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Assesment of Impact of Sewage Effluents on Coastal Water Quality in Hafnarfjordur, Iceland

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ABSTRACT

The impact of sewage disposal on water quality in Hafnafjordur was assessed in December 2003 using sewage pollution markers. Feacal coliforms were used as indicators of bacterial pollution while phosphate, nitrate, silicate and oxygen were used as indicators of possibe nutrient enrichment in the bay. Also monitored were salinity, temperature and depth. Measurements were done on surface waters. Sea-surface temperatures ranged from 2.2 to 9.7ºC increasing towards the sewage outlets. Oxygen values ranged from 6.23 to 9.66 mg/l. Salinlity measurements were generally low and ranged from 15.59 to 32.79 PSU. The counts of feacal coliform were generally high with the counts ranging between 170 to > 16,000 MPN/100 ml. The bacterial counts were higher close to the sewage outlets and decreased with distance from the sewage outlets. Feacal coliform counts were above the limits recommended by European Community Bathing Water Directive (1976) for drinking and bathing and Icelandic regulation for several water uses and may present potential risk to human health. However, it should be mentioned that this monitoring was undertaken when most adverse effects would be expected regarding feacal coliforms since it was the darkest period of the year when bacteria die-off time is longest and during the low tide close to spring tide when influence of freshwater and sewage is high.

The distribution pattern of nutrients in this study indicates that the influence of sewage on nutrients concentrations within the bay was highest close to the sewage outlets. Silicates, TD-P and DP concentrations ranged from 10.1 to 79.8 µM, 0.9 to 5457 µM and 0.73 to 279 µM respectively. Nitrate concentrations were between 7.3 and 25.65µM closer look at the relationships between different nutrients using established relationships from previous work, revealed deviations that are herein attributed to sewage effluent effects. There was a tendency of increase in feacal coliform counts with increasing nutrient load and depth. There is need to prioritize action to minimize or combat the current impacts from sewage disposal reflected in the water quality. Management options are discussed.

Keywords : Hafnarfjordur, Sewage impact, Nutrients, Feacal coliforms, water quality, Legislations, Water quality standards.

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1 INTRODUCTION

The problems associated with sewage disposal have become a major problem of the urban world due to increase in human population and urbanization**.** The commonality of sewage related problems throughout coastal areas of the world is significant since these areas are inhabited by over 60% of the human population. Consequently, domestic waste-water discharges are considered one of the most significant threats of the coastal environments worldwide (GPA 2001). Environmental effects associated with domestic waste-water discharges are generally local with transboundary implications in some areas.

Coastal waters are facing a variety of pressure affecting both the ecosystem and human health through sewage waste-water discharge and disposal practices that may lead to introduction of high nutrient loads, hazardous chemicals and pathogens causing diseases. The adverse public health, environmental, socio-economic, food quality and security, and aesthetic impacts from sewage contamination in coastal areas are well documented**.** (Luker, M. and Brown, C. 1999, Tyrrel, 1999, Danulat *et al* 2002, WHO, 2003). Pollution of the coastal water usually interferes with various water uses. Cultured bivalves are generally reared in areas that are often densely populated and are sensitive to heavy pollution from human activities. Pathogens transmitted by human feaces are most commonly involved and the discharge of sewage polluted by human and animal pathogens into the sea represents the main source of bacterial pollution. Every pathogen present in seawater may be trapped and concentrated in the tissues of the bivalves and so represents a potential heath hazard.

Legislation, directives and water quality standards for various coastal uses like shellfish harvesting, recreation, dinking and aquaculture have been developed in many countries to limit problems associated with sewage. These standards are usually not realized due to poor sewage management. The poor management usually arises from the fact that waste-management decisions take place in complex situations governed by political, bureaucratic, and financial forces that often interfere with the implementation of existing regulations and standards. In most cases, waste disposal decisions encounter resistance and inefficiency in the eventual administrative implementation and financial difficulties that affect the disposer’s ability to comply with the original decision.

The fact that the majority of urban populations depend on coastal surface waters which are usually used for sewage disposal, in one way or another, makes water pollution the principal problem that requires sound management practices to contain impacts. The study is developed to make an assessment in order to evaluate the prevailing situation and provide accurate information on the water quality at Hafnarfjordur using pollution indicators that would give basis for appropriate waste-water management practices. The study tried to answer the following questions: To what extent does the sewage discharge/ disposal impact on the water quality along the fjord? Whether the existing water quality criteria or standards for various water uses like aquaculture, shellfish, bathing and recreation are met, interpret the water quality results assembled during the study, and to determine whether or not the current water quality meets these previously defined standards for designated uses, including public health.

2 LITERATURE REVIEW

2.1 Impacts of sewage effluents

Sewage effluents have historically been discharged through outfall in shallow coastal and waters (Young-Jin Suh and Rousseaux P., 2001, Mclntyre 1995, Klaus Koop and Pat Hutchings 1996) and is one of the major stresses impacting coastal ecosystems. There are usually significant effects on water quality and on marine life arising from sewage disposal. Water quality deterioration is one of the most important water resource issues of the 21st century. Therefore the quality status of coastal surface water is very important and would always be under public scrutiny because of health risk associated with sewage contamination.

The potential deleterious effects of pollutants from sewage effluents on the receiving water quality of the coastal environment are manifold and depend on volume of the discharge, the chemical composition and concentrations in the effluent. It also depends on type of the discharge for example whether it is amount of suspended solids or organic matter or hazardous pollutants like heavy metals and organochlorines, and the characteristics of the receiving waters (NAP, 1984, Canter W., 1996: Nemerow and Dasgupta, 1991). High levels of soluble organics may cause oxygen depletion (Peter and Robin, 2002) with a negative effect on aquatic biota. Contamination of the coastal water may result in changes in nutrient levels, abundance, biomass and diversity of organisms, bioaccumulation of organic and inorganic compounds and alteration of trophic interaction among species. Receiving waters with high flushing capacity are able to dilute or eliminate most of the conventional pollutants but persistent toxic compounds and long lived pathogens will always be troublesome.

2.2 Nutrients

Large quantities of nutrients released into the coastal water through the sewage waste-water may result in nutrient enrichment stimulating algal growth that in turn affects the photic zone depth, cause dissolved oxygen depletion, bioaccumulation of organic and inorganic compounds, and alteration of trophic interactions among both aquatic flora and fauna (Danulat *et al* 2002, Russo, 2002). Elevated nutrient levels may also result in excessive growth of algal blooms, some of which may result in production of algal toxins. The algal toxins are risks for water and seafood quality and safety.

2.3 Effects associated with bacterial pollution

Effects arising from bacterial pollution are many and they involve public health, as well as social and economic implication. The survival of enteric bacteria in the aquatic enviroment has attracted interst in view of its pulbic health significance (Gareth, Rees. 1993, Nelson *et al*, 1996). It has been shown that filter-feeding bivalves, for example mussels and oysters, accumulate pathogenic bacteria in their tissues (Cabelli & Heffernan 1970, Prieur *et al* 1990), making the shellfish unsafe for human consumption. In fact, contamination from sewage discharge has resulted in closure or prohibition of many shelfish areas world wide and on the basis of this contaminations some of these areas have been designated as approved, conditionally approved or not approved areas depending on the situation.

