

# **ASSESSMENT OF WATER QUALITY IN GAUPÅSVASSDRAGET**



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## Abstract

Knowledge about the water quality of the Gaupås watercourse, about 10 km North of Bergen, Norway, is rather limited. Residents, fertilized fields, roads and forests surround the watercourse. There are also several landfills surrounding the watercourse that might have an effect on the water quality. This study tested basic abiotic parameters, bacterial levels and evaluated the biodiversity using different indices. The abiotic factors such as temperature, conductivity and pH varied a little between the sites. The high concentration of bacteria at one of the sites indicated possible sewage leakage from the minor residential areas. The phosphorus values varied considerably between sites, and can be linked to human activities in the area, such as farm fertilization. The diversity indices of average score per taxon (ASPT), Shannon and Biological Monitoring Working Party (BMWP) all indicated fair water quality. In conclusion, the overall water quality in the Gaupås watercourse could be regarded as average. This might be attributed to the long-lasting effect of the landfills in the area.

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## **1. Introduction**

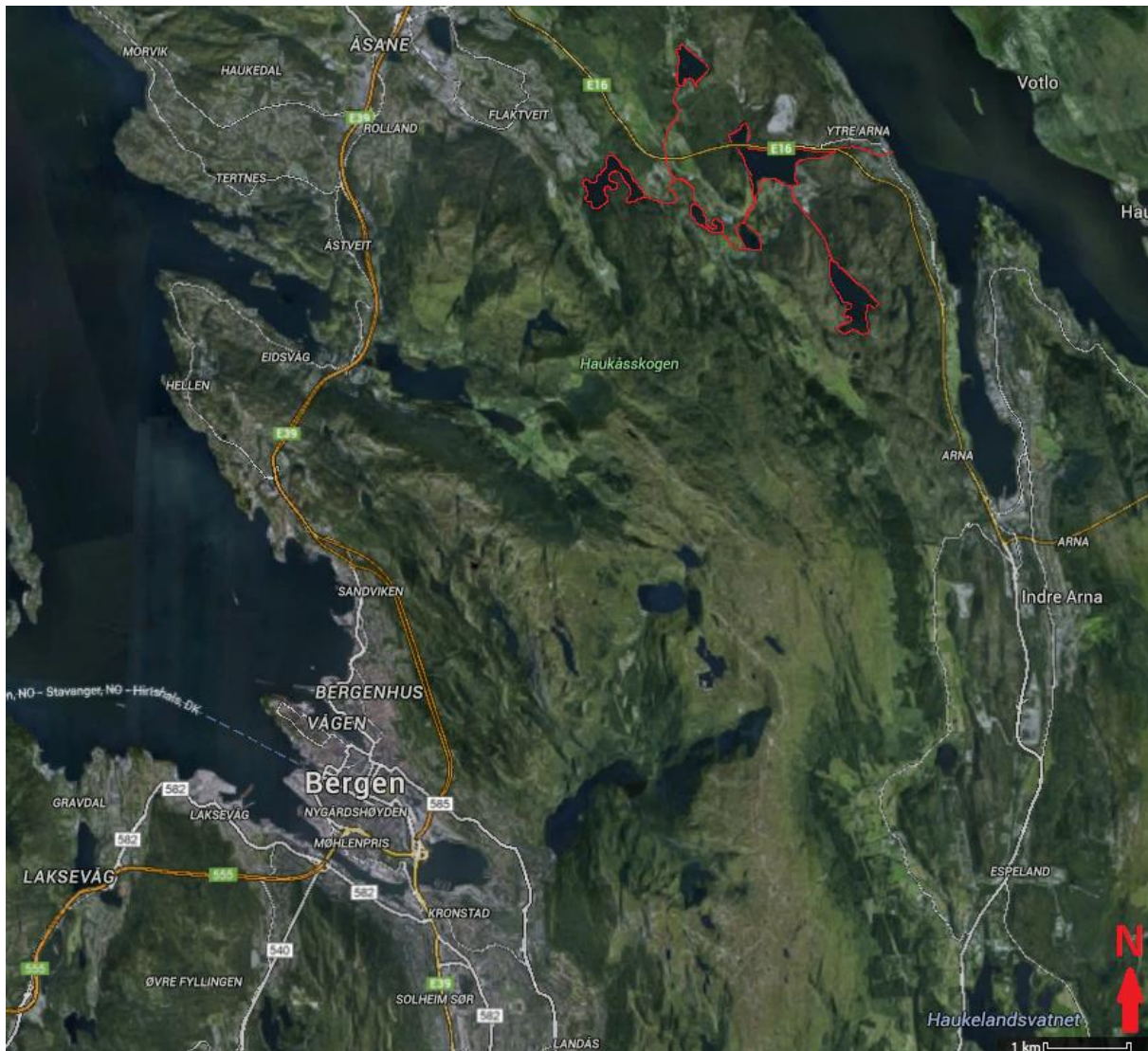
In 2000 the European Union (EU) made a directive that designates a framework for water policy for all its member countries. The directive is meant to protect and improve aquatic environments and promote sustainable water resources. It stipulate that the water quality should be evaluated on a regular basis, and then either protected, enhanced or restored depending on the water quality (The European Parliament and the Council of the European Union, 2000). Norway is, as part of the European Economic Area (EEA), also tied to this EU water directive (European Commission, 2012). The Norwegian Government approved a Framework for Water Management in 2007 that incorporates this water framework directive into Norwegian laws (Iversen, n.d.). A certain quality of lakes and rivers is not only vital for all terrestrial and limnistic species but also high water quality is important for municipal supplies, for production of energy and for fisheries. However, freshwater that is accessible as a resource to humans' accounts for less than 1% of the water on earth (Asaeda *et al.*, n.d.). Therefore, it is important to protect our water resources, both for the sake of citizens and freshwater ecosystems. Earlier studies from this area have focused on pollution by sewage (Johnsen, Bjørklund and Vidnes, 2004) and toxic compounds like heavy metals and DDT-derivatives (Hobæk, 1998). The Gaupås watercourse is used for fishing, swimming and is part of a hiking area. Therefore, it is important to monitor its water quality. The knowledge of the quality of the water in the Gaupås Watercourse is limited (Mr, O. R. Sandven, "Grønn etat", 2008, pers. comm., 30.10.2014).

There is an ongoing cooperation between Bergen Municipality and the teaching staff of the BIO 300 course from the University of Bergen. This cooperation allows biology masters students to study the quality of a number of water resources around the Bergen area, and, at the same time, satisfy the municipality's need of continuous evaluation of these water resources. In cooperation with the Park and Recreation Division (hereafter referred to as Grønn etat), we have tested the water quality from 4 different sites along Gaupåsvassdraget (hereafter called the Gaupås watercourse).

### **1.1 Location**

The Water and Sewage Works in Bergen Municipality is responsible for evaluating and maintaining sustainable water quality in the Bergen area. They have been monitoring the area of the Gaupås watercourse, a watercourse 10 km North of Bergen, Norway. The Gaupås watercourse consists of several connected lakes that all run into Gaupåsvatnet before entering

Sørfjorden at Ytre Arna (Figure 1.1). The watercourse is mostly surrounded by forests, farms, houses and roads. In addition, there are several landfills with unknown content in the area. These landfills have been inactive for about 20 to 40 years. Although, buried in the ground, they might still assert an effect on the surrounding waters (Grønn et al., 2009).



**Figure 1.1:** Bergen City Centre and The Gaupås Watercourse (marked in red). Picture modified from Google Maps (Google Maps, 2014).

## 1.2 Abiotic factors

A number of important indicators to evaluate water quality are abiotic, like temperature, pH, conductivity and phosphorus levels. Normally, the pH of Norwegian lakes and rivers ranges from 6 to 8 (Norsk institutt for vannforskning, 1996). Temperatures above 10°C can lead to a higher growth rate of microorganisms (Folkehelseinstituttet, 2004).

