising using sodium hydroxide, lime and carbon dioxide. Chlorine is added as a gas and in the form of sodium chloride to produce chlorine and chlorine dioxide as disinfectants within the piping network.

This new system is based on the idea that water form Göta älv transits through Delsjöarna and reaches Lackarebäck waterworks, but the water can be used either at Alelyckan or Lackarebäck when necessary (see description of the system in chapter 2).

2. Study Site Description

The real issue of water scarcity
is the availability of water where it is needed,
when it is needed
by the people who need it.
Mr. Nittin Desai
U.N. under secretary general for economic and social affairs

The system considered in this study is the Göteborg's water supply system that involves the river Göta älv, the lakes Delsjöarna and the reserve supply from Lake Rådasjön. Figure 6 shows a schematic overview over the system. Intake of water from the river takes place at Lärjeholm; the water is then conveyed to Hävertstation Alelyckan (pumping station), where chloride is added in the summer season. In the Västra Götaland region, where the city is located, chloride is added from June 1st to September 1st. From Hävertstation Alelyckan the water can be either pumped to Alelyckan waterworks or to the Delsjöarna Lakes. The water pumped to Delsjöarna pass through another pumping station located in the nearby of Härlandatjärn pond (but never reaches that pond) and finally ends up in Lilla Delsjön, specifically at a place called Kotången (Figures 6 and 7).

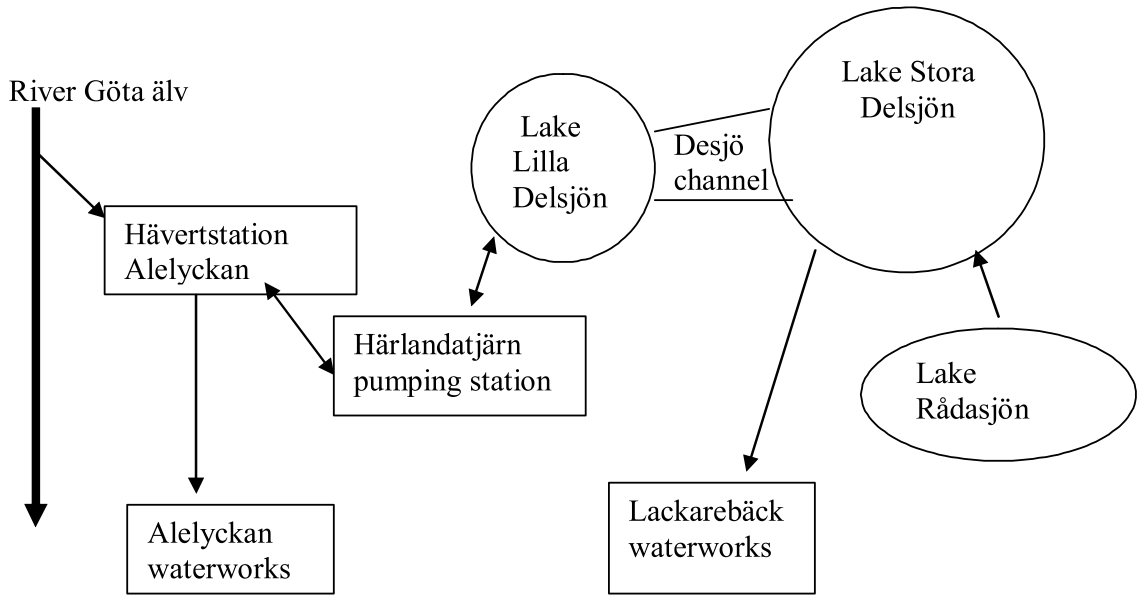


Figure 6: Schema over the system under study.

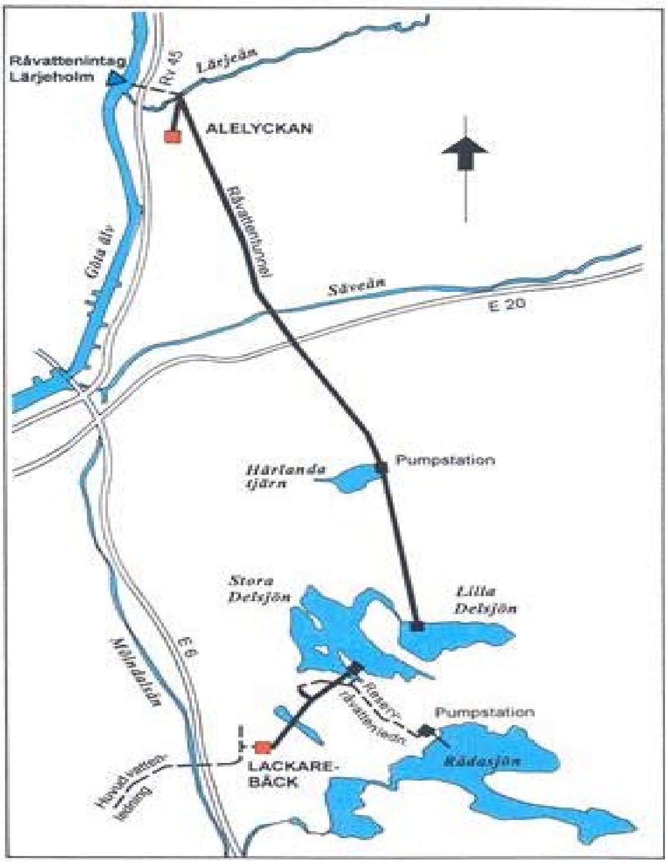


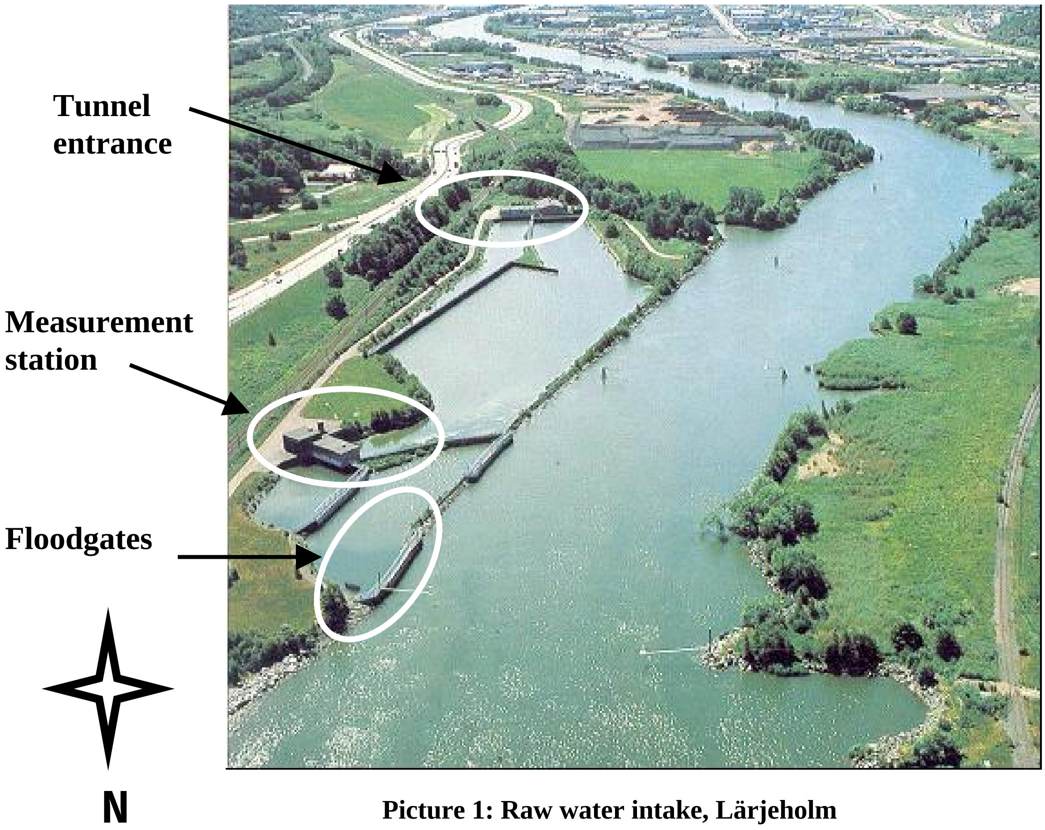
Figure 7: Map of the zone where the system is located (va-verket, 2002)

Lärjeholm

The river intake station Lärjeholm is situated in the northern part of Göteborg. Different parameters are automatically measured online, including pH, conductivity, redox potential and the coliform numers (by the Colilert method). Others such as different microorganisms are measured at-line, meaning that the analysis is not performed automatically at the site. Table 8 shows the raw water characteristics at Lärjeholm for the year 2003. By gravitational flow the water enters the tunnel that connects the intake with both Alelyckan (drinking water treatment plant) and the pumping station Härlanda pond. The pumping station is situated 90m below the surface from where the water is pumped up to the lakes.

When there is an alteration in the water quality from the river, the intake can be closed and Alelyckan receives then water only from Delsjöarna for a maximum of three weeks.

Among the common causes for closing the intake are: elevated bacterial content in the raw water, occasional spills, saline water intrusion into the river and others, such as rebuilding activities within the catchments. During the studied period the intake was closed due to elevated bacterial concentration in 4289 hours (54% of the studied period), and additionally 1206 hours (15% of the studied period)) due to saline intrusion, see Appendix 1.



Picture 1: Raw water intake, Lärjeholm

Table 8: Raw water characteristics at the river site Lärjeholm in Göta älv, year 2003.

Parameter	Unit	Min	Median	Max
Temperature	^oC	0.5	7.1	22.5
Turbidity	FNU	2.4	4.7	40
Conductivity	mS/m	8.9	9.8	112
pH		7.0	7.2	7.5
Alkalinity	mmol/l	0.27	0.30	0.35
Ca^{+2}	mg/l	7.2	7.9	14
Mg^{+2}	mg/l	1.6	1.8	20
Total Fe	mg/l	0.08	0.17	1.8
Total Mn	mg/l	0.004	0.008	0.042
NH_4^+-N	µg/l	<50	<50	50
PO_4^-P	µg/l	<4	<4	8
Colour	mg/l Pt	15	20	100
Extinction 254 nm	ae/cm	0.100	0.113	0.277
TOC	mg/l	4.1	4.6	5.5
Coliforms	CFU/100ml	36	350	6500
Thermoresistant coliforms	CFU/100ml	<10	100	1300
E.coli	CFU/100ml	5	86	1300

Alelyckan Waterworks:

Alelyckan receives water directly from Lärjeholm when the intake is open. When the intake is closed, Alelyckan receives water from the lakes, and the water quality is then different. Table 9 summarizes the water quality in the waterworks during 2003. , The water quality at Alelyckan is very similar to the raw water quality in Lärjeholm (Table 8).

Picture 2: Alelyckan waterworks

Table 9: Raw water quality at Alelyckan and Lackarebäck waterworks, year 2003

		Alelyckan			Lackarebäck		
Parameter	**Unit**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Temperature	^oC	-0,1	7,7	22	1,8	6,0	21,7
Turbidity	FNU	1,4	3,6	10	0,51	0,77	1,3
Conductivity	mS/m	9,0	10,0	37,2	10,2	11,0	12,2
pH		7,0	7,2	7,4	6,6	7,1	7,3
Alkalinity	mmol/l	0,29	0,30	0,38	0,28	0,30	0,39
Ca^{+2}	mg/l	6,9	7,8	9,0	6,7	7,4	7,6
Mg^{+2}	mg/l	1,6	1,8	5,4	1,6	1,8	1,9
Total Fe	mg/l	0,08	0,14	0,21	0,03	0,06	0,10
Total Mn	mg/l	0,004	0,008	0,03	0,006	0,014	0,05
NH_4^+-N	µg/l	<50	<50	50	<50	<50	<50
PO_4^-P	µg/l	<4	<4	4	<4	<4	4
Colour	mg/l Pt	15	20	30	10	20	20
Extinction 254 nm	ae/cm	0,101	0,113	0,151	0,105	0,118	0,135
TOC	mg/l	3,9	4,7	5,5	3,9	4,8	5,7
Coliforms	CFU/100ml	5	190	3200	<1	2	730
Thermoresistant coliforms	CFU/100ml	<1	57	420	<1	<1	3
E.coli	CFU/100ml	<1	50	370	<1	<1	3

Lackarebäck Waterworks:

Picture 3: Lackarebäck waterworks

Water that enters the Lackarebäck treatment plant is withdrawn from Stora Delsjön, see Figure 7. The pumping may happen either at 8m or 16m under the water surface, but the common intake depth is 8m unless the temperature rises over the 20°C in the lakes. Water quality is followed through out the system, certainly in the lakes, where the samples are taken at several points and depths.

Stora Delsjön and Lilla Delsjön have a total surface area of 1.8 Km^2 (Göteborg's water and sewage works annual report 2001) with an approximate volume of $12Mm^3$. They act as water reservoir for Gothenburg city since water can be withdrawn either to Lackarebäck or Alelyckan, see the schematic Figure 8.

Lackarebäck waterworks receives approximately 3600 m^3/h of raw water. When the intake is closed, the lake system Delsjöarna provide both treatment plants with approximately $7400m^3/h$ of raw water. In the case that the water level sinks more than accepted it has been possible to pump water from Rådasjön since 1993. Between January 2001 and May 2004 (almost 3.5 years), $21.1Mm^3$ of water where pumped from this reserve lake, since the intake was closed in total 6928 hours, corresponding to 23 % of this time period (Göteborg water and sewage annual reports).

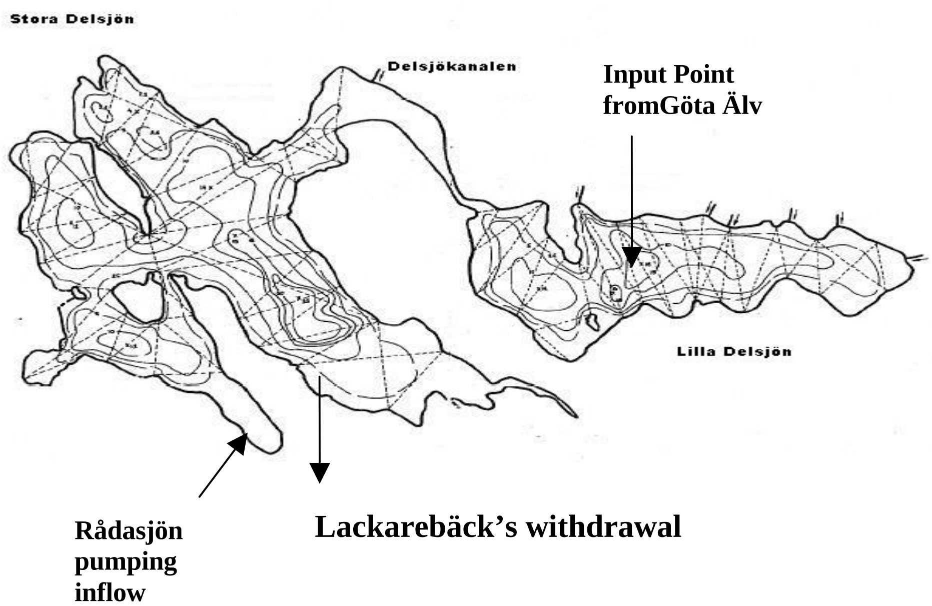


Figure 8: Schematic overview over the lakes (va-verkets intern source).