Data are available linking waste-water contaminated bathing water to swimming associated illnesses (Cabelli, 1979). Epidemiological studies have shown that there is a linear correlation between microbial water quality and gastro-intestinal illnesses (Baron *et al*, 1982. Cabelli *et al,* 1982).

The damages caused by increased illness or mortality due to ingestion or skin contact with contaminated water, give rise to direct health care costs and indirect opportunity costs (World Bank, 2003). The joint Group of Experts on Scientific Aspects of Marine Protection (GESAM, 2001) estimated the impact of bathing in and eating shellfish from polluted seas at a cost of approximately US$ 12-24 billion per year (Table 1).

Table 1. Global human burden and associated economic costs of selected diseases in relation to exposure to marine waters and shellfish contaminated with enteric micro-organisms. Source: GESAMP 2001 (IMO/FAO/UNESCO-IOC / WMO / WHO / IAEA /UN/UNEP).

Disease or cause	Disability Adjusted Life-Years (DALY)	Corresponding economic losses (rounded) in US Million dollars
Tuberculosis	38 000 000	115 000
Malaria	31 000 000	95 000
Diabates	11 000 000	35 000
Trachea, Brachia, Lung cancer	8 800 000	26 000
Stomach cancer	7 700 000	23 000
Intestinal nematodes	5 000 000	15 000
Upper respiratory trackt infections	1 300 000	4 000
Trachoma	1 000 000	3 000
Onchocherciasis	900 000	2 700
Dengue fever	750 000	2 200
Japanese encephalis	740 000	2 200
Chagas disease	660 000	2 000
Leprosy	380 000	1 000
Diphtheria	360 000	1 000
Marine exposure		
Contaminated bathing water	400 000-800 000	1 200-2 400
Contaminated shellfish	3 500 000-7 000 000	10 000-20 000

The GESAMP study based on estimate of the number of bathers and the WHO estimates of the risks at various levels of contamination, reveal that bathing in polluted seas may cause some 250 million cases of gastrinal and upper respiratory diseases every year. The global impact can be measured by adding up total years of healthy life that are lost through diseases, disability and death using the concept of the Disability Adjusted Life Years (DALY) developed by WHO and the World Bank. Results from such excercises, indicate that the world wide burden of diseases incurred in bathing at sea adds up to 400,000 DALY's

Probable loss of tourism income in countries depending on tourism as experienced in Peru in 1999 when the cholera outbreak was severe is an example of the negative consequence that can result from poor sewage managements, the abrupt halt in tourism and agricultural export costed the Peruvian economy US$ 1000 million just in 10 weeks. The total economic loss was more than three times the total national investment in water supply and sanitation improvement in the 1980´s (WHO, 2003). Other possible effects include loss of income for e.g. fishermen, fish processing plants and loss of amenity value when the environment deteriorates.

2.3.1 Bacterial indicators of pollution

The value of the evaluation of water quality by bacterial indicators is of great importance and has been a subject of many investigations attempting to identify the most reliable indicator group as an indication of the presence of pathogens and what levels of indicator will ensure satisfactory water quality. Sewage contains disease causing organisms or pathogens that originate from the interstistinal tract of mammals including humans.

With regard to feacally transmitted pathogens, much information is available concerning the relative validity of indicator groups. Total coliforms have been used as indicators for many years in evaluating water quality for several water uses with respect to domestic waste (Hill, 1996, Cabelli 1972, Tyrrel, 1999; Kashefipour, *et al*. 2002, Lipp E.K, *et al* 2001, Hughes K.A. and Thompson.A.,2003). However, because of the difficulties associated with the occurrence of non-feacal bacteria, feacal coliforms and pathogenic forms such as *Escherichia coli* are now used largely as bacteriological indicators (Thomann RV, and Muller JA, 1987). Many authors have demonstrated the greater validity of the feacal coliform group compared with total coliform group in indicating the presence of *Salmonella* (Geldreich, 1965, Prieur D.G. *et al.* 1990).

Current thinking suggests that feacal coliforms and *E.coli* are not the ideal indicators for sewage pollution in the environment (Gareth, Rees.1993). For example, Cabelli *et al* (1975) indicated that non-feacal sources of at least one member of feacal coliform group, the *Klebsiella* species, had many sources and had been observed in several effluents in the absence of feacal contamination. M.N. Byappanahalli and R.S. Fujioka1998. indicated that the use of feacal coliforms as indicators are not reliable in tropical waters because selected feacal bacteria persist at these latitudes and represent non-fecal contamination. There is growing support that the bacterium *Streptococus feacalis* and some viruses, which are associated with human and animal feaces, may be better sewage pollution indicators since they are more resistant to environmental stress and survive longer. This is for example reflected in the Icelandic regulation for recreational waters.

There are a number of issues directly related to appropriate choice of indicator organism, but it should be noted that the significance of the usual indicators is limited to be an indication of pathogens transmitted by the feacal route. Feacal coliforms are not all pathogenic to humans, it only provides an indication of the amount of feacal load present, which may be contaminated with other pathogens. High levels of feacal coliforms in the recipient waters would mean poor water quality which will affect various water uses. Feacal coliforms were used as indicators of pollution in this study since they are easy to analyse, indicate probable occurence of pathogens and, lastly, they are used by regulations world over to set Bacterial WQS.

2.3.2 Nutrients status in coastal waters of Iceland

The nutrient concentrations of Icelandic shelf waters depend mainly on concentrations found in the oceanic water masses coming into the region. The concetrations are however modified in the nearshore by the interaction of land and sea, admixture of freshwater discharge and changing bathymetry. (Stefansson U. and Olafsson J, 1991), while reporting on nutrient sources of Icelandic coastal waters, indicated the annual mean concentrations of 0.85 µM, 12 µM and 6µM for rivers on the west coast and oceanic winter values of PO_4-P, NO_3-N and Si respectively (Table 2).

Table 2. Dissolved nutrient levels in river waters coastal water (0-200 m). (Stefansson U. And Olafsson J., 1991)

	Winter values (µM)			Annual means(µM)		
	PO_4-P,	NO_3-N	Si	PO_4-P,	NO_3-N	Si
Rivers						
(West coast)	0,6±0,24	3,9	197± 16	0,20	2,1	174
Ocean	0,85	12	6	0,70	9,5	5

The main anthropogenic sources of nutrients are river discharge, domestic sewage, industrial effluents, and runoff from agricultural activities. However nutrient have not been regarded as pollutants in Iceland (NPA, 2001). The water exchange in the shallow waters off the Icelandic coast is usually fast which leads to the assumption that the release of nutrients to the coast is not likely to cause eutrophication in the sea as oppossed to the prevailing global opinion. There are however localised effects due to eutrophication close to sewage outlets. Release of nutrients is expected to decrease in future, due to municipal actions in sewage issues and the statutory treatment of sewage in all areas.