The electrical conductivity is a reflection of the amount of dissolved salt and is attributed to the salinity and mineral content (Kazi *et al.*, 2008). It is also consistent with the concentrations of dominant ions, which originate from ion exchange and solubilisation in the aquifer (Sanchez-Perez & Tremolieres, 2003). Conductivity is also influenced by evaporation, precipitation, tidal regimes and freshwater inflow (Pinet, 2009).

Phosphorus is an important nutrient for all organisms, and is often the limiting element in both lakes and rivers. However, phosphorus is only beneficial for an ecosystem within certain concentrations (Environment Canada, 2013). Main sources of phosphorus are fertilizers, human waste and decaying plants. Excess phosphorus can enter a lake or river as runoff from land through over-fertilization. Too high concentrations of phosphorus can lead to an increased algal growth. When an algae population becomes too large it produces toxins. When a habitat cannot tolerate this algal over-growth, algae start dying, the bacterial flora in the sediments will decompose the dead algae, which can deplete the oxygen in the lake (Environment Canada, 2013). Some parts of the Gaupås watercourse are surrounded by farm land, and are potential sources of excess phosphorus.

## 1.3 Thermotolerant Coliform Bacteria

Another important parameter for assessing water quality is the concentration of thermotolerant coliform bacteria (TCB). The coliform group contains many bacterial species that reside mainly within the intestinal tract of humans and other warm blooded animals. This bacterial group can tolerate temperatures above 40°C. High TCB levels are an indicator of fresh fecal contamination in water. Not all of the microorganisms in this group are pathogenic (i.e. will cause disease), but there are some *E. coli* that is (Degre & Hovig, 2010; Folkehelseinstituttet, 2004). TCB levels can indicate the likelihood of these pathogenic *E. coli*-variants and other pathogenic bacteria in the environment. The higher the number of TCB in a water sample, the higher the probability is for pathogenic strains (Washington State Department of Health, 2011). A parameter set by Andersen *et al.* (1997) describes the relationship between the concentration of TCB and freshwater quality (see appendix A, Table

A.1). This parameter takes a certain TCB-value and attaches to it a certain classification label. These classification labels range from very good to very bad.

## 1.4 Biodiversity

Biodiversity in aquatic environments depends largely on the water quality. Some species are more tolerant to pollution than others, and the abundance of sensitive species can be used as an indication of possible pollutants in the water (Roddis, 2011). Measurements of biodiversity were used as indicators of degree of pollution at the Gaupås Watercourse.

Different diversity indexes can be used to analyze biodiversity data. Diversity indexes are mathematical equations to reflect the structure of the community and to present information on the numbers of specimens and types of organisms (Wilhm & Dorris, 1968). The Biodiversity Monitoring Work Package (BMWP) scores and the Average Score Per Taxon (ASPT) from Martin (2004) can be used to evaluate the effect of pollution pressure, whereas the Shannon Index (Beals, *et al.*, 2000) can be used to calculate the abundance and evenness of the different taxa. BMWP score categories set by Bourne Stream Partnership (n.d.) and ASPT scores categories set by Ouse & Adur Rivers Trust (n.d.) describe the relationship between biodiversity and freshwater quality (see Appendix A, Table A.3, A.4). These score categories take a certain BMWP score or ASPT score and attaches to it a certain classification label. These classification labels range from very poor to very good.

## 1.5 Aim of this study

In cooperation with the Framework for Water Management in Bergen, it has been recognized that there is a lack of knowledge in the ecological and chemical status of lakes and rivers around Bergen. Since previous studies have mainly focused on sewage in Gaupåsvatnet, a further study on the possible effect of the landfills on the watercourse is necessary (Mr. O. R. Sandven, “Grønn etat”, 2008, pers. comm., 30.10.2014).

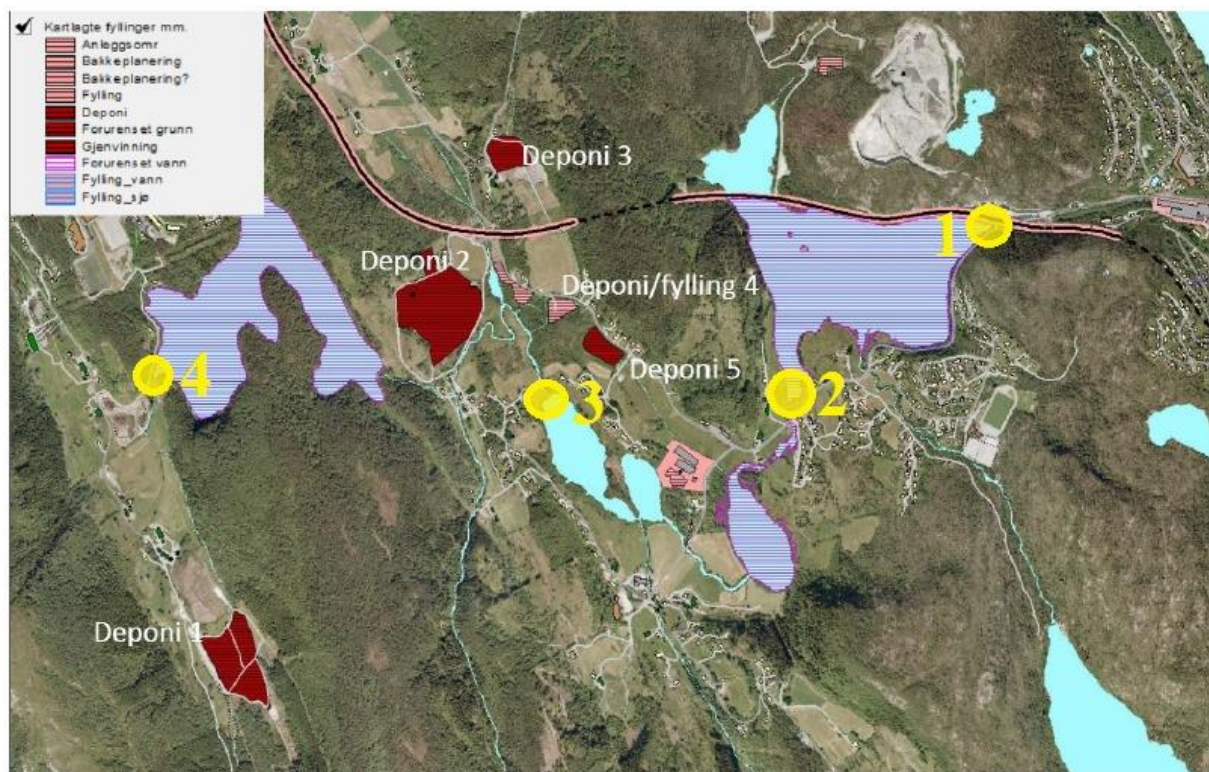
We carefully picked out sampling sites based on the locations of the different landfills and the layout of the watercourse (Figure 2.1). The aim of this study was to use ecological and chemical parameters to evaluate the water quality at selected sites in the watercourse. Our comprehensive study could verify the impact on the quality of the water downstream of the filling sites. In addition, Gaupåsvatnet might be subjected to sewage leakage from the minor residential area nearby (Mr. O. R. Sandven, “Grønn etat”, 2014, pers. comm., 14. November).

We therefore compared both inlet (site 2) and outlet (site 1) measurements from Gaupåsvatnet. With the established cooperation between the University of Bergen and Grønn etat, these observations could serve as reference points for future studies of this watercourse.

## 2. Materials and methods

### 2.1 Location

The Gaupås watercourse, located in Arna to the north of Bergen, is the fifth largest watercourse in Bergen and consists of numerous interconnected lakes, rivers and streams that eventually flow into Sørfjorden at Ytre Arna. Downstream, the watercourse is greatly influenced by industry, larger residential areas as well as a power plant. Because of the industry in Ytre Arna the depth of Gaupåsvatnet is regulated as a source of water power. Upstream, the watercourse is mostly surrounded by farms, hills and forests as well as some smaller residential areas. In addition, there are five landfills upstream which were used to deposit mostly industrial or mechanical waste. These landfills have been inactive for about 20 to 40 years and are now almost entirely buried (Grønn etat, 2009). Figure 2.1 shows the watercourse, the landfills and the sampling sites.