3. Method

General considerations

A complete set of result analysis collected between January 2001 and May 2004 in the different locations of the system (the river intake Lärjeholm, Alelyckan and Lackarebäck waterworks, Lake Delsjön and Lake Rådasjön) was processed and evaluated. Monitoring includes a broad selection of chemical parameters, aesthetic properties and bacteriological parameters (indicator organisms), and are basically the ones mentioned in the standards.
In order to achieve the aim proposed, several steps followed the analysis of the data:

- The first step was to look at the state of the art at every point of the system. This was done looking at the aesthetic properties and microbiological parameters, since Göteborg water and sewage works annual reports mention the better quality of the water entering Lackarebäck in terms of the named parameters. In this step, no consideration was made in terms of the hours that the intake was closed.

- The second step was to verify the possible reduction in concentration of chemical parameters at Lackarebäck in comparison to Lärjeholm. The parameters were selected by studying the annual reports. The first approach was to search those parameters associated to eutrophication (COD, TOC, ext 254nm, etc), the second approach came from the appreciation of differences between the places.

- The third step focused on finding possible correlations between the selected parameters, to verify their dependence. The degree of association between the parameters was measured by computing simple correlation coefficients (r) for Lärjeholm and Lackarebäck, respectively.

- The last step was to calculate the water and pollutant transport budgets for the lakes. This was carried out adapting general hydrologic equations to the system studied.

Correlations Computing

In order to evaluate the correlations between two variables, the Pearson Product Moment, also called Person's correlation coefficient, was calculated. The Pearson coefficient estimates the correlation of the two given random variables. When an assumption is made about the dependency of one variable in another, it affects the computation of the regression line (e.g. linear regression), reversing the assumption of the variable dependencies results in a different regression line (Townend, 2002).

The Pearson product moment correlation coefficient does not require the variables to be assigned as independent and dependent. Instead, only the strength of association is measured. Specifically, Pearson's coefficient (r) is a measure of how well a linear equation describes the relation between two variables X and Y measured on the same object or organism (a measure of the degree of linear relationship). It ranges from +1 to –1. A value of 1 show that a linear equation describes the relationship perfectly and positively, with all data points lying on the same line and with Y increasing with X. See Figure 9.

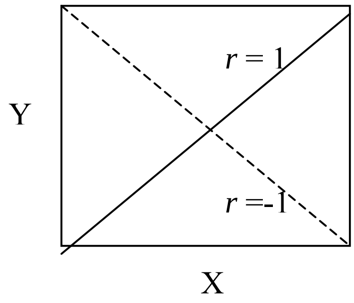


Figure 9: Pearson's positive linear relationship, *r* = 1

A score of -1 show that all data points lay on a single line but that Y increases as X decreases. A value of 0 shows that a linear model is inappropriate, that there is no linear relationship between the variables.

The square of *r* is conventionally used as a measure of the strength of the association between X and Y. The correlations between two variables may be positive or negative. Values of $r^2 > 0.5$ were considered to indicate a high correlation. Values of $0.2 < r^2 < 0.5$ were considered to indicate a "weak" correlation and values < 0.2 were considered to indicate independency between two variables.

The equation used for computing *r* is the one written in the Handbook of Water Analysis (2000) and the one used in the program Microsoft Excel®:

$$r = \frac{n(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[n\Sigma X^2 - (\Sigma X)^2][n\Sigma Y^2 - (\Sigma Y)^2}} \qquad \textbf{Eq 1}$$

In the evaluations all parameters were assumed to be distributed normally, except for the microbiological values that were log-transformed before the statistical analysis.

Mass Balance Calculations

Water budgets can be made using the general hydrologic equation (Boyd, 2000):

Inflow = Outflow ± Change in Storage **Eq 2**

When studying water quality it is necessary to calculate the amounts (masses) of substances involved in pollutants input and output. In order to do that, it is necessary to expand the hydrologic equation by multiplying the amounts of water by the concentration of the variable of interest:

$$M_{in} = M_{out} \pm \Delta M_{removed} \qquad \textbf{Eq 3}$$

In this particular case it is of interest to assess the diminution in the amount of bacteria and other physical-chemical parameters in their residence time in the lakes, Consequently equation 3 can be expressed in terms of reduction:

$$R(\%) = \frac{(M_{in} - M_{out})}{M_{in}} * 100 \qquad \textbf{Eq 4}$$

Where:

R = percentage reduction.
M_{in} = Mass entering the system.
M_{out} = Mass coming out the system.

The system considered for the mass balance is illustrated in Figure 10. M_i represents the mass calculated for the places considered *i.e.* Lärjeholm (L), Alelyckan (A), Lackarebäck (Lack) and Rådasjön (R).

The percentage of reduction (R) for the lakes is given then by the equation 5, and was calculated yearly in the present work to be able to make comparisons between the different years.

$$R(\%) = \frac{M_{Lärjeholm} + M_{Rådasjön} - \left(M_{Lackarebäck} + M_{Alelyckan}\right)}{M_{Lärjeholm} + M_{Rådasjön}} * 100 \qquad \textbf{Eq 5}$$

Calculation of mass balance at Lärjeholm:

When considering Lärjeholm it is necessary to have in mind that water intake is closed along the year when the quality of the water from Göta Älv does not fulfil the quality requirements established by SLVFS1993:25 old quality criteria or when there has been contaminated by accidental spills upstream the raw water intake. In this case the concentrations used in the calculations refer to the periods when the intake has been open. This consideration is explained in Table 10.

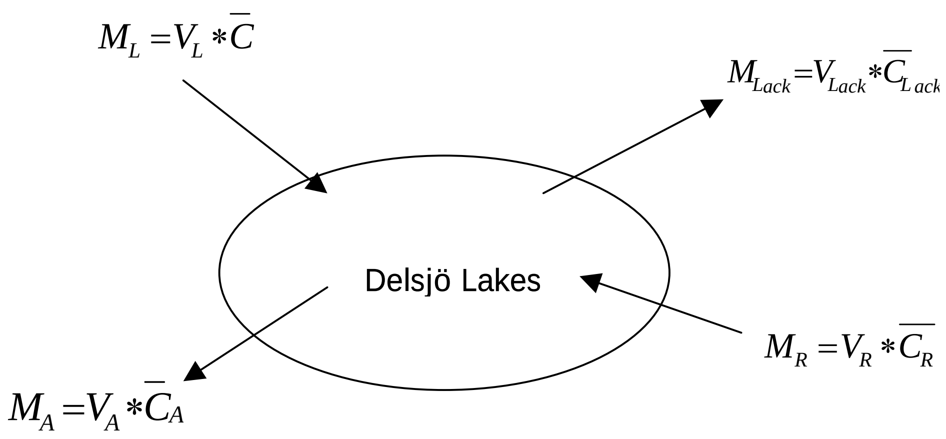


Figure 10: System considered for the mass balance

Table 10: Obtaining of the volume pumped to the lakes in Lärjeholm.

	January	February	March
% Open time	$\%_J$	$\%_F$	…
Volume	V_J	V_F	…
Volume pumped ($\overline{V_L}$)	$\%_J * V_J$	$\%_F * V_F$	…

According to the previous step:

$$M_L = C_L * \overline{V}_L \qquad \textbf{Eq 6}$$

Mass balance calculations at Alelyckan, Rådasjön and Lackarebäck:

Different considerations of the monthly mean concentration ($\overline{C}$) have been made at the different places in order to carry out the mass balance calculations. These considerations are at:

- Alelyckan ($\overline{C}_A$): Here it is necessary to take into consideration the time that the intake is closed when Alelyckan receives water directly from the lakes and not from the river. So to make the calculations, the days when the intake was closed more than 12 hours were not considered.

- Rådasjön ($\overline{C}_R$): At this point the calculation included the volumes pumped and the concentration of the measured parameters. Water quality monitoring in Rådasjön does not follow the same control and sampling programme as in the other places in the system. Turbidity, COD, TOC, ext254, pH etc was therefore not registered here. $\overline{C}_R$ was set to zero when calculating mass balance.

- Lackarebäck ($\overline{C}_L$): Calculations at this point follow the water budget equation.

$$M_{A,L,R} = \sum_{i=Jan}^{Dec} C_i * V_i \qquad \textbf{Eq 7}$$

4. Results and discussion

The first step in this work was to look after the overall situation of the system, see Appendix 4 for details. The diagrams obtained showed a considerable reduction of most of the parameters in their way through the lakes. Significant changes were found within most of the physical and chemical parameters (Appendix 5). Regarding the bacteriological parameters, the differences were notorious comparing Lärjeholm and Lackarebäck.

Aluminium (ICP) was overstepping the guidelines at the river site. Highest changes by the transport and reservoir storage were observed for the turbidity, iron and aluminium levels. The levels of chloride, extinction coefficient, manganese, and sodium however increase in concentrations. Manganese and sodium release could be explained by leaching from the sediments. Manganese may also be released from the sediments by anoxic conditions in the bottom of the lake. Chloride contents reported at Lärjeholm may be influenced by saline intrusion in the river, which is one reason for closing the intake. The chloride content at Lackarebäck may probably result from local pollution sources in the nearby of the lakes, such as urban runoffs. Elevated levels of the extinction coefficient could be related to an increase dissolved natural organic matter (NOM) in the lakes.

4.1 Correlations

Correlation computations were carried out using data from both Lärjeholm and Lackarebäck to have an idea of which parameters had influence over the others, and simultaneously verify if that influence was persistent along the system. Water quality at both places is expected to be different at the river and at Lackarebäck waterworks, as the waterworks is supplied directly from the lakes. Only data from the days were the river intake was open was included in the evaluations.

Lärjeholm:

Table 11 shows the correlations computed for the river Göta älv at Lärjeholm. Numbers above the diagonal cells marked in colour represents correlations for the whole period (Jan 2001- May 2004) while the numbers below the diagonal shows the computed correlation for the year 2003.

As can be deduced from the results presented in the table (upper part of Table 11), turbidity shows good correlations for the whole period with colour, iron, manganese and lead, indicating that particles giving colour or are suspended in the water body, also contributes to the turbidity. Colour also shows good correlation with Extinction coefficient (extinction coefficient at 254nm). Conductivity highly correlates to the chloride as expected, since conductivity is a measure of the ability of water to carry on electric current. The presence of ions increases the conductivity of water, as this by definition (Patnaik, P., 1997) is proportional to the concentration of ions. Iron correlates to manganese and lead, and that could possibly mean that they are present in the same particle in the water. Manganese presents also correlations with lead and cupper and cadmium. Lead correlates well with cadmium and zinc. Bacterial measurements correlate well as the correlation between coliforms, thermotolerant coliforms and *E.coli* were all higher than r^2=0.5.

Table 11: Lärjeholm's correlations results. Numbers above marked in the diagonal cells represents Pearson correlations (r^2) for the period Jan 2001- May 2004, and the numbers below the diagonal show the correlation for the year 2003.

	Pr temp	Turb	Colour	COD:Mn	TOC	Ext 254	pH	Conductivity	Alkalinity	Fe	Mn	NO3+2-N	Cl (titr)	Pb	Cd	Cu	Ni	Zn	Log colif	Log Therm	Log E.coli
Pr temp	1,00	0,08	**0,24**	0,00	0,00	**0,24**	0,03	0,00	0,00	0,02	0,00	**0,51**	0,00	0,15	0,12	0,01	0,16	0,15	0,09	0,11	0,07
Turb	0,11	1,00	**0,52**	0,13	0,00	**0,31**	0,00	0,04	0,01	**0,84**	**0,56**	0,16	0,04	**0,51**	**0,24**	0,14	**0,23**	**0,22**	0,15	0,09	0,04
Colour	0,03	**0,86**	1,00	0,11	0,01	**0,62**	0,01	0,04	0,06	**0,39**	**0,26**	**0,35**	0,04	**0,21**	0,07	0,04	**0,27**	**0,24**	0,03	0,01	0,00
COD	0,02	0,51	**0,50**	1,00	0,05	0,16	0,01	0,01	0,00	0,14	**0,38**	0,04	0,01	0,08	0,14	0,07	0,02	0,00	**0,20**	0,09	0,04
TOC	**0,45**	0,07	0,11	0,02	1,00	0,03	0,07	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,00	0,00	0,02	0,00	0,00	0,00	0,00
Ext 254	**0,26**	**0,54**	**0,61**	**0,66**	**0,39**	1,00	0,04	0,05	0,12	**0,23**	0,16	**0,40**	0,04	0,17	0,01	0,03	**0,40**	**0,27**	0,11	0,03	0,01
pH	0,05	0,15	0,15	0,09	0,12	0,17	1,00	0,01	0,04	0,01	0,06	0,02	0,01	0,14	0,17	0,04	0,06	0,07	0,01	0,04	0,05
Conductiv	0,05	0,15	0,15	0,09	0,12	0,17	0,02	1,00	**0,28**	0,05	0,03	0,00	**1,00**	0,00	0,00	0,03	0,01	0,01	0,00	0,01	0,01
Alkalinity	0,03	**0,27**	**0,29**	0,06	0,01	0,13	0,11	**0,31**	1,00	0,03	0,01	0,00	0,25	0,01	0,00	0,01	0,03	0,03	0,01	0,07	0,04
Fe	0,16	**0,98**	**0,80**	**0,46**	0,06	**0,50**	0,18	0,17	**0,33**	1,00	**0,72**	0,07	0,05	**0,57**	**0,28**	**0,28**	**0,20**	**0,25**	0,14	0,08	0,02
Mn	0,03	**0,79**	**0,91**	**0,68**	0,13	**0,74**	0,04	0,10	0,17	**0,71**	1,00	0,07	0,03	**0,34**	**0,31**	**0,34**	0,13	0,12	0,18	0,16	0,12
NO3+2-N	**0,24**	0,17	**0,21**	**0,27**	**0,23**	**0,60**	0,09	0,09	**0,20**	0,19	**0,29**	1,00	0,00	0,08	0,09	0,02	0,17	0,11	0,08	0,09	0,04
Cl titr	0,05	0,13	0,12	0,08	0,12	0,16	0,01	**1,00**	**0,28**	0,15	0,09	0,08	1,00	0,00	0,00	0,03	0,01	0,01	0,00	0,01	0,01
Pb	**0,36**	**0,39**	0,19	0,06	0,02	0,15	**0,31**	0,01	0,04	**0,44**	0,14	0,08	0,00	1,00	**0,50**	**0,25**	**0,21**	**0,54**	0,08	0,19	0,14
Cd	**0,33**	**0,71**	**0,45**	**0,40**	0,07	**0,47**	**0,31**	0,02	0,06	**0,73**	**0,49**	**0,23**	0,01	**0,76**	1,00	0,18	0,03	0,09	0,16	**0,27**	**0,22**
Cu	0,00	0,18	**0,25**	0,11	0,01	0,12	0,01	**0,21**	0,03	0,16	**0,22**	0,15	**0,23**	**0,20**	**0,25**	1,00	0,08	0,16	0,00	0,02	0,01
Ni	0,19	0,01	0,02	0,01	0,19	0,12	0,04	0,09	0,15	0,01	0,07	0,07	0,10	0,11	0,13	0,04	1,00	**0,40**	0,04	0,09	0,07
Zn	**0,23**	0,03	0,02	0,03	0,08	0,03	0,15	0,00	0,00	0,04	0,01	0,05	0,00	**0,57**	**0,20**	0,10	**0,23**	1,00	0,02	0,10	0,07
Log colif	**0,29**	**0,27**	0,16	**0,50**	**0,27**	**0,58**	0,15	**0,29**	0,00	**0,26**	**0,31**	**0,27**	**0,30**	0,08	**0,35**	0,04	0,10	0,00	1,00	**0,74**	**0,54**
Log Therm	**0,51**	**0,20**	0,07	**0,28**	**0,25**	**0,43**	**0,27**	0,10	0,00	**0,22**	0,17	**0,31**	0,11	**0,28**	**0,50**	0,01	**0,26**	0,08	**0,82**	1,00	**0,82**
Log E.coli	**0,53**	**0,27**	0,09	**0,24**	**0,28**	**0,42**	**0,40**	0,09	0,01	**0,29**	**0,20**	**0,32**	0,09	**0,29**	**0,53**	0,00	**0,22**	0,07	**0,74**	**0,93**	1,00

Correlations computed separately for the year 2003 (lower part of Table 11) are not that much different. Colour correlates well with turbidity and COD (chemical oxygen demand), meaning that coloured particles can be of organic origin and have influence over water turbidity. It also correlates well with the extinction coefficient, colour and COD. Iron and manganese both correlates with turbidity, colour, COD and extinction coefficient, meaning that those two elements are possibly present in particles of organic origin. For 2003 it was also found that nitrogen in the form of nitrate (NO_3^{+2}-N) highly correlates with the extinction coefficient.
The results also show that cadmium correlates well with turbidity, iron, manganese and lead; a possible interpretation of these results is that the particles present in the lakes and contributing to the turbidity are containing these elements. Coliform bacteria highly correlate with COD and extinction coefficient. Thermotolerant coliforms correlate well with temperature, cadmium and coliforms. Finally *E.coli* correlates with temperature, cadmium, coliforms and thermotolerant coliforms.