2.3.3 Legislations and standards on water quality

Historically, sewage has been discharged in raw or partially treated form, through outfalls into the receiving waters, which could be sea, lake or river. Attempts have increasingly been made by several nations to regulate or control the sewage discharges into the receiving waters in order to limit the negative effects. These attempts and their implementations have, however, varied from nation to nation depending on both economic and technological state of the country. The water quality standards and regulations do vary between different countries and international organizations with interest in water quality and safety but all have common the objective to reduce or eliminate pollution.

The water quality regulations can be considered from pollution-control and water-usage. Standards are usually made in reference to designated uses of the water such as farming of fish, shellfish, wildlife, recreation, drinking and use in the food industry. Water quality standards and guidelines should be regarded as tools for sound water resource management, rather than an automatic assurance of good water quality.

The EU for instance has adopted several Directives for the control of urban pollution, many of which, when realized will largely contributes to attainment of good chemical and ecological status of the receiving waters. The Directives include the Urban Wastewater Treatment UWWTD (91/271/EEC), (CEC, 1991); (Zabel Thomas Z. *el al*, 2001, Tyrrel S.F. 1999) which aims to protect surface inland and coastal waters by regulating collection and treatment of urban wastewater and discharge of some biodegradable elements of pollution, the integrated Pollution Control and Prevention (IPPC) Directive (CEC, 1976), and the EU Product Directive that control discharge of effluents from the sewer to the receiving surface waters. The implementation of the UWWTD by member states is expected to be in place by 2005.

The effluent from sewage is expected, through the Urban Wastewater Treatment Directive ((91/271/EEC), to meet required minimum effluent standards for indicator parameters, always with regard to such as, BOD5, COD and TSS and for sensitive recipient also the main nutrient TP and TN (Table 3). The Directive requires as a general rule that all agglomerations above 2000 PE should be provided with collection systems for urban wastewaters and also stipulates the kind of treatment to be received by different areas.

The criteria usually depend on the sensitivity of the receiving waters, which are classified as either less sensitive or sensitive. The former may receive only primary treatment; while the sewage discharges (>10,000 PE) to the latter must go through biological treatment and nutrient removal (secondary treatment). The classification of sensitive areas is based mainly on the risk of eutrophication. The Directive 91/676/EEC concerning pollution caused by nitrates compliments the above Directive in reducing and preventing nitrate pollution to safeguard marine waters from eutrophication. Nitrogen is usually the limiting factor in seawater except where the nutrient loads are high due to external input.

Table 3. Selected standards for domestic and industrial wastewater effluents disharge. Source.:CEC,91/271/EEC, World Bank, 1998, Wider Caribbean Region (WCR) 1998.

Parameter	Unit	EU,1991	WCR,1998	WB,1998
BOD_5	mg/l	25	30(150*)	50
COD	mg/l	125	150(300*)	250
TSS	mg/l	35-60	30(100*)	50
Total-N	mg/l	10-15(S)	10	10
Total-P	mg/l	1-2(S)	1	-

(S): Sensitive areas
(*): Non-sensitive areas

Standards in use in the Wider Caribbean Region (WCR) and World Bank on limit for urban wastewater effluents are comparable but the EU standards seem to be more stringent.

2.3.4 Iceland Regulation on Sewage treatment

The Icelandic regulation on sewage management is an adaptation of the EU directive 91/271/EEC except for the additional requirements on microbial indicators**.** According to Iceland's regulation No. 798/1999, on Drainage Systems and Sewage, all sewage recieving environments must be classified as sensitive or less sensitive and methods of treating sewage must be based on the classification (NPA, 2001). The regulation also contains rules on the treatment of sewage in Iceland, where for example, the implementation of appropriate treatment of sewage from all urban areas shall be completed before year-end 2005 as in the case of EEC Directive on WWTP. To this end Hafnarfjarðarbær, Staðardagskrá 1995, Lög nr.53, 8.mars1995 {Hafnarfjarðarbær, Local Agenda 21. Act No.53/1995}, on financial support to municipalities for Sewage Control, provides for the allocation of grants to municipalities engaged in the development of their drainage systems within the stipulated time frame.

2.3.5 Microbiological water quality standards

Microbiological water quality parameters for different water uses from various government or agencies are presented in Table 4. The table shows some variations in the allowable limit, mainly for bathing waters especially between the EU and others. The EU Directive (76/160/EEC) concerning the quality of the bathing water (CEC 1976) stipulates microbiological criteria for the quality of water which is applied to designated bathing areas or beaches at <2000 feacal coliforms/100ml. WHO and World Bank, USA and WCR required limits for bathing waters are set much lower. The selected standards concur that drinking water supply should not have any feacal coliforms at all. Iceland operates using the EU standard with some few national adjustments.

The microbiological criterion for shellfish for human consumption has been accepted internationally to be 70 total coliforms per 100 ml using MPN, with no more than 10% of the values exceeding 230 MPN/100 ml. The UNEP/WHO standards for shellfish harvesting waters are at the maximum of 10 feacal coliforms /100 ml for 80% of samples taken and no feacal coliforms detected for drinking water (WHO, 1993, UNESCO /WHO/ UNEP, 1992). US, EU and Iceland regulations stipulates that median feacal coliform bacterial concentration should not exceed 14 MPN/100 ml for shellfish growing and harvesting areas with not more than 10% exceeding 43 MPN/100 ml of the shellfish. While 100 MPN feacal coliforms is limit for recreational areas and areas around food industries, waters outside the dilution areas of sewage outlets which must be defined by the appropriate municipality have a limit of 1000 MPN/100 ml feacal coliforms.

Table 4. Selected microbiological quality standards and guidlines for different water uses. (CEC, 1976, World Bank, 1998, Wider Caribbean Region (WCR) 1998, EPA, 1986, Goverment of Iceland (GOI) 1999, WHO, 1993).

Designated as	EU	US	WHO	WCR	ICELAND	WB
Bathing waters	2000(100)	200	400	200	100	<400
Shellfish areas	14	14	10	43	14	-
Drinking waters	<1	0	0		0	-

- Numbers are feacal coliforms MPN/100 ml.

Regulations regarding bacterial standards require that feacal coliforms concentrations in at least in 90% of cases must be below 1000/100 ml for a minimum of 10 samples.

2.3.6 Sewage waste disposal in Iceland

The main sources of sewage in Iceland are residential areas, fish processing, livestock slaughtering, dairy industries, aquaculture, textile industries, tanning plants and some heavy industries. Both the industrial and domestic sewage is usually disposed through the same drainage into the sea. Currently, the majority of sewage in many places in Iceland, is released untreated into the sea (NAP 2001). However, the sewage treatment in Reykjavik and some neigbouring communities accounting for approximately 50% of the population are in good shape. The polluting effects of sewage depend to a large extent on the capability of the recieving environment to dilute the pollution released into it. With the fast water exchange in the shallow waters off the Icelandic coast, pollutants are reportedly diluted to background levels and therefore the sewage derived pollution can easily be kept at minimum levels.

For the same reason, sewage pollution is mainly localised and limited to coastal areas around the ends of drainage pipes from urban areas which indicate that the release of nutrients to the coast is not likely to cause eutrophication in the sea as opposed to the prevailing global situation. The management situation is expected to improve in the whole country with the implementation of the current legislation and requirements for improved utilization of raw materials and increased utilization of organic fertilizers. Release of nutrients is expected to decrease in future, due to municipal actions in sewage issues and the statutory treatment of sewage in Iceland.