**Figure 2.1:** Map of the Gaupås watercourse with the landfills (Deponi) and sampling sites. The four sampling sites are marked with yellow circles, landfills are red and the watercourse is shown in blue (map modified from Ole Rugeldal Sandven, Grønn etat - Bergen Municipality).

## 2.2 Sampling sites

### 2.2.1 Site 1: Gaupåsvatnet

Our first sampling site was at the outlet of Gaupåsvatnet. This is the most downstream lake of the watercourse (Figure 2.2). There are main roads along the entire northeastern shoreline of Gaupåsvatnet, which may contribute to local pollution. In addition, the roads in the area have recently been subjected to construction. The shoreline at the sampling site was rocky with little vegetation. Some mechanical and electrical waste was spread throughout the site, which also may contribute to local pollution. There were no buildings on the site apart from a small pumping house for the regulation of the watercourse. The current was very weak, and the bottom consisted mainly of rock with very little sediment (Figure 2.2).



**Figure 2.2:** *Sampling site 1, at the outlet of Gaupåsvatnet. Notice the surface pollution of the rocky shoreline.*

### 2.2.2 Site 2: Gaupåsvatnet

The second sampling site was near the inlet of Gaupåsvatnet. A few farms and houses surrounded this site, and there were no main roads nearby. The shoreline was full of vegetation, like tall grasses, bushes and some trees. The bottom was rocky near the river delta and got muddier towards the lake. Most of the rocks in the river were covered with grass, most likely due to runoff from land after hay cutting. There were little visible wastes at the site.



**Figure 2.3:** *Sampling site 2, at the inlet of Gaupåsvatnet, is surrounded by a few farms and houses (left and right, out of the picture window), and its banks are covered by abundant vegetation.*

### 2.2.3 Site 3: Kalsåsvatnet

Our third site was near the inlet of Kalsåsvatnet. This site was more remote with only a few houses and one meadow nearby. The area was marsh-like with lots of shoreline vegetation. There was a very weak current a deep sediment layer that was very swampy. There was a dock nearby with one small boat. Some minor mechanical wastes, like pipes and old cars, were dispersed across the area.



**Figure 2.4:** *Sampling site 3, at the inlet of Kalsåsvatnet. The shoreline is very swampy and surrounded by abundant vegetation. The sediment here was mainly loosely packed deep mud, and there were little currents at the surface.*

#### 2.2.4 Site 4: Hjortlandsstemma

The last site was in a river delta by the inlet of Hjortlandsstemma. This area was the most remote of all sampling sites, with no farms, houses or other buildings nearby. The river delta was rocky and there was little vegetation at the river banks. There were smaller plants and trees at the hillsides down to the riverbank. The rocks in the river and the solid bedrock at the river banks were rusty-red, suggesting high iron content.



**Figure 2.5:** *The shoreline at sampling site 4, at the river delta by the inlet of Hjortlandsstemma, borders to a leaf forest, and the riverbed is full of rust-red rocks. There is no human activity nearby.*

## 2.3 Field sampling

### 2.3.1 Weather conditions

The field sampling was done on September 11 2014 between 8:30 and 11:30. There was a lot of morning fog that morning which gradually disappeared, and the air temperature was below 10 °C at all times. There had been little rain (less than 10mm/day) in the days prior to the field day (Yr, 2014), and there was no rain on the field day (Table 2.1).

**Table 2.1:** Local weather conditions measured at weather station Florida in the week before sampling. It is the closest station approximately 8.8 km from the Gaupås watercourse. Mean air temperatures and 24 h precipitation are shown (Yr, 2014).

Date	Mean air temperature (°C)	Precipitation (mm) – 24 h from 07:00
11.09.2014	13,8	0
10.09.2014	13,4	0,3
09.09.2014	13,7	0,1
08.09.2014	14,3	8,7
07.09.2014	14,7	4,7

### 2.3.2 Abiotic parameters

Conductivity, temperature and pH were measured at sites 1, 2, 3 and 4. The conductivity (mS/cm) and temperature (°C) were measured with a portable WTW (Wissenschaftlich-Technische Werkstätten, Weilheim, Germany) Cond 3110 set 2 including a TetraCon® 325-3 conductivity meter placed approximately 20 cm below the water surface at site 1, 2 and 4. The probe reading was recorded when the measures stabilized. The pH was determined with a portable WTW pH 3110 set 2 including a SenTix® 41 pH meter approximately 20 cm below the water surface at site 1, 2 and 4. At site 3 however, temperature, conductivity, and pH were measured in a bucket with water from the site, because there were complications with performing the task directly in the lake.

Sterile 50 ml Falcon tubes were used to collect water samples for analysis of phosphorus. These samples were collected in the same way as the Thermo-tolerant coliform bacteria samples at all sites. Duplicates were taken at each site for a total of 8 samples

delivered to Eurofins Laboratories, Bergen, Norway. The samples were stored in a cooler before they were delivered.

### 2.3.3 Thermotolerant Coliform Bacteria

Sterile 250 ml bottles were used to collect water samples for measuring (TBC) in the water. The samples were taken at approximately 50 cm depth at all sites with the help of an extension rod. The bottles were lowered to desired depth with the top of the bottle pointing down, and then inverted. The bottles filled with water and were carefully retrieved and sealed to minimize the risk of contamination. Three replicates were taken per sampling site. The samples were kept in a cooler with freezing elements and delivered to Bergen Vann KF, Bergen, Norway.

### 2.3.4 Biodiversity

The biodiversity was collected in different ways depending on the accessibility to the sediment at each site. At site 1, because of the rocky bottom, we dug for 20 seconds under the rocks to stir up sediment, and collected the floating particles and animals with a sieve-bottomed bucket. This procedure was repeated three times. At site 2 and 3 there was more available sediments. Therefore, we used a kick sampling technique: while one person spun around and stirred up the sediments with his feet, he dragged the sieve-bottomed bucket in circles under the water; a procedure that was performed for one minute. At site 4 there were mainly large rocks or solid bedrock, so we performed kick sampling 10 meters further upstream in the river. This time one person walked upstream while moving rocks with his feet and dragging the sieve-bottomed bucket behind him to collect sediment; this procedure we performed for one minute. We used water from the representative sites to wash the content from the sieve-bottomed bucket into sampling containers for each site. The samples were stored cool, while transported back to the lab at BIO.

## 2.4 Laboratory analyses

### 2.4.1 Thermotolerant Coliform Bacteria

Bergen Vann KF analyzed the TBC. The samples were plated on m-Fc (Membran-Fecal coliform) agar within 6 hours of sampling, according to the Norwegian Standard NS 4792:1990. The samples were incubated at  $44,5 \pm 0,2^{\circ}\text{C}$  for  $21 \pm 3$  hours. Subsequently, the visible colonies on the agar were counted. The result was reported in Colony Forming Units per 100 mL (CFU/100 mL). For more details about the Norwegian Standard NS 4792:1990 procedure for detection of TBC-bacteria, see Appendix I.

### 2.4.2 Phosphorous

Eurofins Laboratories analyzed the phosphorus samples. The samples were digested according to the Norwegian Standard NS-EN ISO 6878 and were analyzed according to the Norwegian Standard NS-EN ISO 15681-2. The samples were analyzed using Autoanalyzer 3; a continuous flow analyzer (CFA) and reported as  $\mu\text{g/L}$ .

### 2.4.3 Biodiversity

We used a sieve to remove large plant parts and algae from the water samples. We poured the content of each water sample into its own plastic tray, and the organisms were collected with tweezers or spoons and transferred to a six well transparent plate. We used SZ-LTV Olympus (Japan) dissecting microscopes to locate the organisms in the trays. We then identified the organisms down to family level or to subclass Oligochaeta for worms.