The high relationship between bacterial parameters was expected since they are subgroups of the same specimen. Temperature is known to have an effect over bacterial die off, with a more rapid reduction at higher temperatures. The correlation (that may be positive or negative) with thermotolerant and *E. coli* was emphasized during 2003 compared to the period 2001-2004. Cadmium was similarly correlated to these two bacterial parameters. Turbidity shows no correlation at all with bacteria, neither during the period 2001-2004 nor the year 2003. In conclusion, no correlation of evidence was found between the bacteria and non-bacterial parameters.

Lackarebäck

Table 12 shows the correlation statistics at Lackarebäck water treatment plant. Numbers above the diagonal cells marked in colour represents correlations for the whole period (Jan2001- May 2004) while the numbers below show the computed correlation for the year 2003.

Table 12: Lackarebäck's correlations results. Numbers above the diagonal cells marked in colour represents Pearson correlations (r^2) for the period Jan2001- May 2004 and the numbers below the correlations for the year 2003

	Pr temp	Turb	Colour	COD:Mn	TOC	Ext 254	pH	Conductivity	Alkalinity	NO2-N	NO3+2-N	Cl titr	log Colif.	log Therm	log E. coli
Pr temp	1,000	0,114	**0,204**	0,082	0,006	**0,357**	0,017	0,120	0,088	**0,341**	0,195	**0,218**	0,029	0,185	0,161
Turb	0,168	1,000	**0,412**	0,049	0,016	**0,283**	0,006	0,028	**0,225**	0,018	0,109	0,002	0,003	0,102	0,092
Colour	**0,346**	0,178	1,000	**0,235**	0,032	**0,656**	0,043	0,001	**0,412**	0,187	0,177	0,075	0,033	**0,219**	**0,221**
COD:Mn	0,004	0,178	0,029	1,000	0,009	**0,359**	0,000	0,012	0,062	0,057	0,004	0,068	0,002	0,184	0,194
TOC	**0,378**	0,103	0,127	0,012	1,000	0,052	0,003	0,005	0,021	0,017	0,012	0,012	0,197	0,001	0,001
Ext 254	**0,365**	**0,260**	**0,293**	**0,253**	**0,339**	1,000	0,031	0,056	**0,374**	**0,267**	**0,251**	**0,222**	0,010	**0,255**	**0,239**
pH [L]	0,071	0,005	0,149	0,071	0,043	0,000	1,000	0,100	0,003	**0,293**	**0,211**	0,060	0,035	0,000	0,000
Cond [L]	**0,264**	0,001	0,016	0,010	**0,439**	0,141	0,105	1,000	0,065	**0,310**	0,002	**0,814**	0,003	0,051	0,062
Alkalinity	0,150	0,042	**0,225**	0,030	0,108	0,088	0,003	0,001	1,000	0,004	**0,287**	0,001	0,027	**0,249**	**0,268**
NO_2-N	**0,261**	0,047	0,112	0,020	0,080	0,057	**0,436**	0,113	0,006	1,000	0,125	**0,363**	0,007	0,002	0,005
NO_3^{+2}-N	0,042	0,001	0,185	0,130	0,088	0,004	**0,659**	**0,315**	0,140	0,079	1,000	0,026	0,014	0,145	0,141
Cl titr	**0,392**	0,107	0,088	0,002	0,856	0,463	0,056	**0,523**	0,121	0,052	0,091	1,000	0,018	0,000	0,000
log Colif	0,011	0,025	0,000	**0,288**	0,166	**0,360**	0,004	0,029	0,005	0,004	0,050	0,094	1,000	0,009	0,018
log Term	0,078	0,199	**0,314**	0,048	0,022	**0,297**	0,003	0,090	**0,523**	0,083	0,157	0,023	0,129	1,000	**0,972**
log E. Coli	0,078	0,199	**0,314**	0,048	0,022	**0,297**	0,003	0,090	**0,523**	0,083	0,157	0,023	0,129	**1,000**	1,000

Statistics computed for the period 2001 to May 2004 (upper part of Table 12) show only a few correlations between the variables. Several of the correlations observed for the data in Lärjeholm are not found here, except for conductivity and chloride. Turbidity and colour has a correlation of 0,41, which may be considered as low, which means that here in Lackarebäck colour is not connected to the water turbidity as it is in Lärjeholm. Colour was also highly correlated to the extinction coefficient, possibly reflecting the humidification of the water during the lake storage.

The results for the year 2003 (lower part of Table 11) show few strong correlations. Thermotolerant coliforms and *E. coli* was perfectly correlated to each other. Again, turbidity shows no evident correlation with bacteria. Two other correlations are found here, pH with nitrogen and nitrate ($NO3^{+2}$ – N) and TOC (total organic carbon) with chlorine. Chloride was also highly correlated to conductivity.

4.2 Water Quality and Lake Depth

Measurements in the lakes are carried out at different depths and so they are analysed to see if there is any influence over the water quality with the depth.

Lilla Delsjön

Water diverted at the intake i.e. Lärjeholm reaches Lilla Delsjön after being pumped by two pumpstations in the nearby of Lärjeån and Härlandatjärn. Aesthetic parameters and bacterial amount are affected by the time they spent in the tunnel that connects the intake with the lake, so the study of them at different depths can give an idea of their behaviour.

The diagrams in Figure 11 show the aesthetic and bacteriological parameters at different depths.

The plots show no greater differences for the aesthetic parameters between the surface and 5mt depth. However, depth the bacteriological measurements at 5mt show a considerable diminution when compared to the surface measurements, probably due to bacterial decay. Clearly depth influences the bacterial amount in the lake, but not the aesthetic parameters.

Bacteria decrease in amount with the depth, so it is possible to presume that bacteria is not able to survive in the bottom of Lilla Delsjön, and there is a decay in the number because of the depth.

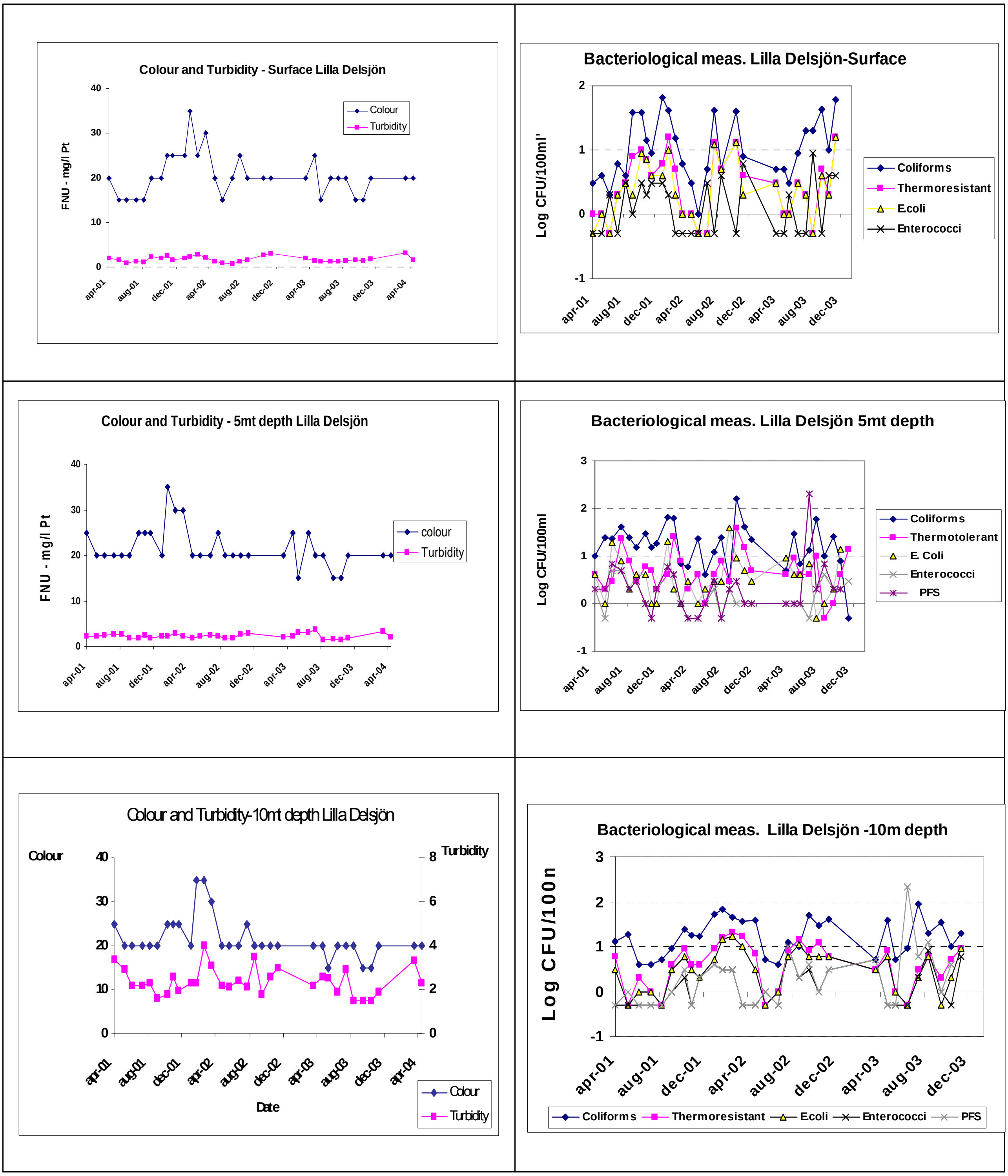


Figure 11: Aesthetic and bacteriological measurements at different depth in Lilla Delsjön.

Stora Delsjön

At this point measurements were done at different depths also, and they were studied and analysed according to that. The aesthetic parameters still show high values, while the bacteriological decrease notoriously. In order to facilitate the comprehension, just the surface and 15mt depth graphs are shown. Bacterial amount is plotted directly in colonies because of the small amount of them. Coliforms and thermotolerant coliforms still are present at this point, but the amount of *E.coli* diminishes considerably. Just PFS (presumptive faecal streptococci) shows an extreme peak in the summer of 2003 in the surface plot.

At 15mt depth aesthetical parameters have almost no difference with those from the surface and regarding bacteriological measurements *E.coli* and coliforms present almost no variation. It is observed though that PFS has a peak in the surface that it is not accounted with the depth.

Water storage in Stora Delsjön leads to improvement in water quality regarding not only bacteriological parameters, but also aesthetic ones. At this point is possible to observe that bacteria is not surviving in the bottom of the lake as also happens in Lilla Delsjön.

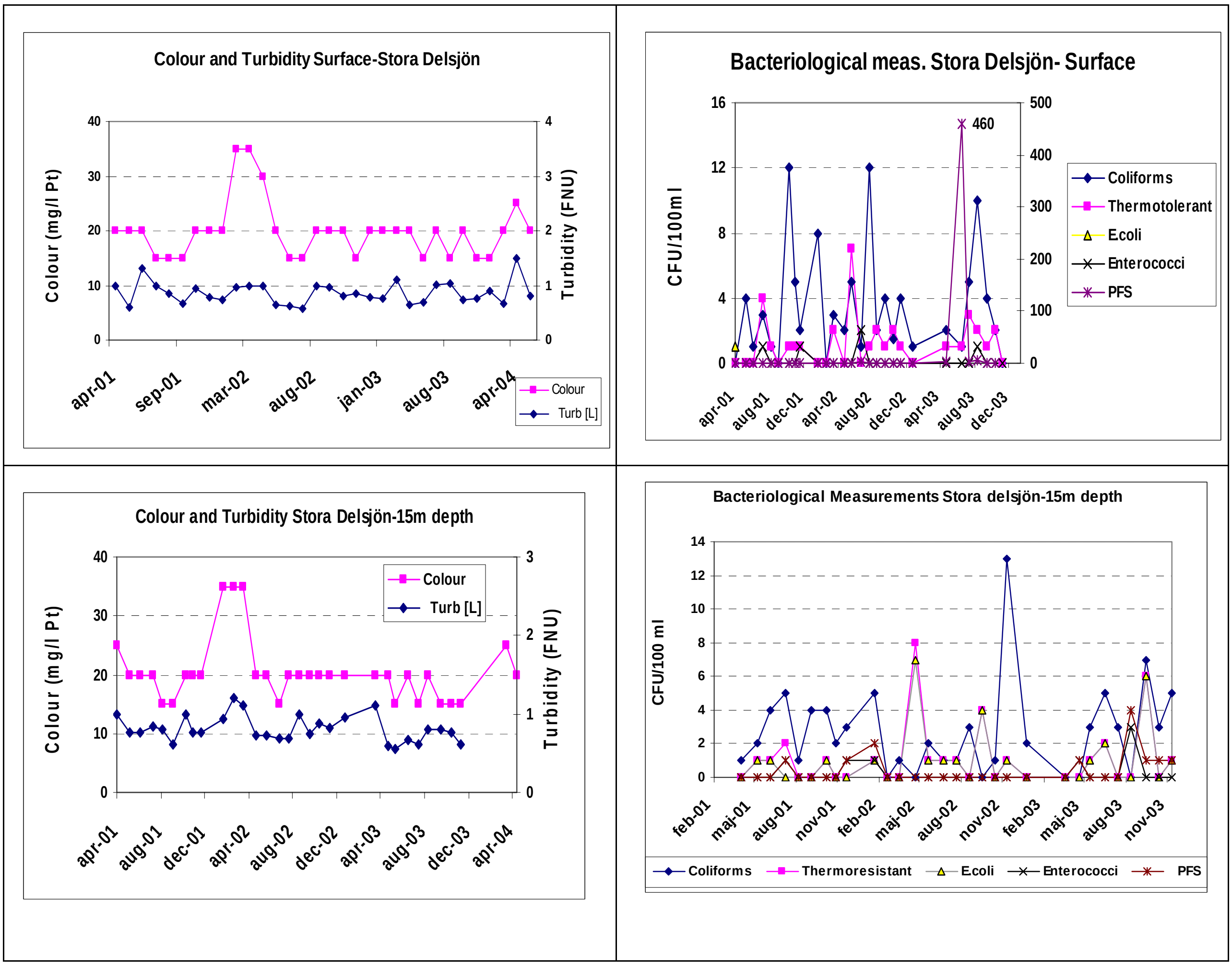


Figure 12: Aesthetic and bacteriological measurements at different depth in Stora Delsjön

4.2 Mass Balance

The mass balance calculations of pollutants were based on annual estimation of the water volumes entering the lakes, assuming that all the water entering the lakes come either from Lärjeholm or from Rådasjön. Runoff from surroundings areas (which accounts for about 10% of the lakes volume per year) during precipitation or natural contribution from streams was not considered. In the same way it was assumed that the withdrawal of water from the lakes was direct delivered to the waterworks. Natural looses, such as evaporation and infiltration, and seasonal variations were not considered. In spring and fall the water column is normally well mixed while in winter and summer stratification occurs. In winter the surface becomes congealed, due to the low temperatures, and in summer layers of water are formed due to the difference in temperature between the surface and the lower layers. It was also considered that Alelyckan receives water that have spent some time in the lakes, but it is not possible to be sure of that, since the water could have recently entered Lilla Delsjön when it was withdrawn to the waterworks.