3 MATERIALS AND METHODS

3.1 Study Area

Hafnarfjordur is located in the southwest of Reykjavik; Iceland (Figure1.) In 2001 the area is inhabited by about 21.000 people.

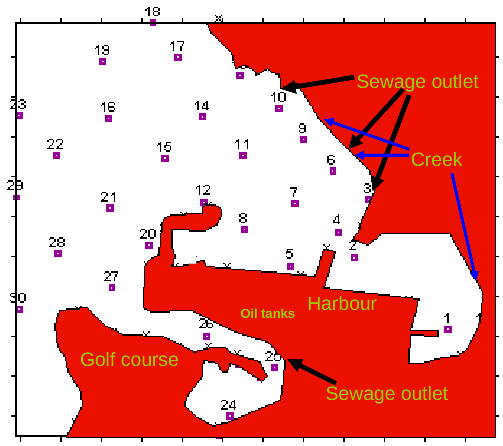

Figure 1: Map of Hafnarfjord showing sampling stations, inflowing freshwater and sewage outlets.

There is a multitude of industries located in the area. These industries include food processing plants, fish net industries and other heavier ones. These industries use the same sewage system as the domestic households to discharge their wastewater. The water quality in the fjord is profoundly influenced by three water regimes: the inflowing underground and surface freshwater, the sewage discharge and coastal sea water. There are four main sewage disposal outlets that discharge directly into the bay. The northwest outlets discharge the sewage untreated into the sea. The southern sewage effluent undergoes some of rudimentary treatment in sewage teatment plant built in 1998. The sewage sludge undergoes screening to get rid of larger particles but no fat floatation or sand sedimentation is done. Currently, the average flow rate is 324 m^3/hour which is approximately 10% of the capacity of the sewage plant. Plans are however underway to improved the sewage treatment system since the right equipment is already in place.

The Hafnarfjordur area is an impotant area for recreation as there is is a golf corse located adjacent to the lagoon in the southern part of the bay.

Over the last fifteen years, three surveys have been carried out within the Hafnarfjord (1988, 1990-1995). The 1988 survey focused mainly on hydrography of the area. The study reported on currents, salinity and temperature distributions. The later surveys reported mainly on prevailing currents and water quality using both total and feacal coliforms as indicators of pollution. It also gave a prediction on future situation when the then proposed landfill would be in place. However, to date, information on the study area is very limited and wholly restricted to unpublished reports. With the land-fill constructed in 1998, the scenario is likely to have changed due to alterations in the hydrodynamics of the area. The increasing human population and industrial activities, especially fish processing, are also bound to have changed the situation since the studies were done in 1990-1995.

3.2 Sample collection

Sampling of surface waters was done on 11th December, 2003 at 30 sampling stations. The sampling area was mapped using GPS within a grid located around the sewage outlet. Samples were taken from near the sewage outfall in order to characterize the sewage before tracing it into seawater. Temperature was taken in situ using a mercury thermometer, salinity was determined in the laboratory by first measuring the conductivity ratio between the sample and standard seawater by Guildline Autosal 8400B salinity meter. The ratio above was converted to salinity by the definition of UNESCO as they are outlined in 'Practical Salinity Scale 1978'. Dissolved oxygen was determined using the standard Winkler method.

3.3 Bacteriological analyses

Samples for bacteriological analysis were collected under sterile conditions and processed immediately after sampling. Faecal coliforms were used as indicators of microbial pollution and were determined by 5-tube MPN technique using selective media. 10 ml, 1 ml and 0.1 ml of water samples were inoculated into tubes with 10 ml of Lauryl Sulfate Tryptose (LST) for preenrichment and incubated at $35 \pm 0.5^{o}C$. Gas formation after 24 hours of inoculation indicate positive presumptive test. Faecal coliforms were confirmed by a further inoculation into 10 ml of EC broth in a water bath for 24 hours at $44.5^{o}C$. Gas production in EC confirmed feacal coliforms. Five tubes were used for each dilution. The first five tubes contain double strength of the broth. The numbers of positive tubes in each dilution were recorded. The resulting numbers were then interpreted from MPN table and then corrected using relevant dilutions.

3.4 Nutrient analysis

Surface water samples collected for nutrient analysis were filtered through 0.45µm polycarbonate filters (Millipore 47 mm diameter) and then deep-frozen for later analysis in the laboratory. Dissolved phosphate, total phosphates (TP), and Silicates were determined using Standard methods of seawater analysis. For analysis of total phosphorus, samples were digested by adding peroxydisulfate Oxidizing reagent (OR), autoclaved for 30 minutes at 200kP (120ºC) then 1.0 ml of 4 M sulphuric acid added. The digested sample was used for total phosphorus determination using the Molybdate Blue method. Dissolved phosphate was also analysed by the Molybdate Blue method after acidifying the sample to 0.4 M H_2SO_4. Dissolved nitrate was determined by a procedure based on the nitrosylchloride method of Armstrong (1963). Absorbance for nitrosylchloride was read from spectrophotometer at 230 nm in 1cm and 10 quartz cells. Correction was done after reduction of nitrate to nitrite by hydrazine sulphate. Absorbance of phosphorus was read at 880 nm using 10 cm glass cuvette. Silicates were determined using the Molybdate

Blue method but at conditions specific to Silicates (pH and ratio of acid and molybdate). The measurement is based on formation of a blue beta -Siliciummolybdate hetero-complex in acid environment. Absorbance was read at 810 nm using a 1 cm glasss cuvette.

3.5 Data Analysis

The stated purpose of the study was to determine the effects of sewage disposal on the water quality of the coastal water. The appropriate methods of analysis were used in order to give clear interpretation and presentation of the information gathered. Cluster analysis was performed based on mean concentrations of indicator feacal coliforms to identify any analogous behavioral pattern between different stations.

4 RESULTS

Sampling was carried out during low tide close to spring tide. The prevailing weather conditions were cold with air temperatures ranging from -1.5 to -3.6ºC. Wind speed was between 3.6 and 4.1 msec^{-1}. The results are presented in this section and appendix 1.

4.1 Physicochemical Parameters

The temperature of surface waters showed a decreasing gradient with distance from land (Appendix I). Temperature values ranged from 2.2 to 9.7ºC, with a mean value of 3.38 ±1.25ºC. The highest and lowest values were recorded at stations 5 and 25 respectively **(**Figure 2 and 3**)**.