Different ecological indexes were used to evaluate the quality of the water samples. We used the Biodiversity Monitoring Work Package (BMWP) scores from Martin (2004) to evaluate the effect of pollutant pressure. This effect was determined by summing up the BMWP scores from each taxon. Consequently, the Average BMWP Score Per Taxon (ASPT) was calculated. The higher BMWP scores and ASPT scores the better the biodiversity. We also used the Shannon index (Beals, *et al.*, 2000) to calculate the abundance and evenness of the different taxa. The Shannon index is calculated by:

$$H = - \sum_{i=1}^R p_i \ln[p_i]$$

Where  $p_i$  is the relative abundance of each specimen calculated by:  $p_i = n_i/N$ , where  $n_i$  is the number of individuals in a taxon, and  $N$  is the total number of individuals.

## 2.5 Statistical analyses

To be able to evaluate if the variance observed in our data were statistical significant, we used the free software environment R. We used different statistical tests that fitted our data. For TCB we used significance tests with generalized linear models (GLM) with Poisson distribution. We chose GLM for these data since it has one response variable (the concentration) and one predictor variable (the site), and the response variable is measured as counts of bacteria in a water sample. We also tested the model fit. After running the GLM, we used a two-sample t-test to study what sites that were significantly different from each other (Appendix C).

To analyze the significance of the observed variance in the concentration on phosphorous between the different sites we used a one-way ANOVA. We chose to do an one-way ANOVA for these data since it has one response variable (the concentration) and one predictor variable (the site), and the response variable is measured as concentration of phosphorus in a water sample; But there are more than one group (multiple sites). We also tested the model fit, but the data had not constant variance, so we chose to run a GLM instead. After running the GLM, we also used a two-sample t-test to study if any of the sites were significant different from each other (Appendix D).

### 3 Results

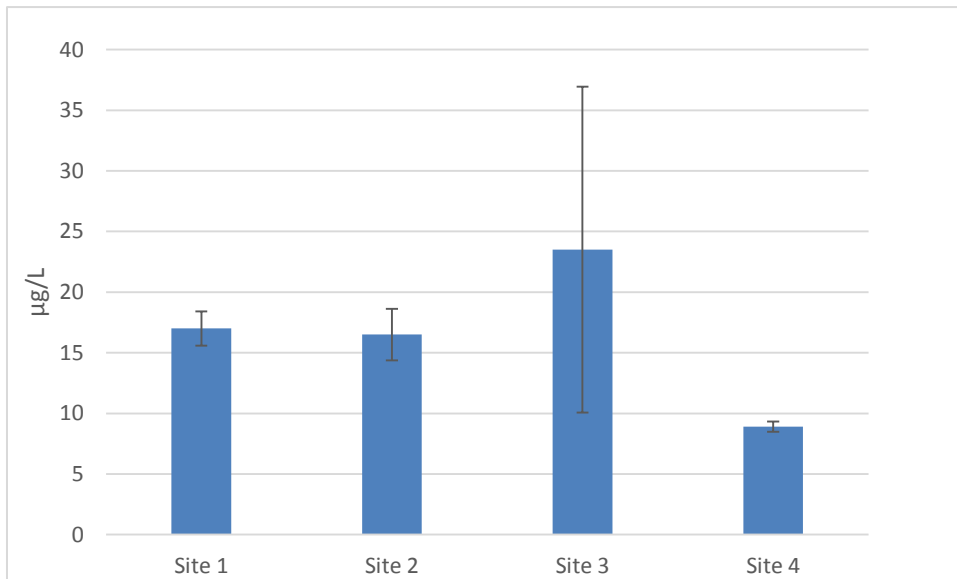
#### 3.1 Abiotic factors

The pH values at the four sampling sites were similar and were generally increasing upstream to downstream in the watercourse from 5.98 at site 4 to 6.64 at site 1. There was a slight fluctuation in temperature, ranging from 12.5 °C to 16.1 °C. The conductivity values (in mS/cm) at sampling site 1 and 2 were very similar, around 48, while the values at sampling site 3 and 4 were higher, 58.6 and 61.9 respectively.

**Table 3.1:** Measurements of pH, temperature and conductivity at sampling sites 1 to 4 in the Gaupås watercourse measured approximately 20 cm below the water surface.

Sampling site	pH	Temperature (°C)	Conductivity (mS/cm)
1	6.64	15.3	48.9
2	6.16	14.1	48.8
3	6.25	12.5	58.6
4	5.98	16.1	61.9

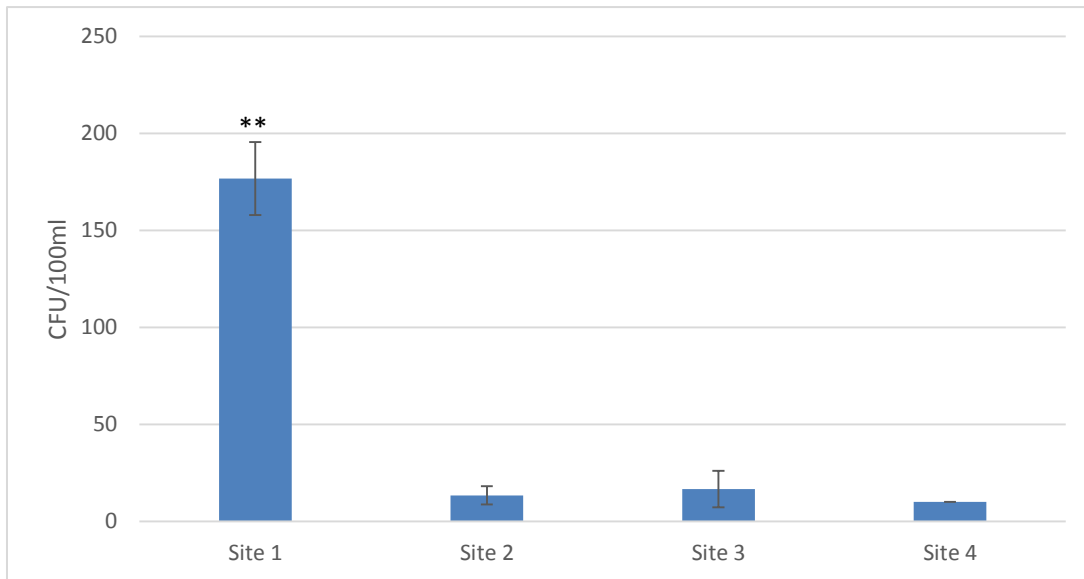
The average phosphorus levels (in µg/L) ranged from 8.9 to 23.5 (Figure 3.2). Site 4 had an average phosphorus concentration of 8.9, while sites 1 and 2 had average concentrations of 17 and 16.5 respectively. The phosphorous values at site 3 ranged from 9.2 to 33 with an average of 23.5. The observed variance between the different sampling sites was not significant (GLM, P=0.4868) (see Appendix D).



**Figure 3.2:** Average phosphorus levels per liter from two replicates at each sampling site collected at approximately 50 cm depth in the Gaupås watercourse. The thin bars are the standard errors for each site.

### 3.2 Thermotolerant Coliform Bacteria

The TCB values (in colony forming units per 100 ml (CFU/100 ml)) were generally under 30, with the exception of site 1, where TCB values ranged between 150 and 190 (Figure 3.1, Table B.1, Appendix B). The TCB value at the most downstream site (sampling site 1) was the highest while site 4 showed the lowest TCB levels. The difference observed between the different sampling sites was significant (GLM,  $P < 0.0001$ ) and only site 1 is significantly larger than any other sites (two-sample t-test,  $P < 0.01$ ).



**Figure 3.1:** Average values of colony forming units (CFU) of thermotolerant coliform bacteria (TBC) at sites 1 to 4 in the Gaupås Watercourse. Three replicates were taken at each site, at approximately 50 cm. The thin bars are the standard errors for each site.

\*\*\*) Site 1 is significantly different from each of the other sites.