Generally speaking in the year 2003 Delsjöarna showed to have a decreased capacity in raising the water quality coming from Lärjeholm. Years 2001 and 2002 show similarities in some of the compared parameters, but the year 2002 is when the lakes showed their best capacity in increasing water quality. The results obtained are presented in Tables 13, 14 and 15 of this report for all the parameters measured at the places of interest for this purpose. However, it is necessary to mention that data from Rådasjön not always was available for all the parameters in all the years.

When looking at physical-chemical properties, see Table 13, colour and COD are the only parameters in which data from Rådasjön was available for the computing of the reduction. Colour presents a good reduction in both 2001 and 2002, but in 2003 there is no reduction at all. COD also presents good reduction percentages in both 2001 and 2002, but in 2003 the results are the same as for colour. The same trend is observed for the other parameters, even when Rådasjön data was not available.

Looking at the microbiological parameters, significant reductions were obtained in both 2001 and 2002 (Table 14). In 2003 however, the percentage of reduction decreased in all the measured organisms. In the case of enterococci and PFS (presumptive faecal streptococci), Rådasjön data was not available and thus the results presented here are affected by this lack of information.

Table 13: % Reduction of some Physical-chemical properties

	2001	2002	2003
Turbidity	97	97	54
Colour	90	87	-4
COD	87	84	-30
TOC	84	86	-77
Ext 254	86	83	-81
Conductivity	87	83	-4
Alkalinity	87	84	-81

Shaded area: data from Rådasjön are not available.

Table 14: % Reduction of microbiological parameters

	2001	2002	2003
Coliforms	97	95	53
Thermoresistan	99	98	86
E.coli	99	98	73
PFS	-	98	44
Enterococci	98	98	-

Shaded area: data from Rådasjön are not available.

Table 15 shows reduction percentages of chemical parameters measured at the four places considered for the mass balance study. There are cases where just one year was measured, considering also that data from Rådasjön was not available. As said before, this situation can lead to misconceptions or wrong interpretations of the trends observed, so for a better understanding of the lakes behaviour would be necessary to have all the data that can be useful for that purpose.

Table 15 shows that chemical parameters follow the same trend as in the previous tables. Again 2003 were less efficient for the Delsjöarna in their capacity to increase the water quality. Year 2002 is the one where water reaches the best quality and in 2001 the reduction is not as good as in the other years, even when in this year data from Rådasjön is not available and was not considered for the calculations.

Table 15: % Reduction of some chemical parameters

	2001	2002	2003
Ca ICP	74	86	-38
Mg ICP	-	86	15
Na ICP	64	80	25
K ICP	73	85	-10
Fe ICP	95	93	42
Mn ICP	62	70	-139
Al ICP	-	95	49
Al^{+3}	88	93	23
NO2-N	87	85	-65
$NO3^{+2}$-N	90	88	-33
PO_4-P	97	99	-
F IC	88	99	-58
Cl IC	69	72	-93
Cl titr	86	78	40
SO4 IC	76	83	-43
As ICP	67	83	-25
Ba ICP	-	86	-41
Pb ICP	84	90	-12
B ICP	-	81	-3
Cd ICP	-2	84	11
Co ICP	-	89	9
Cu ICP	77	88	-13
Cr ICP	81	89	-29
Mo ICP		87	-38
Ni ICP	81	89	-3
Zn ICP	85	90	19
GC tot/IS	87	87	-59

Shaded area: data from Rådasjön are not available.

Table 16: Radasjön pumping (Mm3) and total closed hours between 2001-2003

Year	Lärjeholm Pumping (Mm^3)	Rådasjön Pumping (Mm^3)	Intake (closed hours)
2001	33.296	3.09	1475
2002	31.174	7.48	2139
2003	33.67	6.39	2184

The intake was increasingly closed from 2001 to 2003 (see Appendix 1 for details), and thus the lakes receive more water from Rådasjön in order to keep the water level, this information is summarized in Table 16.

During 2002 and 2003 different volumes pumped to the lakes from the river, even though the total time when the intake at the river (Lärjeholm) was closed was similar. Still is possible to confirm 2002 as the best year in terms of reduction percentage of the measured parameters.

To check if the reduction was constant during the year, the % of accumulated monthly reduction was plotted for coliforms and colour in Figures 11 and 12. In both cases it is clear that the reduction is similar for the years 2001 and 2002, with the difference that 2002 begins with a low reduction and then recovers. Year 2003 clearly was not good in terms of reduction.

As can be seen in the Figure 13, colour reduction in the lakes was efficient in 2001 and 2002, even though considering that 2002 begins with a low reduction of 40%. Colour reduction in 2003 was poor, with negative values that show a trend to improve during the year.

Coliforms reduction shows a similar pattern to the one of colour for the years 2001 and 2002. The results are summarized in Figure 14.

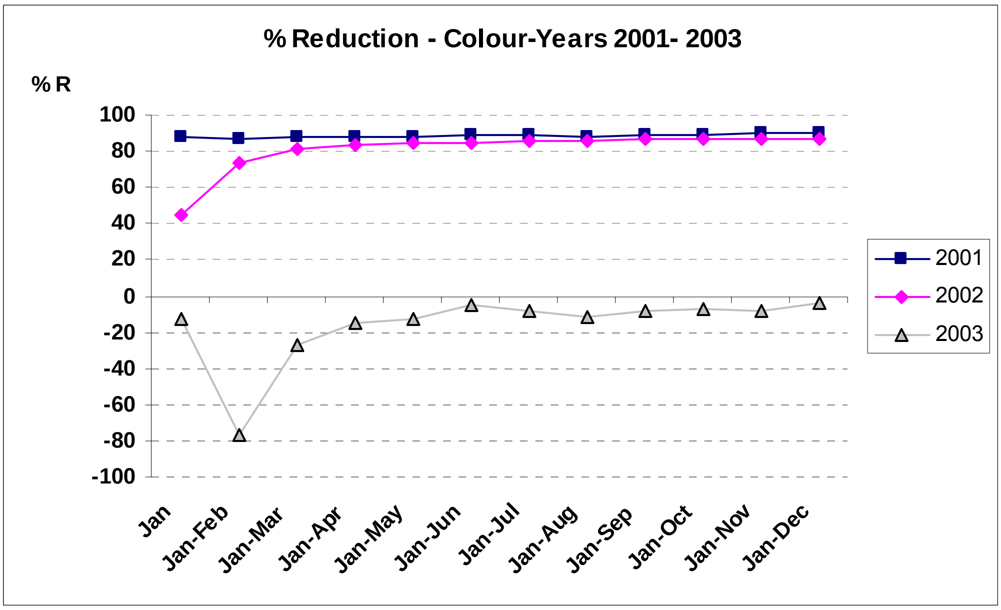


Figure 13: % Accumulated reduction for colour years 2001 –2003.

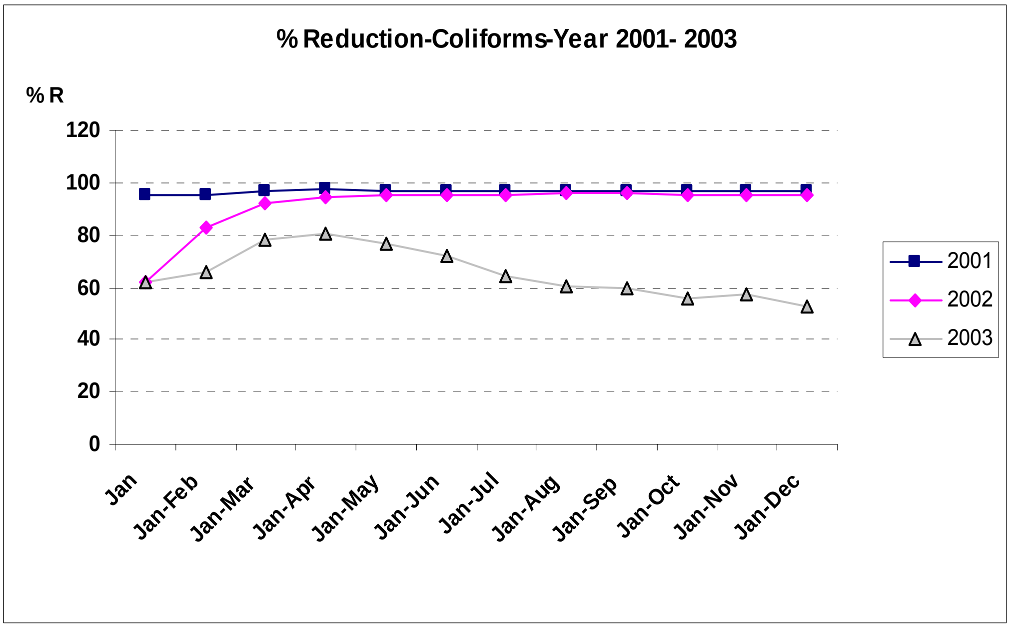


Figure 14: Coliforms reduction for the years 2001-2003

The reduction capacity of Delsjöarna, regarding coliforms, began positively in 2003 but then during the year this capacity was diminishing. In 2003 there are no signs of recovering reaching at the end of the year the lowest value (52.96%).

The reduction (%) considering the residence time was done for colour and coliforms was evaluated, assuming that the water entering Lackarebäck has spent at least three months in Delsjöarna Lakes. To do the calculations, the datasets were lagged three months in comparison to each other. For example, water entering the lakes between January and March was considered to be taken out between April and June. Natural contributions/withdrawals of water and seasonal interferences were not included in the considerations. The results are summarized in Table 17.

Table 17: Reduction (%) considering retention time

	W_{in}	W_{out}	% R coliforms	% R colour
2001	Jan-Mar	Apr-Jun	97	90
	Apr-Jun	Jul-Sep	96	91
	Jul-Sep	Oct-Dec	96	90
	Oct-Dec	Jan-Mar(02)	96	84
2002	Jan-Mar	Apr-Jun	96	78
	Apr-Jun	Jul-Sep	97	91
	Jul-Sep	Oct-Dec	94	86
	Oct-Dec	Jan-Mar(03)	98	89
2003	Jan-Mar	Apr-Jun	64	-24
	Apr-Jun	Jul-Sep	38	12
	Jul-Sep	Oct-Dec	35	-19

W_{in} = water that enters Delsjöarna

W_{out} = water that enters both water works

The results obtained when considering the retention time show a high degree of reduction during 2001 and 2002. A lower reduction was obtained during 2003. These results are in concordance with the ones obtained when doing the annual estimation and are therefore a confirmation of the diminution in the lakes capacity in reducing the bacterial amount and improve aesthetical properties from the raw water entering Lackarebäck.

5. Conclusions.

Göteborg's water supply system was evaluated over the period from January 2001 to May 2004 from data collected by the Göteborg Water and Sewage Works (Göteborgs va-verk). The system includes the river intake (Lärjeholm), the pumping stations at Lärjeån and Härlanda Pond, the lakesystem Delsjöarna, Rådasjön Lake and the waterworks Alelyckan and Lackarebäck. Since the early days of the city, the water has been provided from the river Göta älv, and diverse strategies have been applied in order to maintain the quantity and quality of drinking water to the city. The incorporation of the lake system to the system supply came in the 60's when Lackarebäck Waterworks was built. River diversion or pumping water from the river was fond to be the appropriate and cost-effective water supply in Göteborg, continuously developing and facing higher water demands each day.

The raw water supply is complex in the sense of the numerous inputs and outputs present in it. Different actions are undertaken to handle problems related to the raw water quality. The river intake can be closed up to three months, due to the water quality in the river, and Alelyckan waterworks is then fed from Delsjöarna. The intake has been closed more frequently during the last years. Water form the river has high amounts of colour, turbidity and bacteria, which affect the water treatment in terms of costs. Water from the lakes carries considerable lesser amounts of pollutant loads, which in turn means lower costs and treatment time. This difference in water quality can be viewed as a key water management tool. Costs and troubles caused by water with higher levels of colour and turbidity can lead to a change in the current way of running Lackarebäck.

The difference in the water quality at Lärjeholm and Lackarebäck was established by looking at the parameter changes over the system (Appendix). Most of the parameters notoriously decrease during the reservoir storage in the lakes, except for chlorine, sodium, the extinction coefficient and manganese. The increase of sodium and chloride may be explained by natural occurrence or local pollution of the lakes. The higher extinction coefficient of the lakes may be related to the occurrence of natural organic matter, mainly supplied by high runoff from the surroundings areas.

Manganese concentrations showed a seasonal variation, with an increase during fall as the water column started to mix at the end of the summer stratification period with release of manganese ions from the bottom of the lakes due to the anoxic conditions. Manganese is of concern, because high levels may imply further needs for treatment associated with higher operational costs.

The reduction of the bacteria was one of the benefits achieved by pumping water from the river into the lakes. The first important reduction takes place by the tunnel transport from Lärjeholm (the river), passing two pump stations to reach Lilla Delsjön. The transport takes around 2 days (vaverket's intern information). The retention time may be of significant importance for the reduction of microorganisms. The conditions in the levels of oxygen and nutrients may limit the survival of microorganisms (e.g. the bacteria) during the transport. Other factors that dictate the survival, as given by the conditions in the lakes, are the temperature, predation by other micro organisms and sunlight conditions.

Correlations between the continuously registered parameters were statistically evaluated to measure the interrelationship. With an attempt to explain the better water quality entering the Lackarebäck waterworks, correlations within this dataset were compared to Alelyckan waterworks. Thereby 13 correlations of importance (r^2>0,5) were revealed from data for the period 2001-2004 at the river site Lärjeholm (24 correlations for the year 2003), while only two correlations at Lackarebäck waterworks (5 for the year 2003). It should be mentioned that this analysis was carried out with only 5 months data form 2004. Several correlations were expected, such as conductivity and chloride or extinction coefficient and colour. Different correlations were observed at Lärjeholm compared to the Lackabäck waterworks. This may indicate that the lake storage was not only affecting the amount of substances but also their interaction.