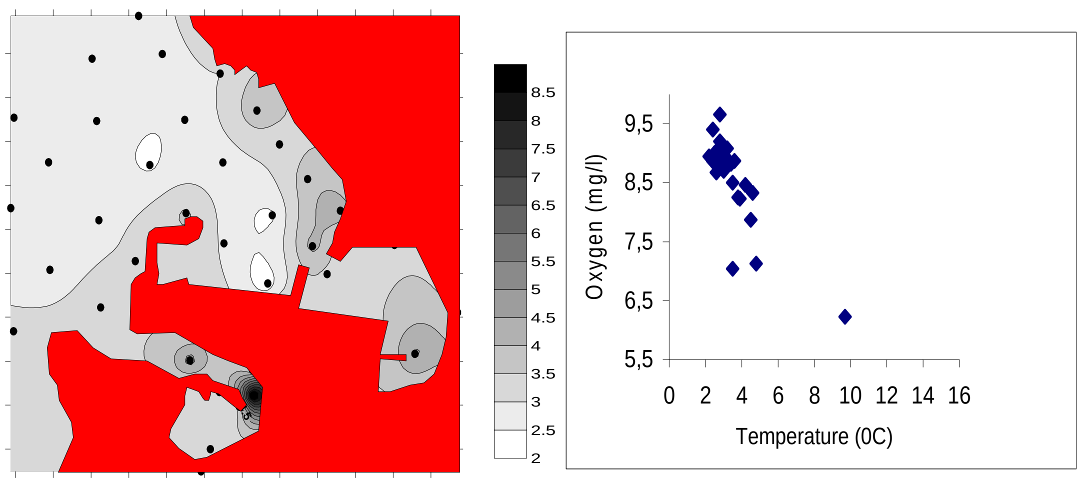

Figure 2: Sea-surface temperature at Hafnarfjord, Dec, 2003.

Temperature values decreased with increasing depth and salinity levels.

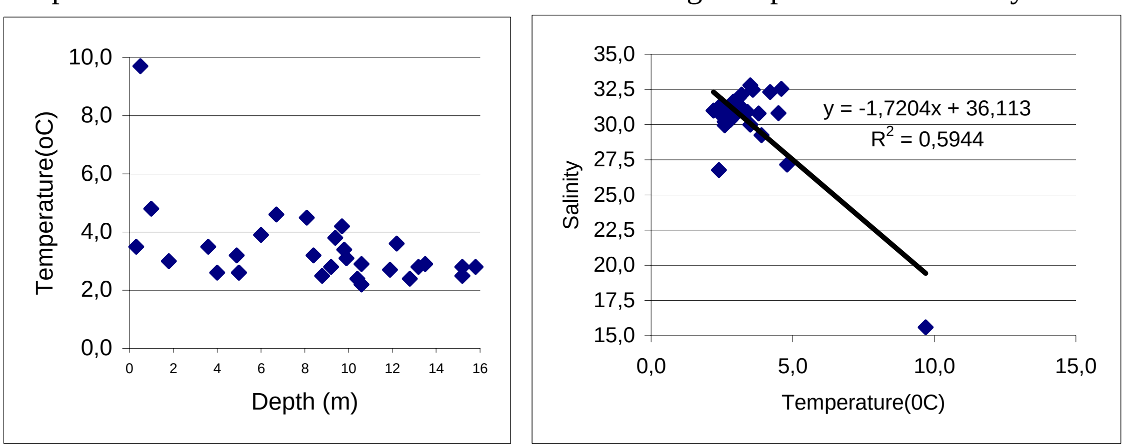

Figure 3: Relationship between temperature , salinity and depth.

4.1.1 Salinity.

The sea-surface salinities measured are presented in Figure 4. The salinity values were generally low and ranged between 26.78 to 32.7 PSU, a mean values of 30,80± 1,35.

Lower salinities were recorded at stations near shore, while higher salinities were recorded off the Harbour. Salinity at the southern sewage outlet was very low (15.59 ‰) and therefore was treated seperately when calculating the mean value. Highest salinity was recorded at station 27 which is off the harbour and could be under relatively greater tidal influence indicated by the inflow of fresh sea water from the west. Noticible also was the influx of freshwater in the southern part into bay and also the incoming river on the northen area which results in relatively lower salinities.

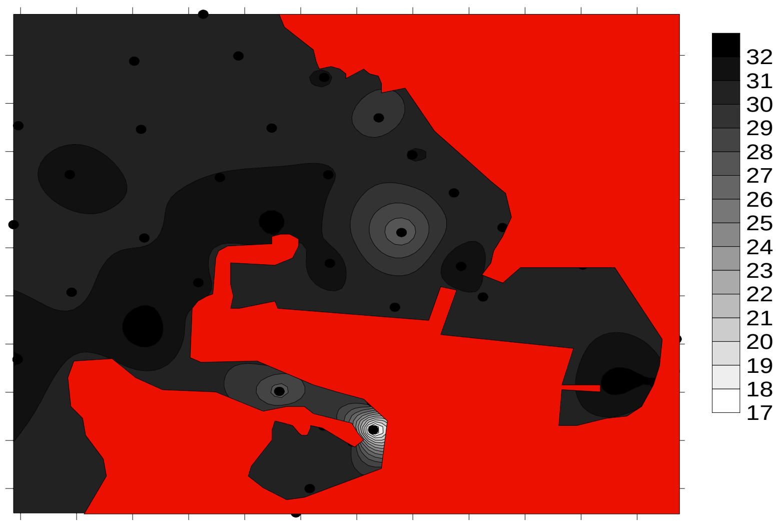

Figure 4: Salinity distribution at Hafnarfjoird, Dec, 2003.

The lowest salinities were found along the coast of Hvaleyri (Station 25). The station is located in the vicinity of the southern sewage outflow, but diluted rather fast since at station 26 downstream of the sewage, the salinity had increased considerably. The spatial distribution of dissolved oxygen and percentage saturation values in the surface waters are presented in Figure 5. The concentrations were relatively high but a positive gradient in concentration from the shallow waters into the deeper waters was indicated. The recorded values varied ranged from 6.23 to 9.66 mg/l, with mean of 8.62 ± 0.74 mg/l.

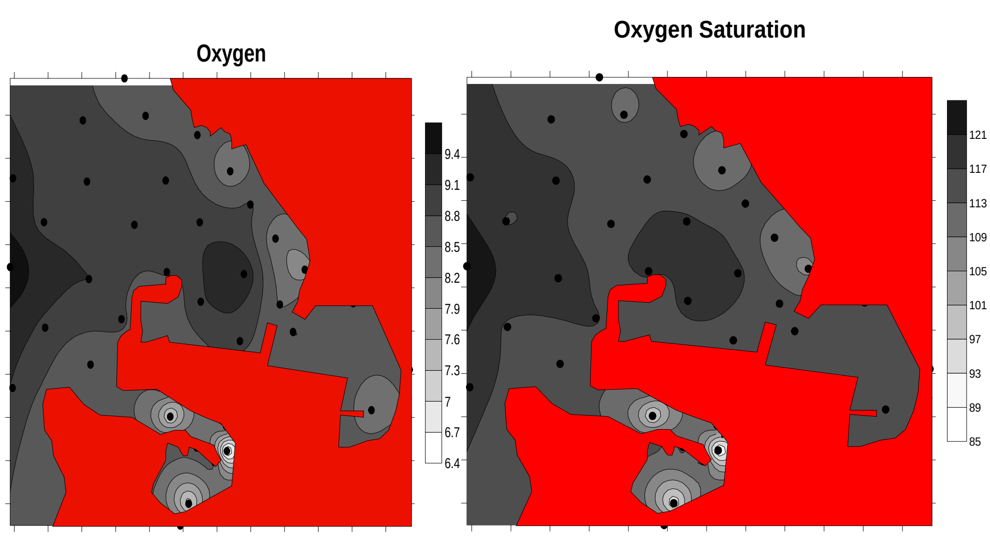

Figure 5: Dissolved Oxygen and % saturation at Hafnarfjord, Dec. 2003

Lowest oxygen value (6.23 mg/l) was recorded at station 25 close to the southern sewage outlet, while the highest value was at station 29 one of the outermost stations. The saturation values had the same trend as indicated by the dissolved oxygen. Dissolved oxygen was at super-saturation in almost all the stations except at stations 24 and 25, the landlocked Hvaleyrartjorn and at the southern sewage outlet. The saturation percentage values varied from 86.54 to 125.47% with a mean of 113.57 ± 8.5%. The highest oxygen saturation values were observed at station 29 characterized by the inflowing fresh seawater.