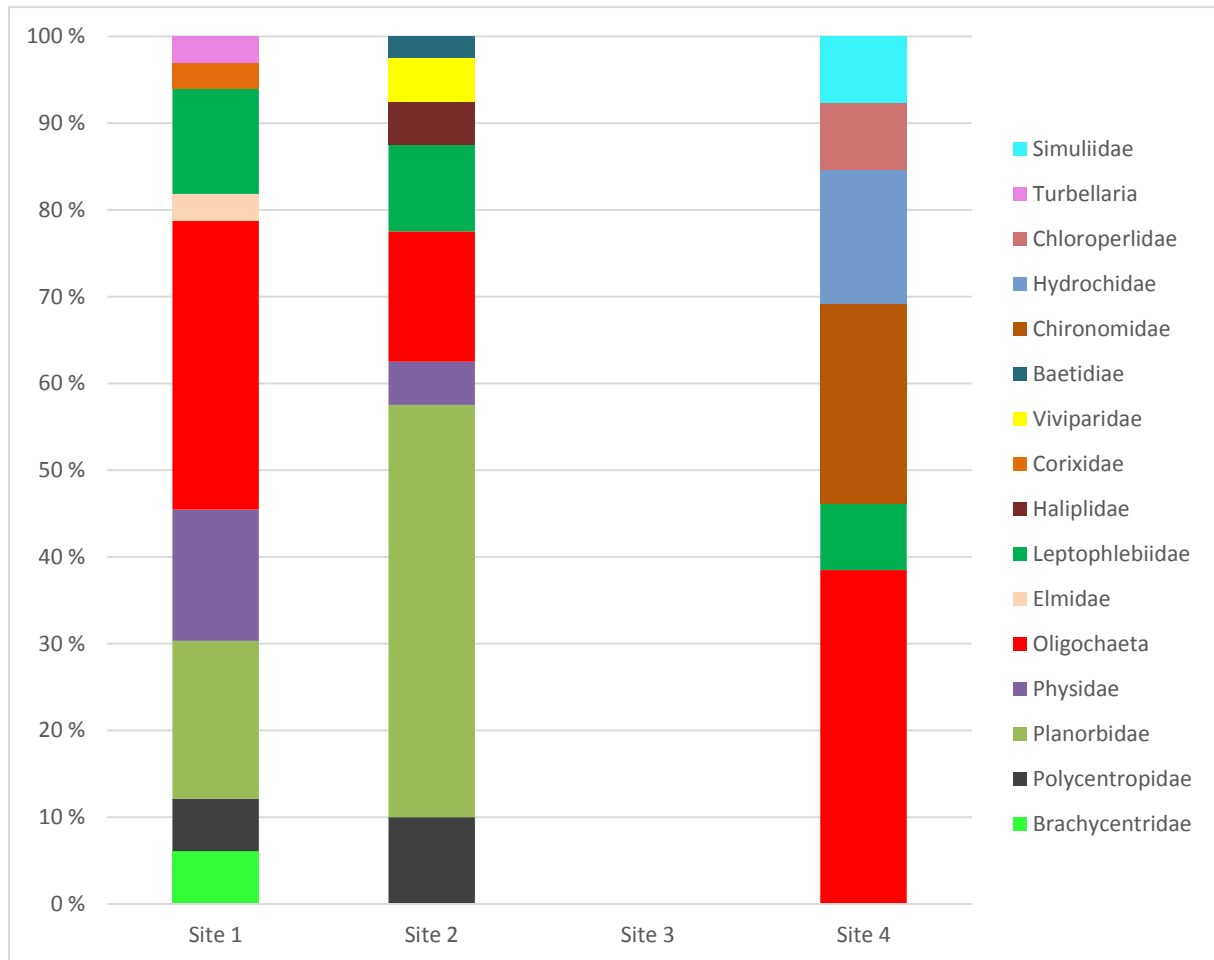
### 3.3 Biodiversity

A total of 86 individuals belonging to 16 taxa were found in the Gaupås watercourse. The number of taxa was similar between the sites (Figure 3.3). Site 2 had the highest abundance with 41 individuals and site 4 the lowest with 13 individuals (Table B.3, Appendix B). Biodiversity sampling at site 3 gave no individuals of any species.

Site 1 had the highest values of Shannon's diversity index ( $H=1.79$ ) while site 2 ( $H=1.57$ ) and 4 ( $H=1.59$ ) were similar to each other (Table 3.2).

The Biological Monitoring Working Party (BMWP) score ranged from 38.2 to 45.0 (Table 3.2). Site 2 had the highest BMWP score followed closely by sampling site 1 with 44.8.

The average score per taxon (ASPT) scores at the three sampling sites are similar and range from 5.0 to 6.4 (Table 3.2).



**Figure 3.3:** Total composition on family level of samples from sites 1 to 4 of the Gaupås watercourse. Three replicates from each site were taken by digging and collecting the floating particles with the sieve-bottomed bucket. One sample per site was taken by using a kick sampling technique at sampling site 2, 3 and 4. A total of 86 individuals from 16 taxa were found. Only benthic organisms are presented.

**Table 3.2:** Biological Monitoring Working Party (BMWP) scores, Average Scores Per Taxon (ASPT) and Shannon index calculated of each sampling site in the Gaupås watercourse. The categories enclosed by parentheses are the interpretations of the different scores based on the parameter set by Andersen et al. (1997) (Tables A.3 and A.4, Appendix A).

Site	BMWP score	ASPT score	Shannon index ( $H'$ )
1	44.8 (moderate)	5.6 (fair)	1.79
2	45.0 (moderate)	5.0 (fair)	1.57
3 <sup>a</sup>			
4	38.2 (fair)	6.4 (good)	1.59

a) Samples were taken but no organisms were found.

## **4. Discussion**

The results from the tests on abiotic factors show that the temperature, pH and conductivity varied in the Gaupås watercourse, but these variations are within the normal range for Norwegian lakes and streams for the time of year when the study was conducted. Testing for phosphorous showed that the phosphorous concentrations varied slightly, but this variation was insignificant. The bacterial levels varied substantially, and the bacterial concentrations at site 1 were significantly larger than the levels from the other sites. The biodiversity in the Gaupås watercourse varied, but was in general good or fair. The exception is site 3, where no biodiversity except bacteria were found.

### **4.1. Site 1: Gaupåsvatnet**

The average TCB value from site 1 was about a 10-fold higher than the average values from the other sites, with 177 CFU/100 mL. The value was categorized as less good according to Andersen *et al* (1997) (Table A.1, Appendix A). TCB is an indicator for fresh fecal contamination of the water and the results for site 1 suggest sewage leakage from the minor residential area around site 1 (Mr. O. R. Sandven, “Grønn etat”, 2014, pers. comm., 14. November).

The average phosphorus value from site 1 was categorized as less good according to Andersen *et al.* (1997) (Table A.2, Appendix A). Possible sources of excess phosphorus are over-fertilization and sewage (Environment Canada, 2013), and the reason for the slightly elevated concentrations of phosphorus at sites might be sewage leakage from the residential areas nearby, or runoff from fertilized grass fields close to the sites.

The BMWP score of site 1 was 44.8 and classified as moderate according to Bourne Stream Partnership n.d. (Table A.3, Appendix A). The ASPT score was 5.6 and classified as fair according to Martin (2004) (Table A.4, Appendix A). The Shannon index was 1.79. Based on these three indices the water quality was classified as moderate. Site 1 had 8 taxa, including Polycentropidae in which the individuals are sensitive to pollution, and Brachycentridae in which the larvae are intolerant to pollution. These species indicate good water quality (Brady, n.d.). Both the Brachycentridae and Polycentropidae, which we also found at site 1, belong to the Caddisflies, of which different species indicate good water quality conditions (New York State Department of Environmental Conservation, 2014).

However, site 1 had a small amount of caddisflies, but a larger amount of pollution-tolerant species such as Planorbidae.