Mass balance calculations were undertaken based on several assumptions. These assumptions had to do with the inputs and outputs to the system. The natural runoff to and from the lakes, and the presence of leakages or seasonal interferences was not corrected for the evaluations. The fact that the lakes have a retention time of three months adds some extra complication to the model used. The calculations were done using monthly average values and the retention time was considered only to corroborate the results. Through mass balance calculations it was possible to assess the capacity of the lake system to reduce the levels of different parameters. The results corroborated that the lakes significantly reduced pollutant loads. The reducing capacity was not constant in the period studied. Similar reductions were observed for the years 2001 and 2002, while 2003 was unexpectedly bad in terms of reduction.

The obtained results may be correlated to the water volume pumped from Lärjeholm to maintain the level in the lake system Delsjöarna. Between 2001 and 2002 this volume was reduced by 2.122 Mm^3 as the intake was closed 2139h in 2002 (1475h in 2001). Simultaneously, pumping from Rådasjön Lake was increased by 4.39 Mm^3, which may influence the water quality during the year 2002. Between 2002 and 2003 water pumped from the river increased by 2.46 Mm^3 and water pumped from Rådasjön decreased by 1.09 Mm^3. The intake from the river remained open in a similar extent in 2002 and 2003.

Again, the years 2001 and 2002 were good years in terms of pollution reduction. Though, the bad pollutant reduction results for the lake system Delsöarna in 2003 can be associated to the bad water quality in the river and the pumped water from the lake Rådasjön.

From the results obtained it is possible to affirm that an increased load of chemicals or bacteria could affect in the long term the capacity of the lakes in reducing them. Today the reduction is appreciable, as the diagrams in section 8.5 showed, but according to the water budget there is a deterioration of this capacity under 2003.

6. Further Studies

As a result of the analysis and results of this thesis work it was found a great difference between water entering the system at Lärjeholm and water at Lackarebäck waterworks. This difference resides basically in the diminution of all measured parameters, i.e. aesthetical, chemical and microbiological. Present results shows that the lake system Delsjöarna are effective in reducing the amounts of measured parameters. It has been shown, through mass balance calculations using an ideal site model, that the reduction was very low in 2003. However, these results should be confirmed by taken into considerations other inputs and outputs as well as the seasonal changes that may affect the lakes. Deeper and longitudinal studies are needed. A period of 5 or 6 years may be appropriate to confirm trends discussed within the present study. Additional measurements are needed for the lake Rådasjön to confirm the relative impact of this lake in the system analysis. The impact from Rådasjön may represent increased risk for productions of biofilms.

It would also be of interest to focus on the water transport between the river and Lilla Delsjön. Present study indicates that the retention time within the tunnel transport influenced the chemical and bacterial loads. In order to do this, the method carried out by Garvey et al (1998) could be applicable. The method involves a coliforms die-off field study using aliquots of coliforms inside membrane bags cultivated at different depths and places. The method also implies use of drogues designed to travel with the flow of water monitored using the GPS technology (Global Positioning System). As a result the study proposes a model that will be able to predict the water quality in the reservoir.

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Appendix

Diagrams given below give additional information regarding the present situation at the river intake at Lärjeholm and the lakes Delsjöarna.

1. Lärjeholm: closed hours and causes for closing the raw water intake.

The closed hours during the studied period are presented in Figure 1, but ahead in the appendix this time is not considered since what was intended in this part was to give an overview of the situation of the different places of the system between January 2001 and May 2004.

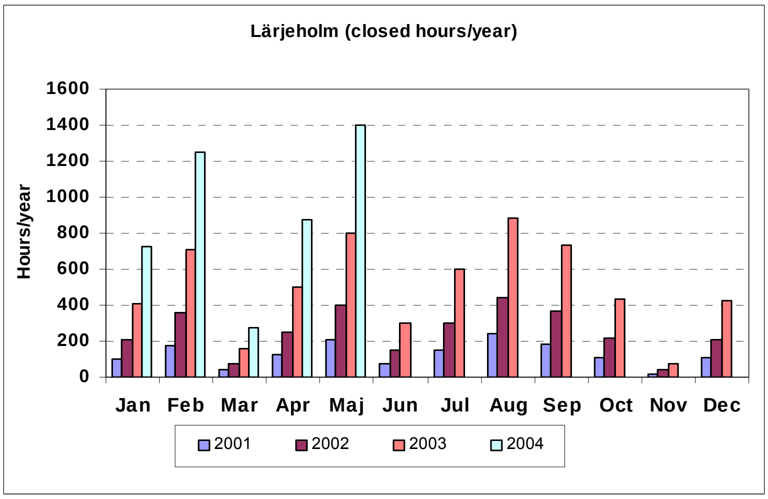


Figure 1: River Intake, closed hours 2001 – 2004.

Table 1: Intake closing causes, hours per year

Cause	2001	2002	2003	2004*	Total (hours)
Salt	153	294	746	13	1206
pH	0	0	0	0	0
Redox	0	0	0	0	0
Chem. Spill	0	0	25	0	25
Oil	102	0	247	0	349
Turbidity	153	18	95	0	266
Bacterial/drain	797	1663	822	1007	4289
Other	270	164	249	111	794
Total(hours/year)	1475	2139	2184	1131	6929

* : data collected until May

2. *Volumes pumped from Rådasjön Lake into Delsjö Lakes*

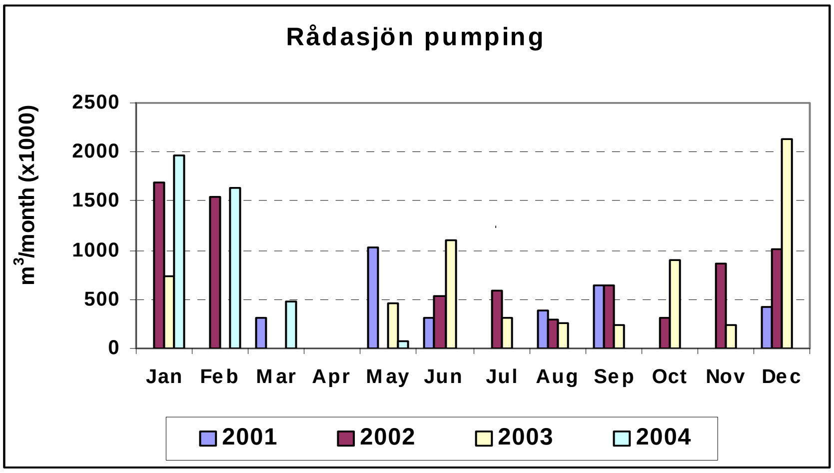


Figure 2: Water pumped from Rådasjön during 2001 – 2004

3. *Volumes involved in Alelyckan and Delsjö Lakes*

Table 2: Water processed in Alelyckan waterworks.

Alelyckan (Mm^3)	2001	2002	2003
Total received	34,3	34,6	37,4
From Göta Älv	28,9	26,5	29,4
Total delivered (potable water)	31,1	30	31,7

Table 3: Water volumes received and delivered by the lakes, 2001 –2004.

Delsjöarna (Mm^3)	2001	2002	2003
To Lackarebäck	32,1	32,1	33,8
To Alelyckan	5,42	8,11	8,05
From Göta Älv	33,2	31,2	33,7
From Rådasjön	3,2	7,9	6,5

4. *Reception and analysis of the data.*

This section will introduce the situation regarding the measurements of the diverse parameters in order to understand the processes in the system. Figure 3 shows the variations of coliforms along the whole system, from the river intake Lärjeholm to Lackarebäck waterworks. Coliforms were selected for their characteristics as indicator microorganism giving a degree of water contamination. The concentrations are given in logarithmic values to facilitate comparisons. Also some assumptions were made in order to facilitate calculations when measurements results were given in terms of "<"when observed to be below the detection level. Undetectable values were set at half the value of the detection level.

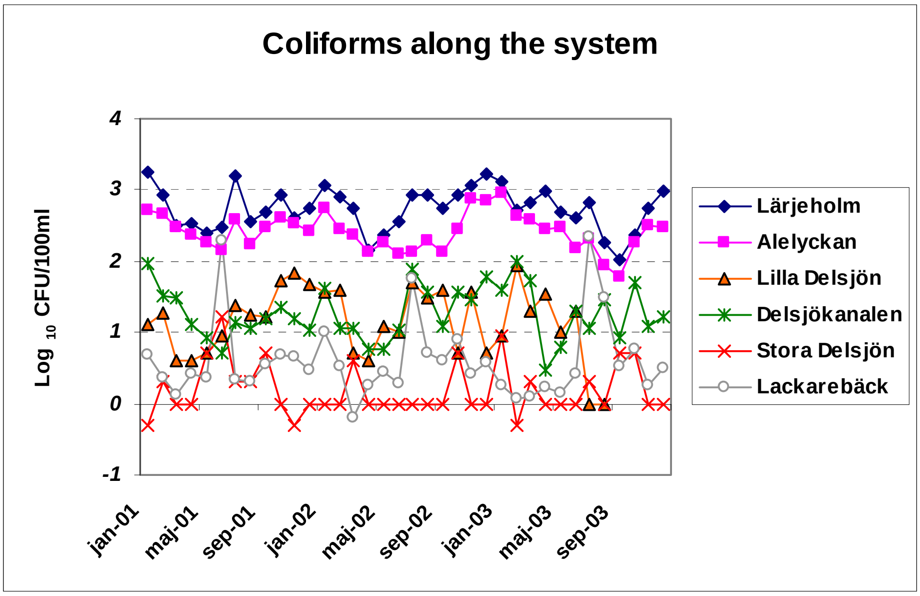


Figure 3: Coliforms along the system.

The amount of bacteria was reduced during the transport from the intake to the lakes and waterworks. Alelyckan shows levels similar to Lärjeholm. Alelyckan receives water from Delsjöarna when the intake is closed, possibly lowering the bacterial amount. Lilla Delsjön and Delsjökanalen were observed to contain lower bacterial amounts compared to Lärjeholm and Alelyckan. The bacterial amount in Stora Delsjön shows a considerably diminution, though having some extreme peaks. The water at Lackarebäck contained higher amount of coliform bacteria than Stora Delsjön with some extreme peaks, which probably may be explained by local contaminations or bacterial growth.

River Intake - Lärjeholm

The monthly average values of the aesthetic and bacterial parameters were compared to the old guidelines given by SLVFS 1993:35. The levels of turbidity and colour were given in Figure 4. The guideline values regarding colour (<50 mg Pt) were not overstepped.

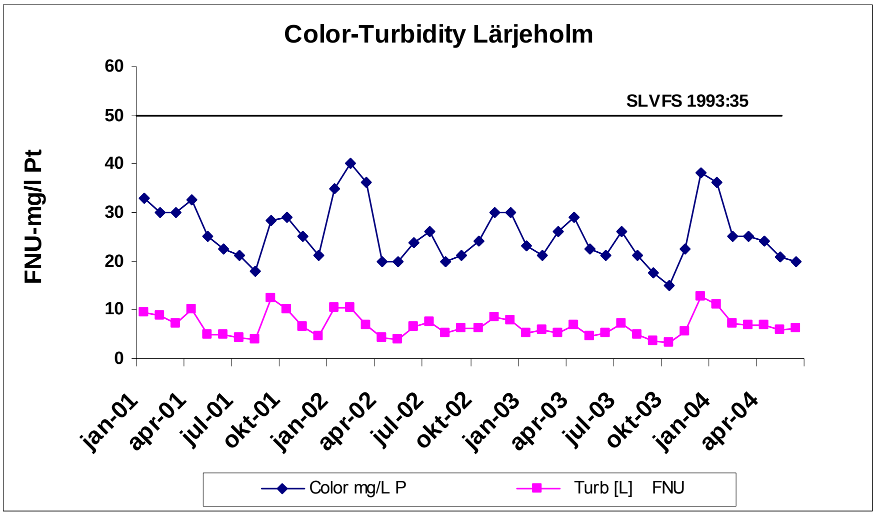


Figure 4: Colour and turbidity measurements-Lärjeholm

Considering the bacteriological parameters the montly average values were not overstepping either the guideline values for *E.coli* (<500 CFU/ 100ml) or coliforms (< 5000 CFU/ 100 ml). Although, the presence of fresh faecal contamination and or wastewater contamination in the river cannot be neglected according to what it is established in the literature (section 1.4 of this report), and occasionally high levels (above the guideline values) are registered in Lärjeholm.

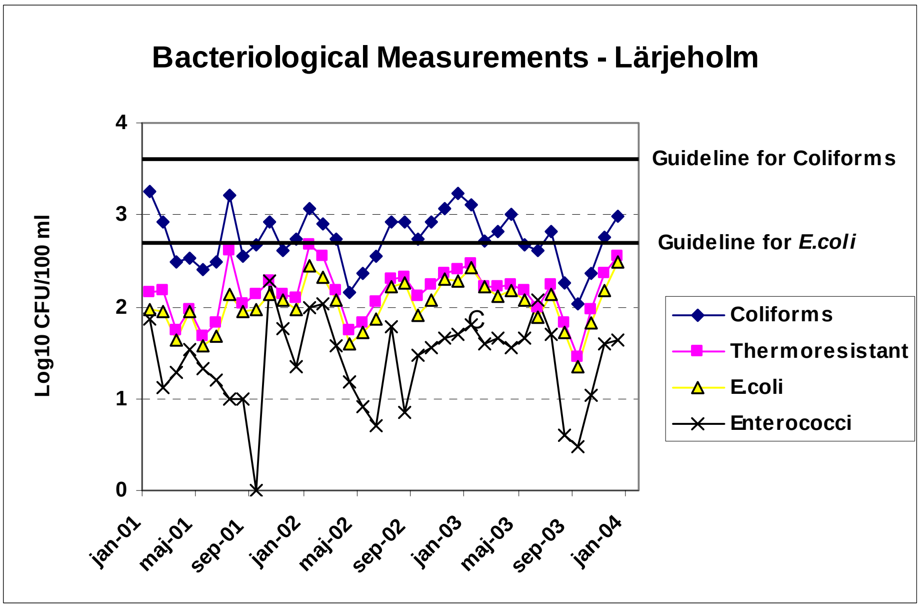


Figure 5: Bacteriological measurements-Lärjeholm

Alelyckan Waterworks

Water that enters Alelyckan comes either directly from the intake or from the lakes, depending on the intake being closed or not. In Figure 6 are presented the aesthetic parameters recorded at Alelyckan. No consideration of the time where the intake was closed is made here.

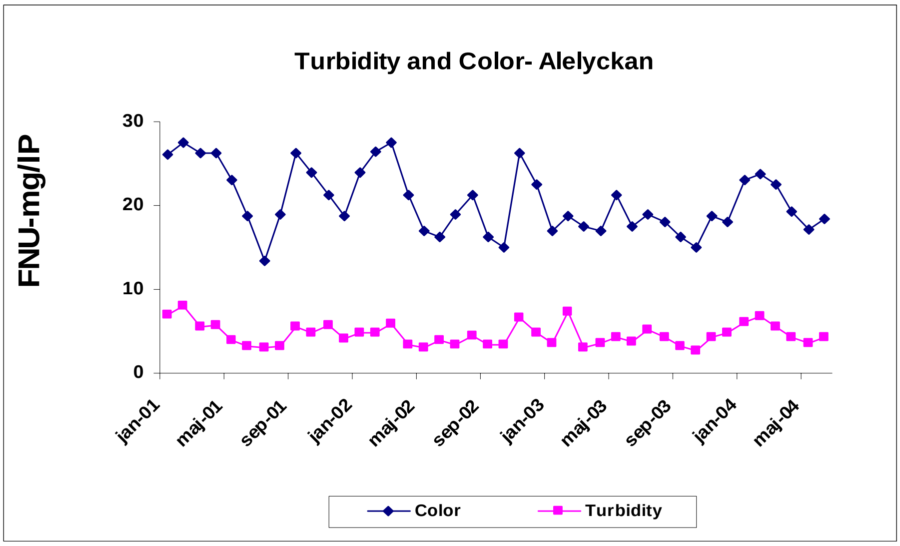


Figure 6: Aesthetic Parameters-Alelyckan

Looking at the figure it is possible to verify a decrease in the values of the aesthetic parameters, compared to those observed at Lärjeholm, since some of the water entering the waterworks had been stored in the lakes for a while.