4.2 Nutrients

The concentration of all the nutrients monitored were highest at the sewage outlets but there was however a rapid decrease with depth.

4.2.1 Silicates

Spatial variation of silicates in surface waters at Hafnarfjordur is shown in Figure 6 and Table 5. The silicate concentrations were generally high in the whole study area compared to ocean water around Iceland. The silicate concentrations ranged from 10.1 to 79.89 µM. The highest concentration was recorded at station 25, which is located at the southern sewage outfall indicating the sewage as a source of silicate. The four lowest concentrations, 10.1 µM, 14.8 µM, 19.8 µM and 20.2 µM were recorded at stations 27, 12, 8 and 20 respectively indicating a flow of low silicate water from the west into the area sweeping across the inflow of high silicate water from the sewage and Hveleyrarlon. Silicate concentrations had a negative correlation with sea-surface salinity and positive with dissolved phosphate.

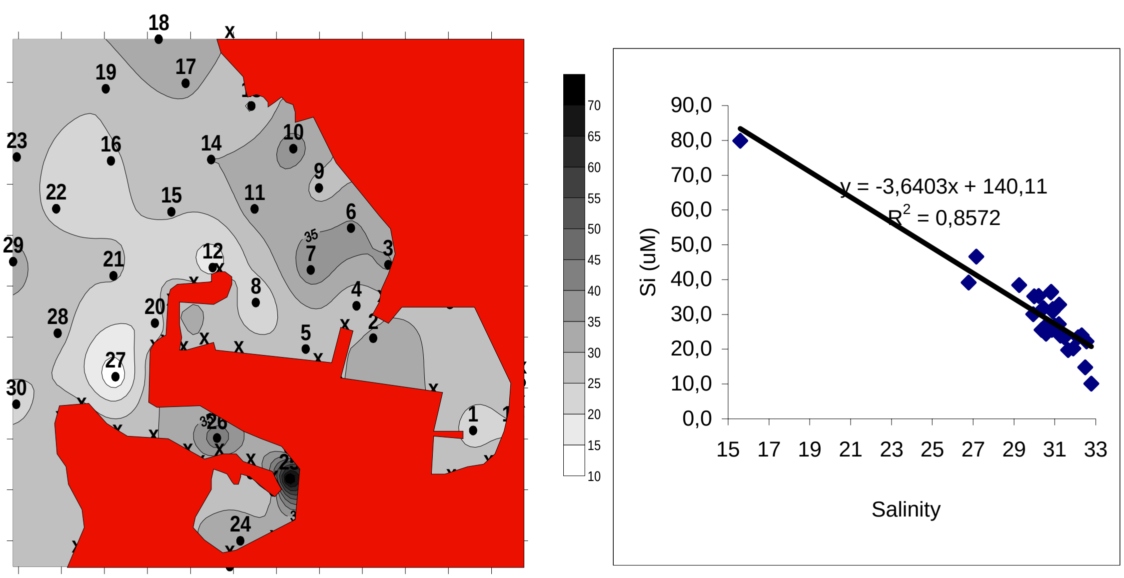

Figure 6: Silicate concentrations (µM) at Hafnarfjord, Dec. 2003.

There were also relatively high silicate concentrations at stations 6 and 7 as well as 10, 11 and 18 where the sewage outlets from the northern part of Hafnarfjordur Bay are. Though silicates seem to correlate very well with salinity, more samples would have provided stronger evidence of this relationship. Both silicates and nitrates concentrations indicated tendency to decrease with increasing salinity located together with a river in between them. Thus several sources of silicate are present in the area. It confirms that silicate can be good of freshwater, sewage included.

Table 5: Total Dissolved phosphate, Dissolved phosphate, Nitrate and Silicates concentration in Hafnarfjordhur, December, 2003.

Stations	Si(µM)	TD-P, µM	D-P, µM	D-NO3, µM
1	22,3	1,18	0,95	18,1
2	31,5	1,23	1,10	14,4
3	36,5	3,11	1,38	12,5
4	24,0	1,28	1,00	18,1
5	26,8	1,16	1,20	18,5
6	36,3	1,94	1,70	16,8
7	39,1	1,16	1,19	22,6
8	19,8	1,21	0,98	16,6
9	27,2	1,33	1,17	13,8
10	38,4	1,14	1,25	21,3
11	32,8	1,25	1,04	17,7
12	14,8	1,28	1,11	14,4
13	23,9	1,33	1,18	13,1
14	30,1	1,46	1,19	19,6
15	25,6	1,16	0,93	13,8
16	24,4	1,51	1,22	12,5
17	30,9	1,05	0,82	14,9
18	35,3	1,19	1,09	14,6
19	25,5	1,18	0,84	17,7
20	20,2	2,83	1,16	17,9
21	25,6	1,30	1,05	17,2
22	23,4	1,13	0,67	8,4
23	26,4	1,04	0,70	10,3
24	35,2	3,48	1,45	16,8
25	79,9	5457	276,00	25,6
26	46,7	93	53,00	25,4
27	10,1	2,21	1,69	11,2
28	27,1	1,23	1,00	13,3
29	31,8	0,90	0,59	7,3
30	23,4	1,42	0,95	

4.2.2 Phosphates

The Total dissolved phosphorus (TD-P) concentrations were higher in the vicinity of sewage outfalls. The concentrations ranged from 0.9 to 5457 µM (Table 4). The lowest concentration was recorded at station 27 at the inflow of low silicate and high salinity seawater from the west, while the latter was recorded at station 25 next to the southern sewage outfall**.** There was rapid dissipation of phosphorous from higher concentration at the pollution source to near background level at sea.

Dissolved phosphorous concentrations had a similar trend as TD-P. The concentrations ranged from 0.59 to 276 µM. All stations had concentrations between 0.59 µM and 1.7µM, except in stations 25 and 26, where concentrations were 276 µM and 49.07 µM respectively. The ratio between dissolved phosphorous and total dissolved phosphorous was high or on average 80% in most of the stations, except at sewage affected stations where the ratio was below 50%. Due to the complexity of the nutrient data collected, attempts were made to separator exclude some outlying points for correlation purposes.