#### 4.2 Site 2: Gaupåsvatnet

The average TCB concentration at site 2 was 13 CFU/100 ml and was classified as good according to the parameter set by Andersen *et al.* (1997) (Table A.1, Appendix A).

The average phosphorous concentration at site 2 was classified as less good according to the parameters set by Andersen *et al.* (1997) (Table A.2, Appendix A). The reason for the slightly elevated concentration of phosphorus at site 2 might be sewage leakage from the residential areas nearby, or runoff from fertilized grass fields close to the sites.

The BMWP score at site 2 was 45.0 and classified as moderate according to Bourne Stream Partnership n.d (Table A.3, Appendix A). The ASPT score at site 2 was 5.0 and was classified as fair according to Martin (2004) (Table A.4, Appendix A). The Shannon index of site 2 was 1.57. Based on these three indexes the water quality was classified as moderate. Site 2 had the highest amount of taxa (9 taxa) and we found Polycentropidae, which is sensitive to pollution. Moreover, Polycentropidae belongs to the Caddisflies, of which different species illustrate good quality conditions (New York State Department of Environmental Conservation, 2014). Site 2 had a small amount of Caddisflies and a large amount of pollution-tolerant species such as Planorbidae.

#### 4.3 Site 3: Kalsåsvatnet

The average concentration of TCB at site 3 was 17 CFU/100 ml and was classified as good according to Andersen *et al.* (1997) (Table A.1, Appendix A).

Site 3 had the highest levels of phosphorous of all the sites and the average value were classified as bad according to the parameters set by Andersen *et al.* (1997) (Table A.2, Appendix A). The high concentration of phosphorous at site 3 can be explained by runoff from fertilized soil, combined with a slow current and the relatively small size of the lake. Some phosphorous could also come from personal sewage treatment plants that wash out the wastewater into the lake (Mr. O. R. Sandven, “Grønn etat”, 2014, pers. comm., 14 November). Interestingly, we found a considerable variance between the duplicates at site 3. The measured concentrations were 33 and 14 µg/L, which according to Andersen *et al.* (1997) would imply either less good or bad quality. It is likely that the general phosphorus level is

situated between these measurements. This illustrates the importance of replicates, to make sure that the measurements get close to the real value.

We found no biodiversity at site 3. The sediments were swamp-like, thick and compact, which might lead to lower oxygen diffusion into the sediments. The low amount of oxygen in the sediment might contribute to a lower biodiversity. However, we cannot know this for sure, since we did not measure the oxygen concentration on the lake nor sediment. Another reason might be that our sampling technique was less effective at this location. We did not manage to swirl up the swamp-like sediment as much. Further research would be needed to determine if there are any animals living in the sediment at all.

#### 4.4 Site 4: Hjortlandsstemma

Site 4 had the lowest pH (5.98) compared with the other sites and was slightly more acidic. There was a slight increase in pH from site 4 downstream to site 1 (except site 3). The slight increase might result from the river accumulating waste and toxic materials from other rivers and streams. However, this increase is only subtle. The lower pH at site 4 might also be due to the trees around the site, since decomposed leaves lower the pH of surrounding waters (Moen, 1998, p. 32).

The average concentration of TCB was 10 CFU/100 ml and was classified as good according to Andersen *et al.* (1997) (Table A.1, Appendix A).

Site 4 had the lowest average phosphorus concentration with 8.9 µg/L. This was classified as good according to Andersen *et al.* (1997) (Table A.1, Appendix A). This area borders to forest and small-uncultivated hills, implying fewer phosphorus runoff. However, there were some fields upstream from site 4 which could lead to some excess phosphorus runoff.

The BMWP score of site 4 was 38.2 and was classified as fair according to Bourne Stream Partnership n.d (Table A.3, Appendix A). The ASPT score of site 4 was 6.4 and was classified as good according to Martin (2004) (Table A.4, Appendix A). The main reason for the high ASPT is probably Chloroperlidae with a BMWP score of 12.4, which is a lot higher than any other taxa we have found. Therefore, we will not give the ASPT score too much weight. The Shannon index of site 4 was 1.59. Based on these three indices the water quality was classified as poor. There was only one Chloroperlidae, and these are specifically sensitive to dissolved oxygen levels (Wisconsin's Citizen-Based Water Monitoring Network, 2007).

The rocks in the river and the solid bedrock at the riverbanks were rusty-red at site 4, suggesting the presence of iron, possibly from the landfill upstream. We have not been able to find references to the direct effect of landfills on water quality. However, there are multiple studies on lakes, rivers, and ground water near landfills to determine a possible effect (Aanes 2014; Bækken 2007; Lyngkilde & Christensen 1992; Wakida & Lerner 2005). A limited number of macro invertebrate species might be detected in a stream with highly dissolved iron and lower pH (under 3.5) (ENVIRO SCI Inquiry, n.d.). The pH was near neutral, and we therefore suggest that the iron might be one of the factors that contribute to the lowest abundance of individuals (13) at site 4.

#### 4.5 Comparison with previous studies

In 2004 Norsk Institutt for Vannforskning (NIVA) made a review of the results from different studies conducted on several watercourses, including the Gaupås watercourse (Table 4.1) (Hobæk and Bjørklund, 2004). Their measurements from Hjortlandsstemma are very similar to our results from site 4, although our sampling site was closer to the inlet of the lake. Interestingly our TCB measurements were much lower than all previous studies. Our study also showed a lower level of phosphorus concentrations. There might be a decreasing trend over the years. A possible decrease in sewage leakage from the residents at Flaktveit might explain these lower levels of phosphorus and TCB.

For the whole Gaupås watercourse, site 1 is probably the most representative for overall comparisons, since it is downstream from the sampling site used by previous studies. Here we measured a higher TCB concentration, but a lower phosphorus concentration. The higher TCB levels might be due to more sewage leakage or maybe even fecal pollution from animals and pets. The lower phosphorus levels could be due to less runoff from fertilized fields. However, our data are not directly comparable as we compare with a study that reports the maximum value from several sampling days. Hobæk (1995) has also measured the pH in both Hjortlandsstemma and Gaupåsvatnet. Our measurements showed a slightly higher pH in Gaupåsvatnet, and a slightly lower pH in Hjortlandstemma compared to Hobæk's measurements.

**Table 4.1:** TCB, total phosphorus and pH measurements in Gaupåsvatnet and Hjordlandsstemma from previous studies. The values from our own study are also presented for comparison.

	Gaupåsvatnet			Hjordlandsstemma		
	pH	Phosphorous (µg/L)	TCB (CFU/100 ml)	pH	Phosphorous (µg/L)	TCB (CFU/100 ml)
<b>1992</b>		26 <sup>a</sup>	25 <sup>a</sup>		30 <sup>a</sup>	310 <sup>a</sup>
<b>1995</b>	6.4 <sup>b</sup>	25 <sup>a</sup>	62 <sup>a</sup>	6.2 <sup>b</sup>	19 <sup>a</sup>	225 <sup>a</sup>
<b>1998</b>		30 <sup>a</sup>	105 <sup>a</sup>		21 <sup>a</sup>	95 <sup>a</sup>
<b>2014</b>	6.4	17	95 <sup>c</sup>	6.0	8.9	10

a) Hobæk og Bjørklund (2004)

b) Hobæk (1995)

c) This value is the average of the mean values from the inlet and the outlet.

## 5. Conclusions

We conclude that the overall quality of Gaupåssvatnet is fair. The sites we studied had an average biodiversity, despite the slightly high phosphorus concentrations. These phosphorous concentrations were most likely caused by runoff from fertilized fields, as well as minor sewage leakages around the lake. In addition, it is possible that the elevated bacterial levels at site 1 were more influenced by sewage leakage from the neighboring residential area. Our studies at site 3 showed no biodiversity, so no conclusion on biodiversity can be made for that site. We remain critical over this observation and further studies should investigate this further. Except for site 3, site 4 was the least diverse, most likely due to chemical runoff from the landfill at Hjortland, despite the more normal phosphorous and bacterial levels.