Regarding bacteriological measurements, Figure 7 shows the situation at Alelyckan.

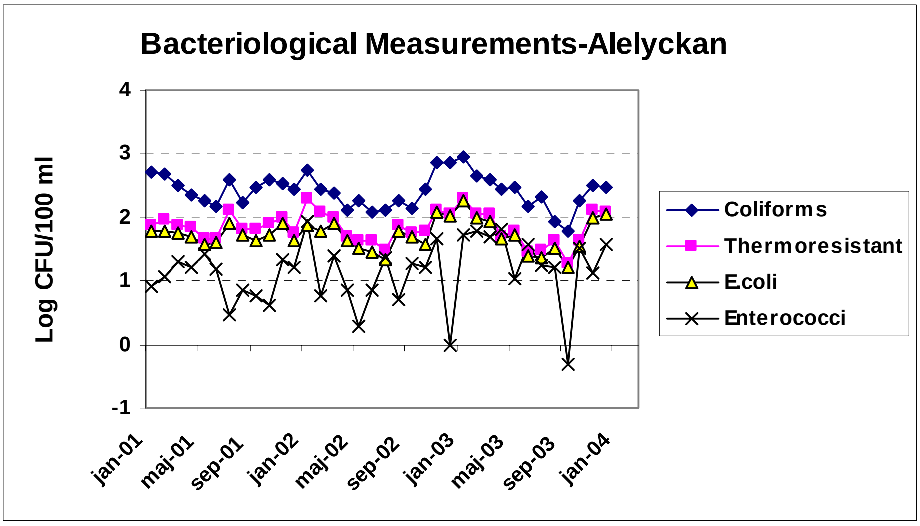


Figure 7: Bacteriological Measurements-Alelyckan

Bacterial amounts are still high at Alelyckan, especially coliforms. Thermoresistant and *E.coli* show similar trends, reaching very low values along the studied period, probably due to the time stored in the lakes. Enterococci show further diminution in their amount when entering Alelyckan.

Delsjökanalen

The Delsjö channel is an open artificial channel that connects the two lakes. In the channel only bacteriological measurements were carried out, which are shown in Figure 8. Montly average values of Coliforms and *E.coli* did not overstep the guideline value given by SLVFS 1993:35, <5000 and < 500 CFU/100ml respectively.

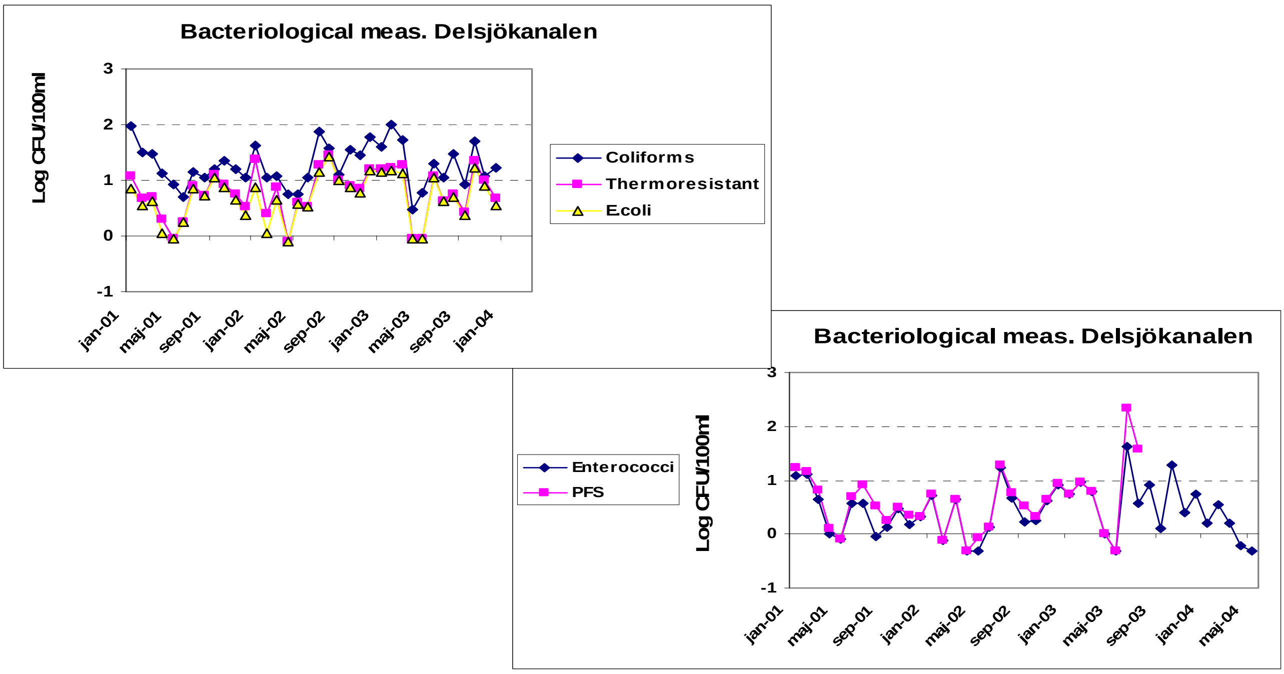


Figure 8: Bacteriological Measurements- Delsjökanalen

As can be seen, faecal coliforms and *E.coli* are occur at high levels. Monthly average peaks of *E.coli* were observed in August 2002 and in October 2003. Coliforms are still present in much higher values than *E.coli* but they are far below from the guideline values (<< 5000 CFU/ 100ml).

__Lackarebäck Waterworks:__

Water quality that enters Lackarebäck waterworks is comparatively better to the Lärjeholm's one, even though some relative extreme values were found in the last set of control measurements before the production process. Turbidity, colour and the bacterial amount is low, though some extreme values were registered under the summer season.

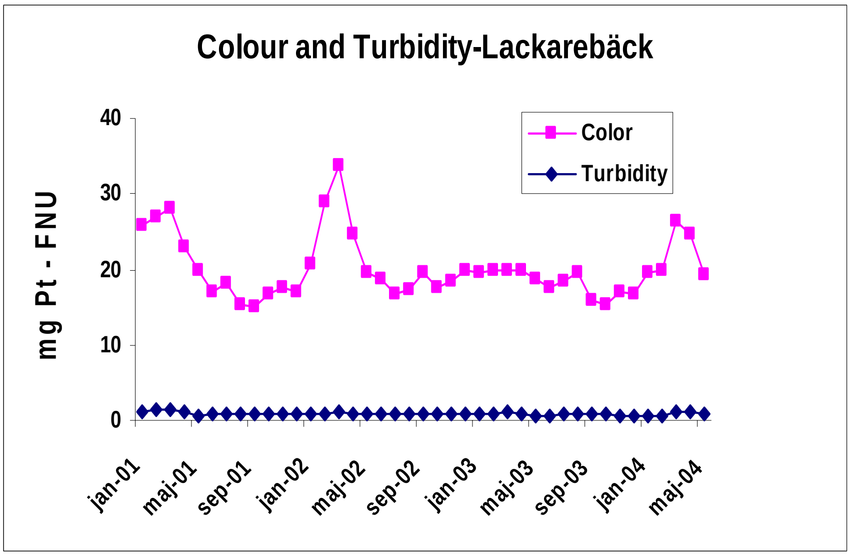


Figure 9: Aesthetic Parameters-Lackarebäck

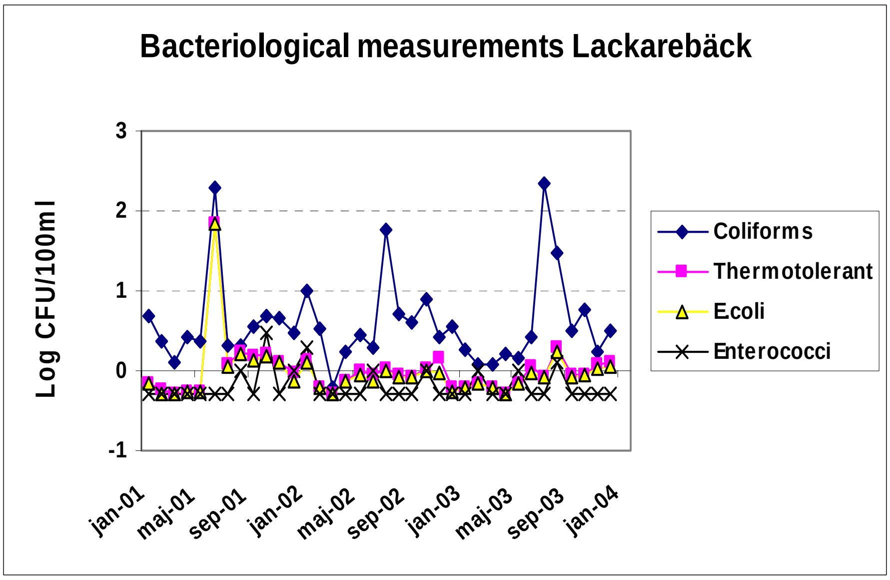


Figure 10: Bacteriological Measurements -LAckarebäck

5. Changes in the system

It has long been known that the water entering Lackarebäck had much better quality than the one entering Lärjeholm. In order to verify this situation it was necessary to look after the parameters that showed great differences at both places. As has been showed in this report, aesthetic parameters and bacterial amount show a dramatic diminution while water stays in the lakes. Bacterial amount it is of interest because implies a better raw water quality entering the waterworks. Bacterial measurements are of interest when looking at the parameters that change while the water remains in the Delsjöarna. Bacterial amounts are known to be lower at Lackarebäck, and in this section the amount of that difference will be clarified.
Chemical parameters also are of interest and in this case the parameters were found looking at the annual reports from the years under investigation, where the annual median values are published. These parameters are: turbidity, oxygen, sodium, iron, manganese, aluminium, chloride, nitrite, nitrate, phosphor and zinc.

Coliforms

Bacteriological measurements are among the parameters showing the biggest changes. Being coliforms an indicator organism is interesting to see how much was the decrease in their number at Lärjeholm and Lackarebäck. See Figure 11. Differences at both places are notorious. Just three peaks in Lackarebäck reach high amounts of coliforms and always in summer time, so it is possible to presume that there is some bacterial grow under that season. Otherwise, it is possible to affirm that a decrease in the amount of coliform bacteria occur while the water is in the lakes.

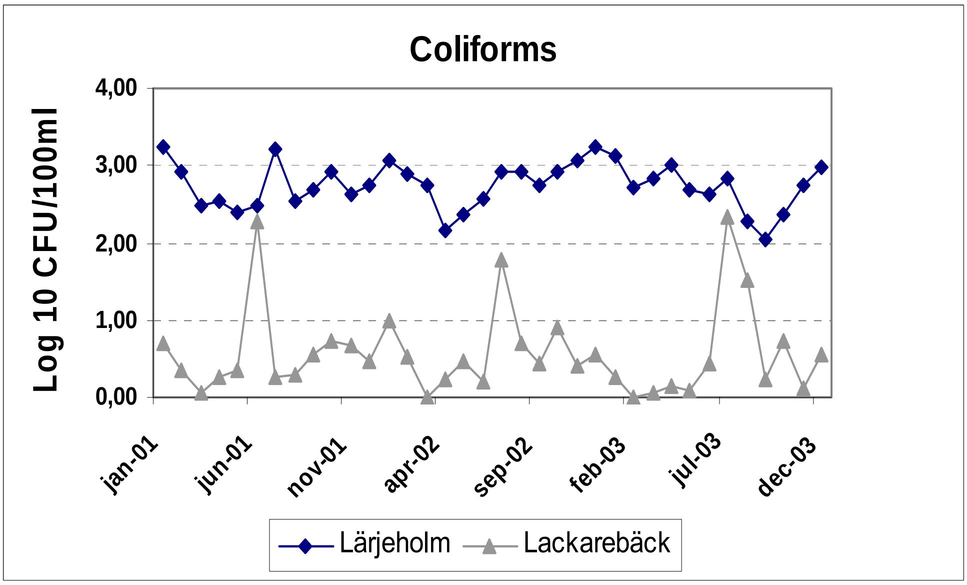


Figure 11: Coliforms measurements at Lärjeholm and Lackarebäck

E.coli

Amounts of *E.coli* are of interest because of its direct association to faecal contamination. *E.coli* values in Lärjeholm and in Lackarebäck are plotted to verify their change in the system. See Figure 12. *E.coli* shows a great diminution between the river intake at Lärjeholm and Lackarebäck. Just one peak reaches a high value comparable to the amount of *E.coli* present at the river intake, and also this peak is due to occur in summer like the ones from coliforms, so presumably this peak corresponds to some specific contaminating event.

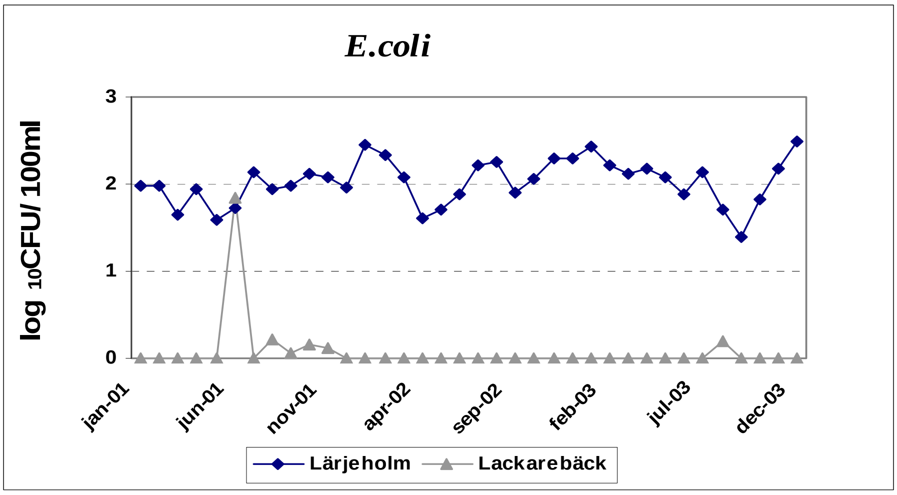


Figure 12: *E.coli* measurements at Lärjeholm and Lackarebäck

Enterococci

Enterococci are also of interest regarding faecal contamination, and that is why it is considered within the indicator microorganisms. Enterococci are found in great amount at the river intake, but not at Lackarebäck, where it is not always present and detected, as clearly can be seen in Figure 13.