D-P and TD-P concentration had high and positive linear correlation in both stations affected by the sewage (y= 0,8007x +0, 0312, R2=0, 7124,) and those stations that are least affected by the sewage (y=0,4337x +0, 0334, R2=0, 8715), (Figure 7).

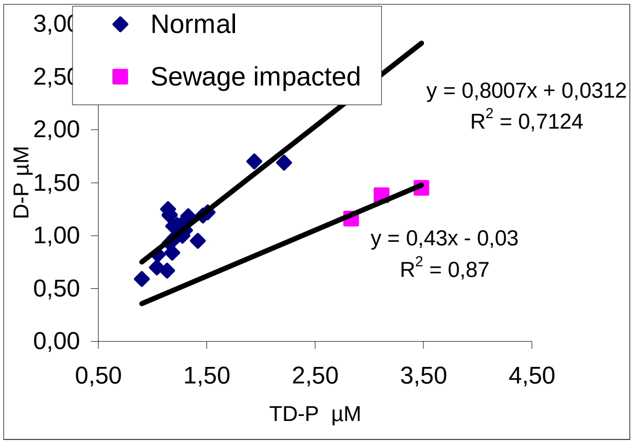

Figure 7: Correlation between total phosphate and dissolved phosphate.

4.2.3 Nitrates

NO3 concentrations are presented in Table 5 and Figure 8. The concentrations ranged from 7.3 µM to 25.65 µM with a mean of 16.01± 4.4 µM.

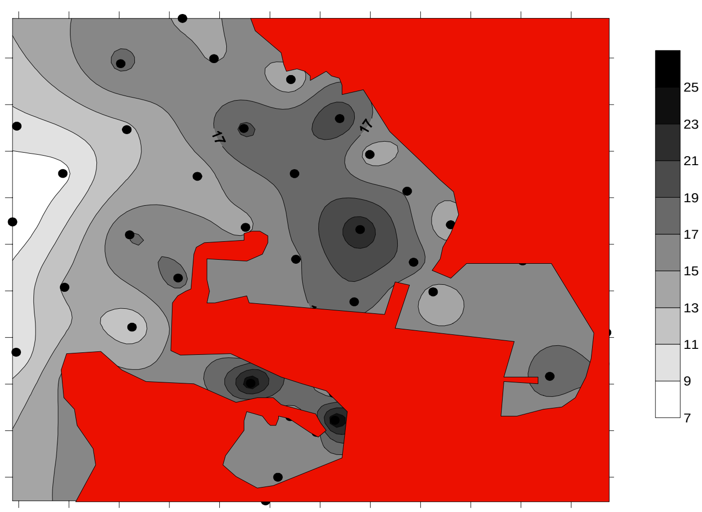

Figure 8: Nitrate concentration (uM) at Hafnarfjord, Dec.2003.

The highest concentrations 25.6 and 25.4 µM were recorded at stations 25 and 26 respectively, in the vicinity of the sewage outlet in the south. The lowest concentration was recorded for station 29 which is exposed to the inflow of fresh seawater. There was a general decrease in observed concentrations to background levels at stations 22 (8.4 µM) and 29 (7.3 µM). Attempts were made to separate points which were more affected by the sewage when determining correlation between different nutrients as these points had concentrations which were significantly outlying. NO_3 had significant positive correlation with TD-P, D-P, silicates and salinity (Figure 9 and 10).

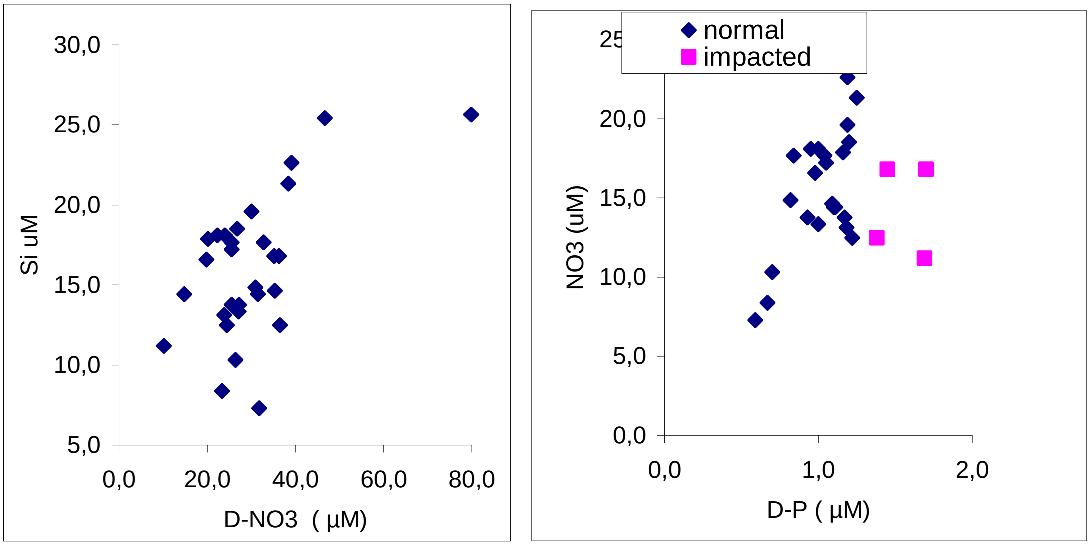

Figure 9: Correlation between nitrates , silicates and dissolved phosphate.

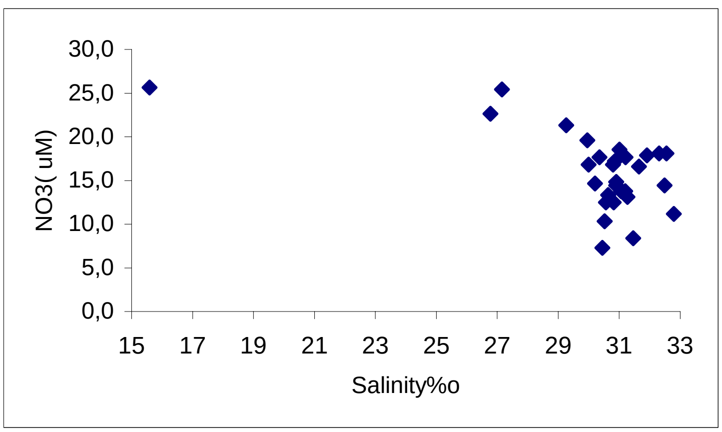

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Figure 10: Correlation between salinity and nitrates.

4.3 Bacterial indicators of sewage

Feacal coliform counts in the surface water in Hafnarfjordur are presented in Figure 11. The distribution was widespread as they were detected throughout the whole study area. The distribution was highly variable with significant differences existing between the sampling sites. The concentration ranged between 170 and >16000 NPM/100 ml. Highest densities were recorded in seawater near the outfalls (3, 24 and 25) but, the enteric bacterial load decreased with increasing distance from the sewage source. Lowest feacal coliform concentrations were recorded in stations farthest away from the sewage disposal points.