The TCB values were good, except at site 1 and the phosphorus levels varied from good at site 4 to bad at site 3. Site 4 had a slightly elevated conductivity compared to the other sampling sites, as well as a lower pH. Lastly, the biodiversity index of BMWP varied from moderate to poor, and ASPT varied from good to fair.

From a comparative point of view we cannot say very much about the landfills' effects on the water, because we have no previous studies with which to compare our results. Additionally we did not sample at the landfills directly. As previously stated, there are multiple studies on landfills, but it does not seem to study the consequence on water quality. We interpret this as that there is an assumption that landfills does have a negative effect on water quality, but it is hard to get data proving this. Therefore, we conclude that a possible reason for the low water quality interpret from biodiversity indices can be due to an effect from the landfills; since the other factors we measured where mostly fairly good. Future studies are therefore necessary to understand the possible effect of the landfills.

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## Appendixes

### Appendix A

**Table A.1:** Ecological parameter for freshwater based on concentration of thermotolerant coliform bacteria. This parameter was set by Andersen et al. (1997).

Concentration (CFU/100 ml)	Condition category
<5	Very good
5-50	Good
50-200	Less good
200-1000	Bad
>1000	Very bad

**Table A.2:** Ecological parameter for freshwater based on concentration of phosphorus. This parameter was set by Andersen et al. (1997).

Concentration of phosphorus ( $\mu\text{g/L}$ )	Condition category
<7	Very good
7-11	Good
11-20	Less good
20-50	Bad
>50	Very bad

**Table A.3:** Biodiversity Monitoring Working Party (BMWP) score categories (Bourne Stream Partnership, n.d.)

BMWP scores	Category	Interpretation
0-10	Very poor	Heavily polluted
11-40	Poor	Polluted or impacted
41-70	Moderate	Moderately impacted
71-100	Good	Clean but slightly impacted
>100	Very good	Unpolluted/not impacted

**Table A.4:** Average score per taxon (ASPT) categories (Ouse & Adur Rivers Trust, n.d.)

ASPT	Water Quality
>7	Very good
6.0-6.9	Good
5.0-5.9	Fair
4.0-4.9	Poor
<3.9	Very poor

## Appendix B

**Table B.1:** *The measured thermotolerant coliform bacteria at sites 1 to 4*

Sample Site	Replicate number	Concentration (CFU/100mL)	Average CFU value <sup>a</sup>	SD <sup>b</sup>
1	1	190	177	18.85
	2	190		
	3	150		
2	1	10 <sup>c</sup>	13	4.71
	2	10		
	3	20		
3	1	10 <sup>c</sup>	17	9.43
	2	30		
	3	10		
4	1	10 <sup>c</sup>	10	0
	2	10 <sup>c</sup>		
	3	10		

a) The measured concentration from each site given as colony forming units (CFU) per 100 mL incubated for  $21 \pm 3$  hours.

b) The standard deviation between the colony forming units (CFU) of thermotolerant coliform bacteria values at each site

c) These values were given as  $<10$ , but we used it as  $=10$  for the purpose of this report.

**Table B.2:** *The measured concentration of phosphorus at sampling sites 1 to 4 in the Gaupås watercourse.*

Sample site	Replicate number	Concentration ( $\mu\text{g/L}$ )	Average <sup>d</sup>	SD <sup>e</sup>
1	1	18	17	1.41
	2	16		
2	1	15	16.5	2.12
	2	18		
3	1	33	23.5	13.46
	2	14		
4	1	9.2	8.9	0.42
	2	8.6		

**Table B.3:** *The total biodiversity that was sampled at sampling site 1 to 4 in the Gaupås watercourse*

Phylum	Class	Order	Family	Number of individuals			
				per site			
				1	2	3	4
Platyhelminthes	Turbellaria			1			
		Tricoptera	Brachycentridae	2			
			Polycentropidae	2	4		
			Elmidae	1			
		Coleoptera	Halplidae		2		
			Hydrochidae				2
Arthropoda	Insecta	Diptera	Chironomidae				3
			Simuliidae				1
		Ephemeroptera	Leptophlebiidae	4	4		1
			Baetidae		1		
		Hemiptera	Corixidae		1		
		Plecoptera	Chloroperlidae				1
Annelida	Clitellata	Oligochaeta (subcl.)		11	6		5
			Planorbidae	6	19		
Mollusca	Gastropoda		Physidae	5	2		
			Viviparidae		2		

## Appendix C

```
# To analyse the significance of the observed variance between the different sites for
# the concentration of thermotolerant coliform bacteria, we used generalized linear
# models (GLM). We chose to GLM for this data since it has one response (the concentration)
# and one predictor (the site), and the response is measured as counts of bacteria in
# a water sample.
```

```
bacteria.df <- read.table('clipboard', header=T, sep='\t')
attach(bacteria.df)
head(bacteria.df)
# The data copied are from the raw data Table B.1 in Appendix B
```

```
# The hypothesis:
# H0: There is no difference in the bacteria concentration between the sites.
# HA: There is a difference between the sites.
```

```
result.bacteria <- glm(Concentration~Site, family=poisson)
```

```
pchisq(result.bacteria$dev,df=result.bacteria$df.res,lower=F)
# 4.156691e-27
# We have overdispersion since the value is close to zero. So need to use quasipoisson.
```

```
result.bacteria <- glm(Concentration~Site, family=quasipoisson)
```