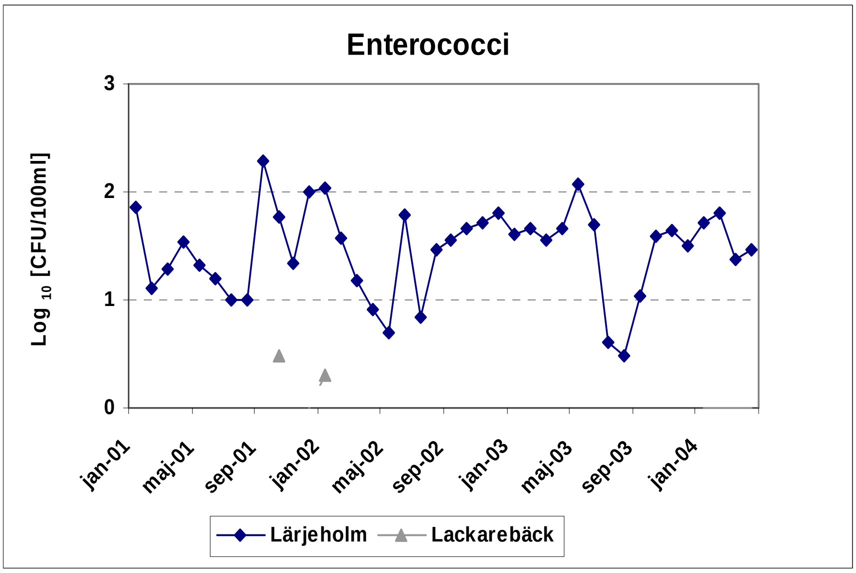


Figure 13: Enterococci amounts at Lärjeholm and Lackarebäck

Thermoresistant Coliforms

Is another of the so-called indicator microorganisms. Thermoresistant coliform bacteria are part of the coliform bacteria measured to the raw water entering both Lärjeholm and Lackarebäck. As can be seen in Figure 14, thermoresistant coliforms are quite high at Lärjeholm, but almost not detected at Lackarebäck.

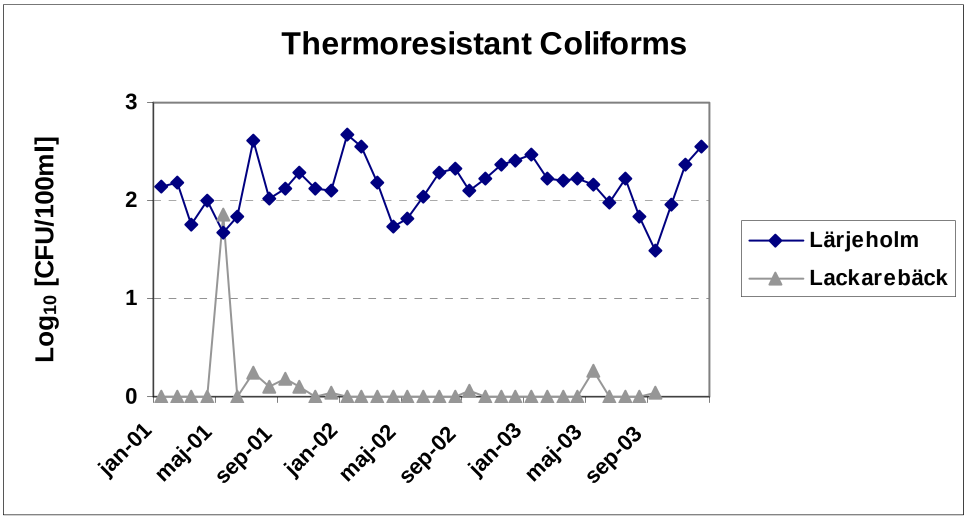


Figure 14: Thermoresistant coliforms measured at Lärjeholm and lackarebäck

Aluminium

Aluminium commonly comes from soil weathering and is released under acidic conditions. Aluminium (ICP analysis methodology) is overstepping the guideline (0,1 mg/L) at Lärjeholm and having a peak at the end of 2003. Measurements at Lärjeholm differ considerably from the ones at Lackarebäck, place in which the guideline is not overstepped, as the Figure 15 shows.

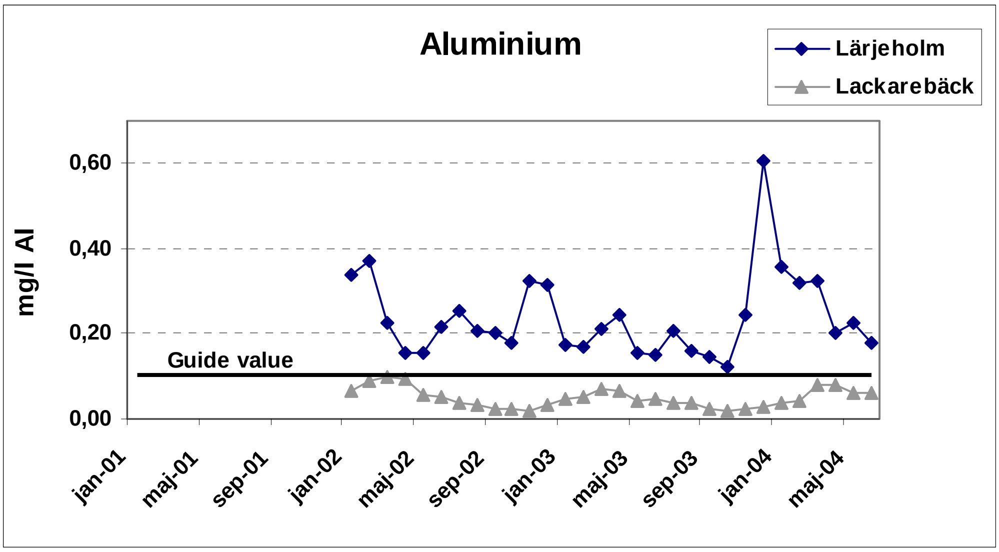


Figure 15: Aluminium concentrations at Lärjeholm and Lackarebäck

Chlorine (Cl)

Chlorides (Cl^-) are the common constituents of all natural waters (Tomar, 1999). This may be due to leaching of chloride containing rocks and soils, which come in contact with water in areas adjacent to the ocean (Wetzel, 2002). Sewage produced after domestic use of water is also rich in chlorides because of the significant chloride concentration in human wastes (Tomar, 1999). Human excreta, mainly urine, are rich in chlorides. Thus, domestic water contributes considerably to the chloride amount in water streams.

Chlorine is present at both studied places in a low quantity but at Lärjeholm peaks are observed along the studied period. Those peaks are always connected to the river intake closing due to saline intrusion. This is in consistence with what is established by literature (Wetzel, 2001), that chloride is not a dominant specie in an open lake ecosystem but is present in places in the nearby of the ocean, due to atmospheric transport. Figures 16 and 17 are showed the reported concentrations of chlorine at the selected spots. At both places, concentration is higher in Lackarebäck than at Lärjeholm.

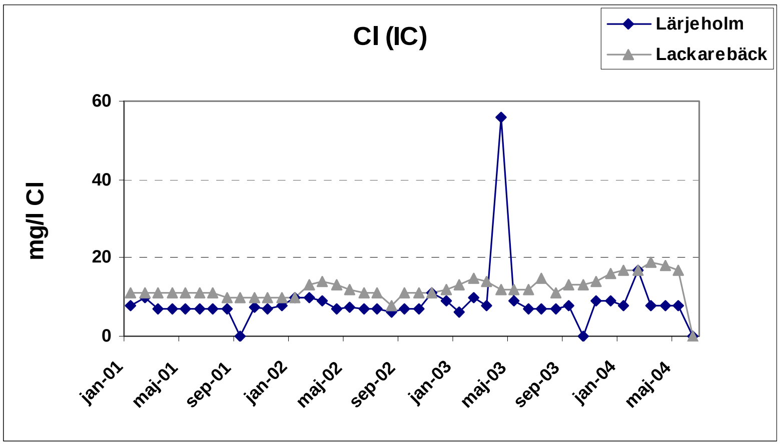


Figure 16: Chloride concentrations obtained by ion chromatography

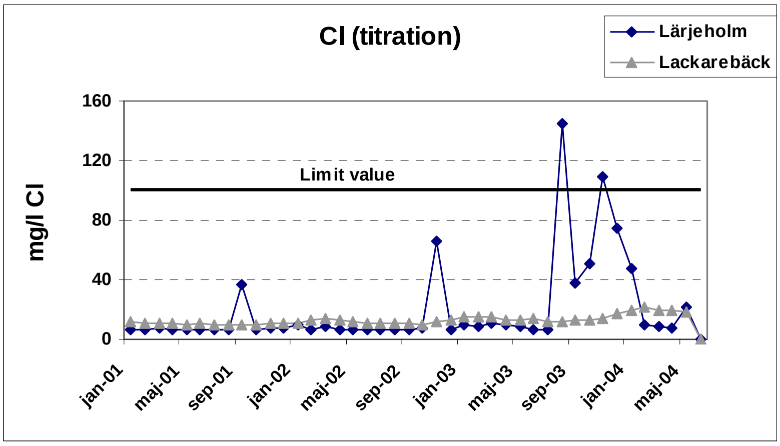


Figure 17: Chloride concentrations obtained by titration

According to Water Quality Surveys (WHO1978) the presence of chlorides in surface water or groundwater can be related to pollution, with origin either at industrial or household sewage. The same guide remarks that chlorides are present when having faecal contamination and thus can be used as a signal of faecal pollution.

COD

Chemical Oxygen demand (COD) is a measure of the oxygen equivalent of organic matter in the sample that is susceptible to oxidation by a strong oxidizing agent, such as chromate or permanganate (Patnaik, 1997). The COD is considered mainly in representation of pollution level of domestic and industrial wastewater, or contamination level or surface, ground and potable water (Tomar, 1999). Commonly COD is used to define the strength of wastewater containing non-biodegradable organic substances or compounds that inhibit biological activity (Wetzel, 2002). No differentiation can be made between biologically oxidazable and biologically inert organic matter, which is a limitation of the method.

COD values show similar trends in both places, Lärjeholm and Lackarebäck as can be seen in the Figure 18, indicating that the amount of organic material does not change in the lakes with respect to the river.

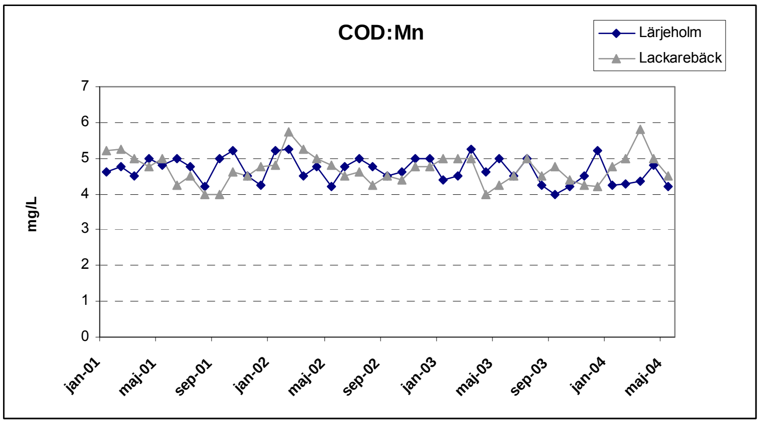


Figure 18: Chemical oxygen demand measured at Lärjeholm and Lackarebäck

Extinction 254 nm

The presence of organic matter, particularly humic acids has a marked impact on the amount and character of light in the water column. The presence of small amounts of dissolved organic matter increases the absorption in the UV and violet due to the fact that natural organic matter exhibits an aromatic character, measurements of light adsorption at 254nm thus, gives an idea of the presence of natural organic matter (Sung, 2003).

Measurements done at the places of interest, Lärjeholm and Lackarebäck, show a slight increase of this parameter at Lackarebäck, indicating the presence of organic substances at this point. These increments are notorious in spring, from February until May, when snow smelting and posterior rain events wash out the surfaces adjacent to the lakes. See Figure 19.

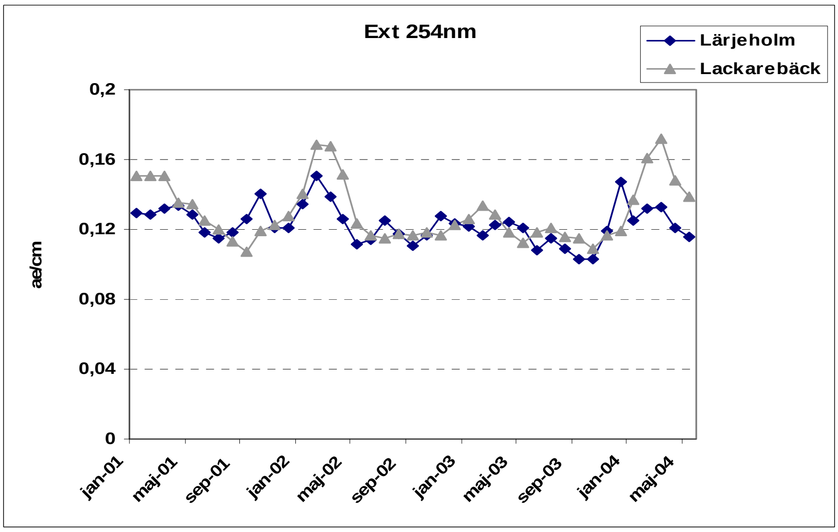


Figure 19: Extinction Coefficient measured at Lärjeholm and Lackarebäck

Iron

Iron in natural waters is a common problem, occurring from natural weathering or erosion of rocks (Wetzel, 2002). Iron shows several fluctuations along the river intake, but not all of them can be seen in Lackarebäck waters. Figure 20 shows iron trends in the mentioned places, values are far from the guideline for raw water (Fe ≤1 mg/l). Fluctuations in the amount of iron in the river can be due to the presence of suspended particles, as was mentioned before, and it is clear that the fluctuations are not affecting the amount of iron in Lackarebäck waters.

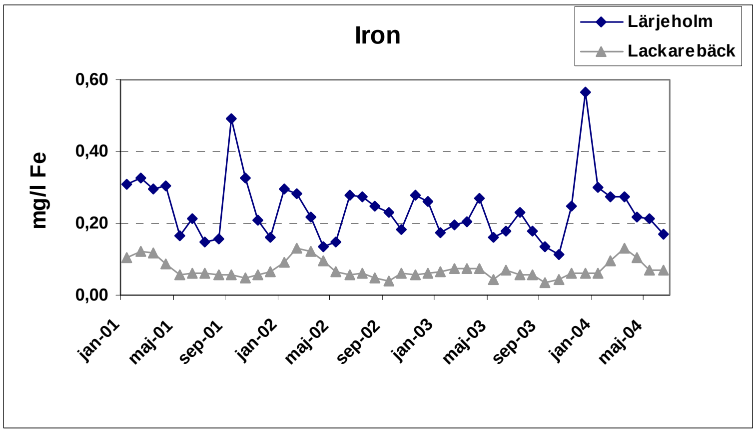


Figure 20: Iron concentration at Lärjeholm and Lackarebäck

Manganese

Manganese occurs naturally in many waters but can also be introduced by the industry (WHO 1978). It can produce a brownish discoloration and have a very unpleasant odour and taste. Manganese is considered a micronutrient of importance (Wetzel, 2002) for aquatic organisms, but on the other hand if present in drinking water can produce alteration to the coloration of it (SOSFS 2003:17) and additional operational costs (Le Vaillant *et al*., 2000).

Manganese also shows variations from one point to the other, always under the guideline. Lackarebäck concentrations are higher that the one at Lärjeholm, as Figure 21 shows. This can be a consequence of anoxic conditions in the bottom of the lakes (hypolimnion) due to seasonal stratification, as can be seen in the figure manganese peaks appear always at the beginning of the autumn, when summer stratification ends.