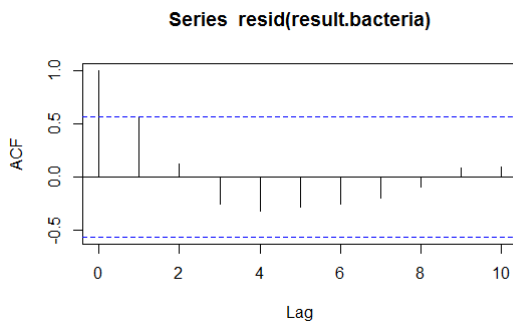
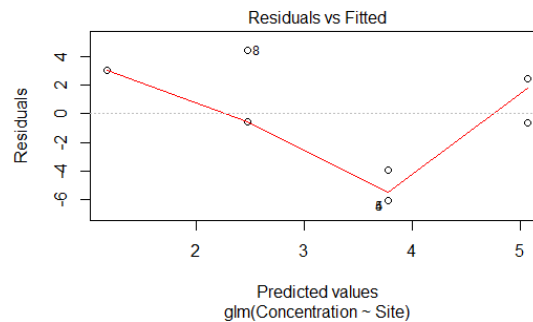
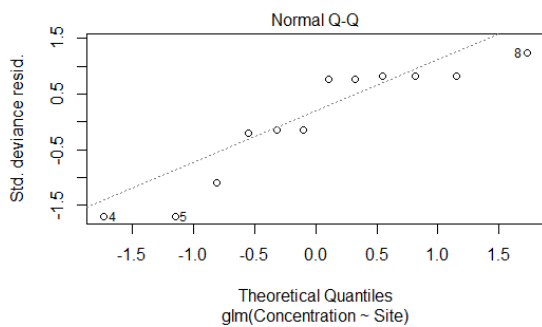
```
anova(result.bacteria, test='Chi')
# Analysis of Deviance Table
# Model: quasipoisson, link: log
# Response: Concentration
# Terms added sequentially (first to last)
# Df Deviance Resid. Df Resid. Dev Pr(>Chi)
# NULL          11  947.51
# Site 1  797.74    10  149.77 1.994e-13 ***
```

```
summary(result.bacteria)
# Call:
# glm(formula = Concentration ~ Site, family = quasipoisson)
# Deviance Residuals:
#   Min       1Q   Median       3Q      Max
# -6.1047 -1.4899  0.9463  3.0060  4.4131
# Coefficients:
#   Estimate Std. Error t value Pr(>|t|)
# (Intercept)  6.3613    0.3466  18.352 4.97e-09 ***
# Site        -1.2967    0.2305  -5.625 0.00022 ***
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# (Dispersion parameter for quasipoisson family taken to be 14.76994)
# Null deviance: 947.51 on 11 degrees of freedom
```

```
# Residual deviance: 149.77 on 10 degrees of freedom
# AIC: NA
# Number of Fisher Scoring iterations: 5
```

```
# Since the P-value is less than 0.05 (P=<4.97e-09) we can reject the null hypothesis.
# There is an significant difference between the sites.
```

```
plot (Concentration~Site)
plot (result.bacteria)
acf (resid(result.bacteria))
```



```
# The residual vs Fitted indicates that there is no constant variance, and the Q-Q plot
# is not normally distributed.
# The Lag/ACF plot shows that the data is independent, since the bars are underneath the
# dotted line.
# So we have used the correct model.
```

```
#####
```

```
# Use a two-sample t-test to determine what sites that are significant different from
# each other.
```

```
bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
# Site 1 vs Site 2
t.test (Concentration~Site)
# data: Concentration by Site
# t = 11.8842, df = 2.249, p-value = 0.00448
# alternative hypothesis: true difference in means is not equal to 0
```

```
# 95 percent confidence interval:
# 110.0510 216.6156
# sample estimates:
# mean in group 1 mean in group 2
# 176.66667 13.33333

# Site 1 is significant different from Site 2

bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
# Site 1 vs Site 3
t.test (Concentration~Site)
# data: Concentration by Site
# t = 10.7331, df = 2.941, p-value = 0.001888
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# 112.0176 207.9824
# sample estimates:
# mean in group 1 mean in group 3
# 176.66667 16.66667

# Site 1 is significant different from Site 3

bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
# Site 1 vs Site 4
t.test (Concentration~Site)
# data: Concentration by Site
# t = 12.5, df = 2, p-value = 0.006339
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# 109.2980 224.0354
# sample estimates:
# mean in group 1 mean in group 4
# 176.6667 10.0000

# Site 1 is significant different from Site 4.

# Site 2 vs site 3
bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
t.test (Concentration~Site)
# data: Concentration by Site
# t = -0.4472, df = 2.941, p-value = 0.6856
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -27.32454 20.65788
# sample estimates:
# mean in group 2 mean in group 3
```

```
#      13.33333    16.66667

# Site 2 is not significant different from Site 3

# Site 2 vs 4
bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
t.test (Concentration~Site)
# data: Concentration by Site
# t = 1, df = 2, p-value = 0.4226
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -11.00884 17.67551
# sample estimates:
# mean in group 2 mean in group 4
#      13.33333    10.00000

# Site 2 is not significant different from Site 4

# Site 3 vs 4
bacteria.df <- read.table ('clipboard', header=T, sep='\t')
attach (bacteria.df)
t.test (Concentration~Site)
# data: Concentration by Site
# t = 1, df = 2, p-value = 0.4226
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -22.01768 35.35102
# sample estimates:
# mean in group 3 mean in group 4
#      16.66667    10.00000

# Site 3 is not significant different from Site 4
```

## Appendix D

```
# To analyze the significance of the observed variance between the different sites for
# the concentration of phosphorus, we used one-way ANOVA.
# We chose to do one-way ANOVA for this data since it has one response (the concentration)
# and one predictor (the site), and the response is measured as concentration of phosphorus
# in a water sample; But there are more than one groups (multiple sites).
# The samples are thought to be independent.
```

```
phosphorus.df <- read.table('clipboard', header=T, sep='\t')
attach(phosphorus.df)
# The data copied are from Table B.2 in Appendix B
```

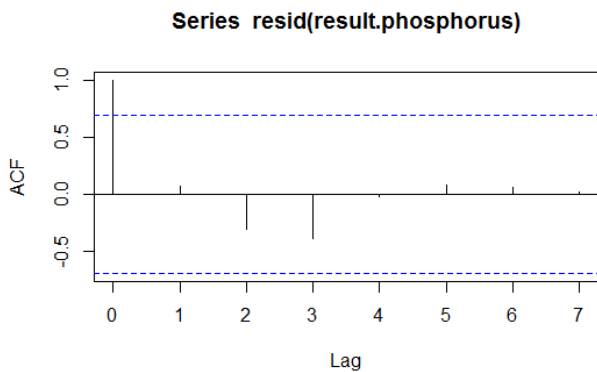
```
# The hypothesis:
# H0: There is no difference in the phosphorus concentration between the sites.
# HA: There is a difference between the sites.
```

```
result.phosphorus <- aov(Concentration~Site)
```

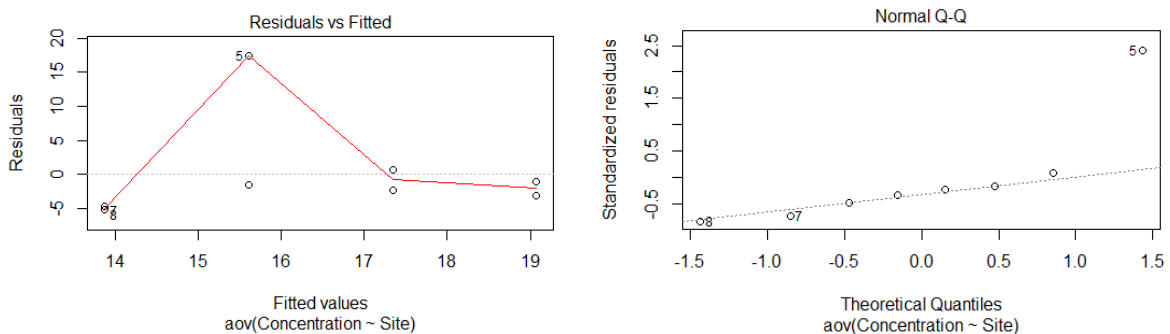
```
summary(result.phosphorus)
```

```
# The difference is not significant P=0.513, so we cannot reject the null hypothesis.
```

```
acf(resid(result.phosphorus))
```



```
plot(result.phosphorus)
```



```
# Independence is maintained.
# Normality is maintained.
# Constant variance is violated.

# Since constant variance is violated, we will run a glm.
phosphorus.glm <- glm(Concentration~Site)
anova(phosphorus.glm, test='Chi')
# Analysis of Deviance Table
# Model: gaussian, link: identity
# Response: Concentration
# Terms added sequentially (first to last)
# Df Deviance Resid. Df Resid. Dev Pr(>Chi)
# NULL          7  401.19
# Site 1 29.929    6  371.27 0.4868

# There are still no significant difference between the sites.
# But from Figure 3.2, it seems like Site 4 can be significant different from the others.
# So we will run a two sample t.test between site 4 and the other sites.

# Site 4 vs Site 1
phosphorus.df <- read.table('clipboard', header=T, sep='\t')
attach(phosphorus.df)
t.test(Concentration~Site)
# data: Concentration by Site
# t = 7.7584, df = 1.179, p-value = 0.05905
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -1.243601 17.443601
# sample estimates:
# mean in group 1 mean in group 4
#      17.0      8.9

# There is no significant difference between Site 4 and 1

# Site 4 vs Site 2
phosphorus.df <- read.table('clipboard', header=T, sep='\t')
attach(phosphorus.df)
t.test(Concentration~Site)
# data: Concentration by Site
# t = 4.9683, df = 1.08, p-value = 0.1129
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -8.747964 23.947964
# sample estimates:
# mean in group 2 mean in group 4
#      16.5      8.9

# There is no significant difference between Site 4 and 2
```

```
# Site 4 vs site 3.
phosphorus.df <- read.table ('clipboard', header=T, sep='\t')
attach (phosphorus.df)
t.test (Concentration~Site)
# data: Concentration by Site
# t = 1.5361, df = 1.002, p-value = 0.367
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
# -105.6025 134.8025
# sample estimates:
# mean in group 3 mean in group 4
#      23.5      8.9

# There is no significant difference between Site 4 and 3
```