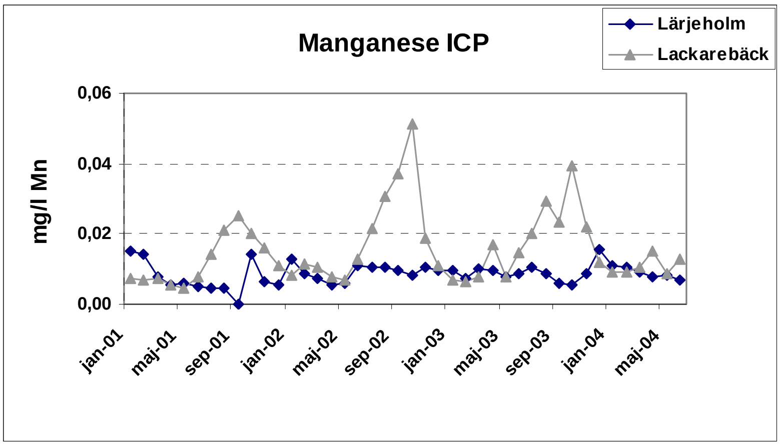


Figure 21: Manganese measurements

Nitrogen Compounds

Nitrogen is one of the most abundant elements in the nature, present in the air and important organic molecules as amino acids and nucleic acids (Handbook of water analysis, 2000). Dead and decaying animals and plants contribute to the presence of nitrogen compounds to the environment. Animal wastes, sewage, industrial effluents and agricultural wastes are some other sources of nitrogen compounds (Tomar, 1999). These nitrogen rich compounds can be discharged directly into streams or can enter waterways through surface runoff or ground water discharges.

Nitrites

Nitrites are the result of biochemical oxidation of ammonia or the reduction of nitrates (Wetzel, 2001) and their presence can be associated to pollution of the body water.
Nitrite is present in the sampled spots at a very low quantity. However some peaks are observed at Larjeholm (Figure 22).

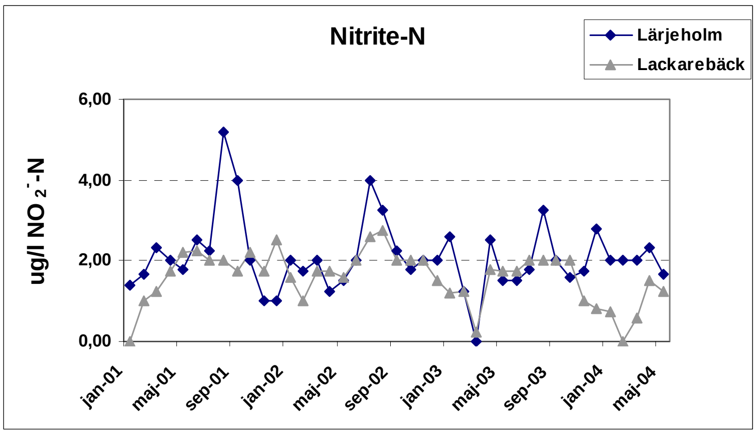


Figure 22: Nitrite measurements at the selected places

Nitrates

Nitrates are the end product of the biochemical oxidation of ammonia, being the latter formed as a result of the breaking up of proteins as stated in Water Quality Surveys (WHO, 1978). The same reference says that nitrates are present in surface waters unless in the presence of a period in which intensive development of phytoplankton occurs. In such periods the content of nitrate can reach negligible values. Increased nitrate concentrations can be associated to faecal pollution in the preceding period.
Nitrates are present in the studied places at a much higher quantity that the reported for nitrites but still far under the national guideline for raw water (≤ 5mg/l). Values at Lärjeholm are higher than the ones at Lackarebäck as can be seen in Figure 23.

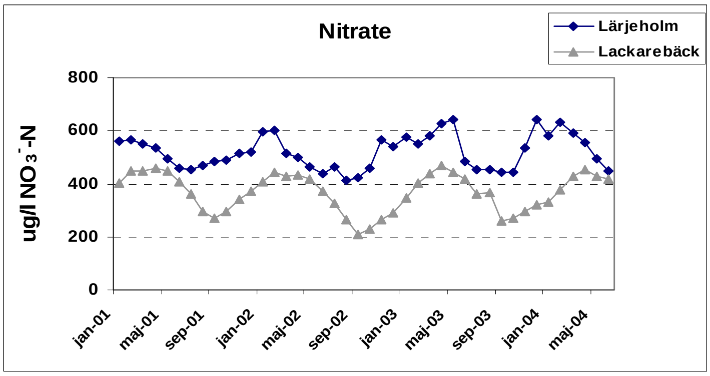


Figure 23: Nitrate measurements at Lärjeholm and Lackarebäck

Oxygen

Oxygen was reported as suffering a significant change in the annual reports, but when looking at the monthly average values, the oxygen amount is more or less constant in both places. This can be due to the fact that the annual reports of the Waterworks use median values, instead for average values. Figure 24 shows the oxygen trend along the period and the national guideline for oxygen amount in raw water (% $O_2 \geq 50$).

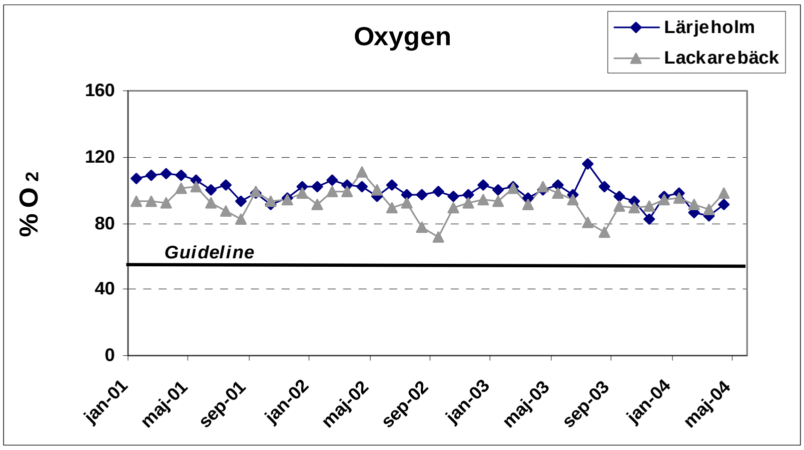


Figure 24: Oxygen concentrations at Lärjeholm and Lackarebäck

Phosphorus

Considered as a bulk element, phosphorus is present in plants and other organisms in diverse form. Their release to the environment is one of the causes of eutrophication in aquatic systems since Phosphorus concentrations in surface waters are generally quite low (Boyd, 2000). What it is observed is that at Lärjeholm phosphorus concentration does not remain stable along the period studied, and that the concentration is dramatically reduced at Lackarebäck as can be seen in Figure 25.

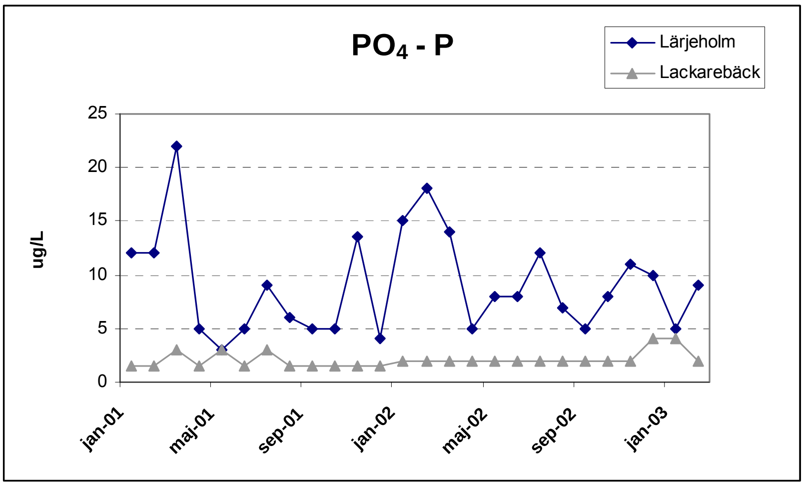


Figure 25: Phosphorous concentrations at Lärjeholm and Lackarebäck

Sodium

Sodium is the most common non-toxic metal found in natural waters (Tomar, 1999). It is abundant in earth's crust. Sodium salts are highly soluble in water, so are leached from soil and rocks. Sodium salts are commonly used in various industries, thus are present in significant quantities in industrial wastes.

It is possible to appreciate that the amount of sodium present at Lärjeholm is slightly minor with respect to the one recorded at Lackarebäck (Figure 26). In general this cation shows low concentration except for some peaks related to saline intrusion at the end of 2002 and 2003 at the river intake. However these fluctuations were not recorded at Lackarebäck. Even so, the values are far away from the guideline for this ion, i.e. 100mg/L Na.

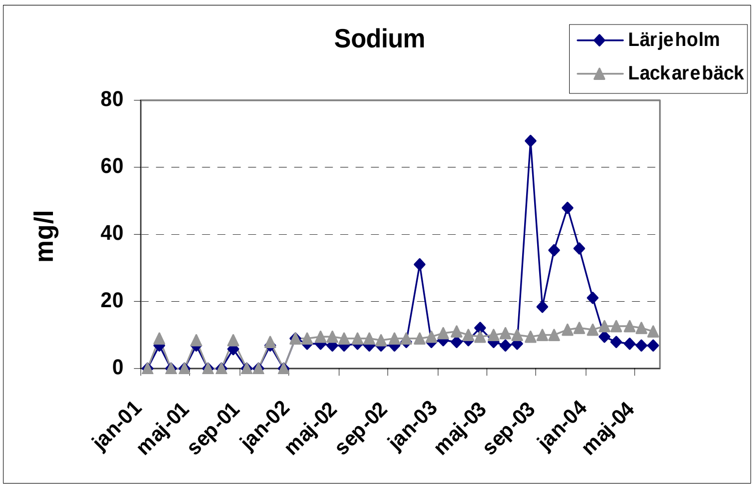


Figure 26: Sodium concentrations at Lärjeholm and Lackarebäck

Turbidity

Turbidity indicates the light-transmitting capability of water and wastewater with respect to colloidal or suspended matter (Tomar, 1999). It is a measure of the extent to which light is either absorbed or scattered by suspended matter in water, but it is not a direct quantitative measurement of suspended solids (Handbook of water analysis, 2000).
Turbidity is one of the parameters that show a big difference between the intake and the final step at Lackarebäck. Figure 27, accounts on it. This dramatic change may be associated to the precipitation of the suspended particles while they are in the lakes, considering that the residence time in the lakes is 4 months (va-verket's intern data).

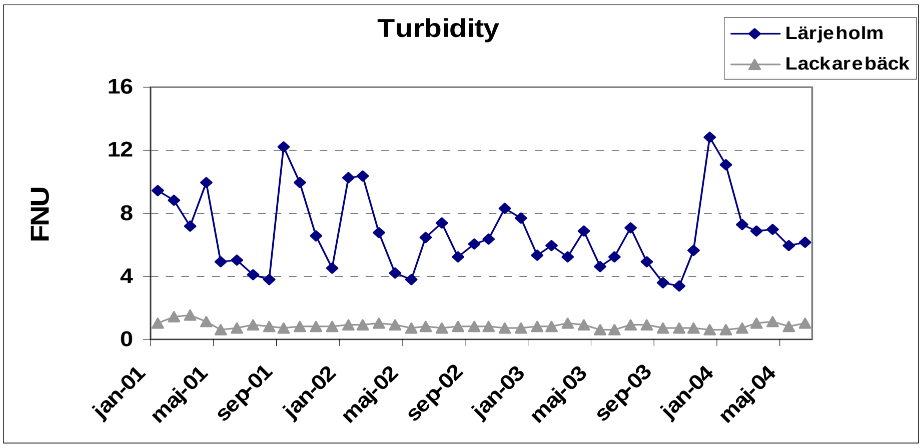
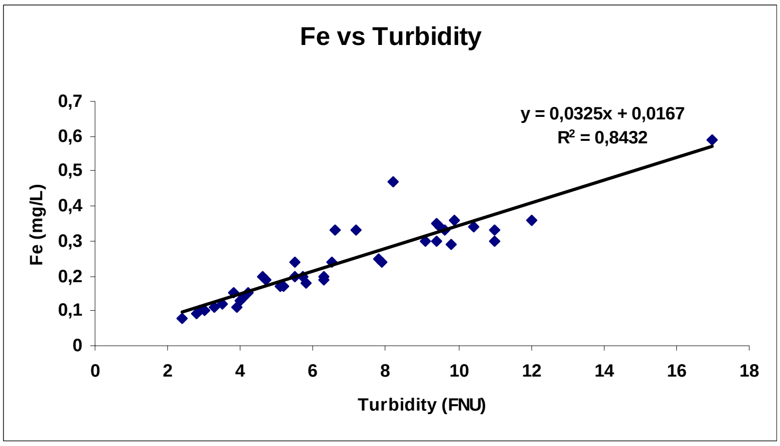


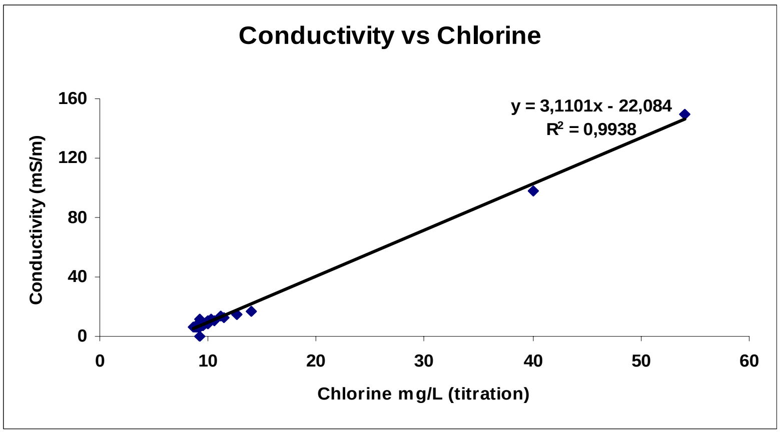
Figure 27: Changes in turbidity

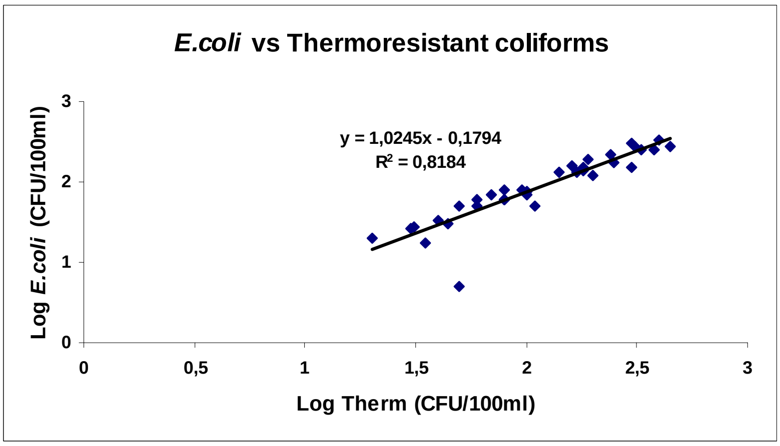
6. *Correlations diagrams*

Correlation diagrams are constracted based on results given in the report, Tables 11 and 12. Here are represented the correlations found as good, according to what was established in the section 4.1 of this report.

a) Lärjeholm







b) Lackarebäck