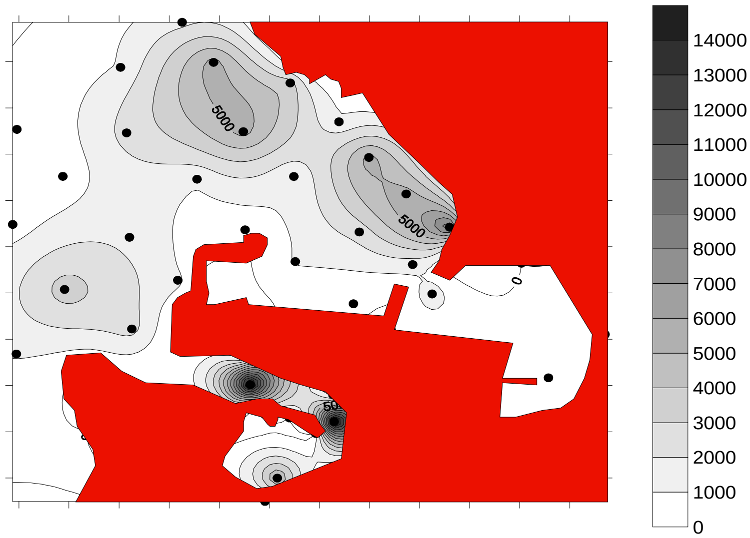

Figure 11: Feacal coliform levels at Hafnarfjordur, December 2003.

The lowest concentration (170 MPN/100 m) was recorded at station 5. Feacal coliform counts at stations, 12, 22, 23 and 29 were at medium levels ranging from 230 to 490 MPN/100 ml. Stations, 9, 14, 17 and 24 were similar with high feacal coliform level of 5400 MPN/100 ml. The concentration trends from this study, points to the fact that both feacal coliforms and silicates have sewage as their main source. Results show that there was positive correlation between feacal coliforms counts and the various nutrients studied (Figure 12). Though the correlations were weak, they were however significant at p=0. 05. There was general tendency of an increase in feacal coliform counts with increasing nutrient concentrations.

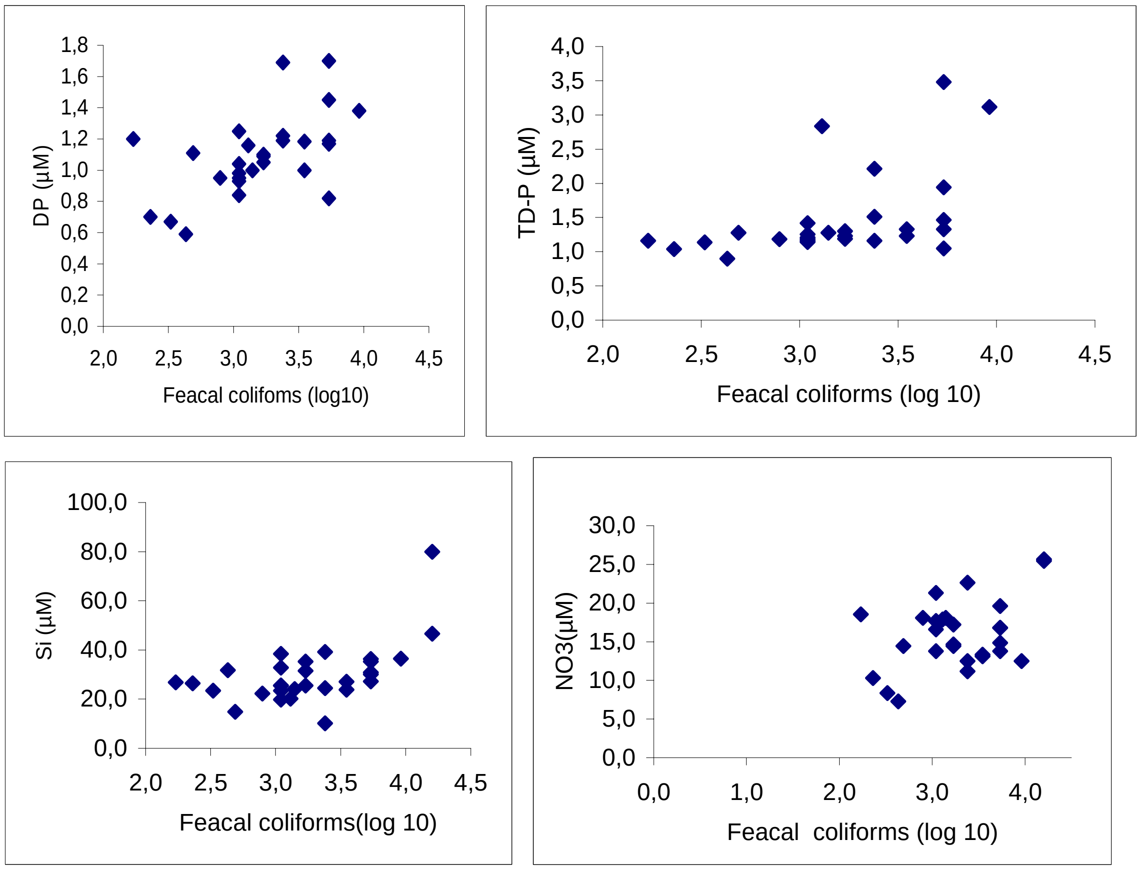

Figure 12: Correlation between feacal coliforms and nutrient (NO3, DP, and Si).

There was significant negative correlation between log transformed feacal coliform counts and salinity (p=0.05). Feacal coliform counts also decreased with depth away from the sewage outlets (Figure 13).

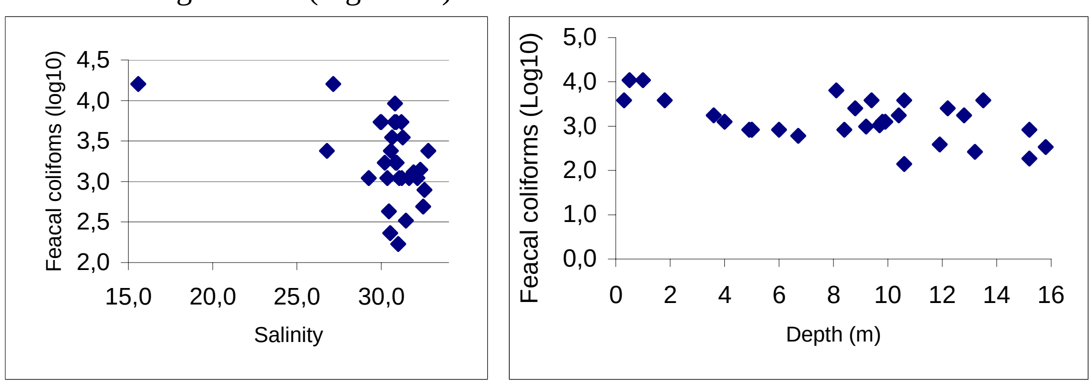

Figure 13: Distribution of feacal coliforms in relation to depth and salinity.

Cluster analysis based on the mean concentrations of indicator feacal coliforms from the different stations, grouped the stations into three groups as shown in Figure 14. Three distinct groups were identified with less than 75% similarity between the custers. Cluster 1 (low indicator levels, 170-490 MPN/100 ml); Cluster 2 (medium indicator levels;

1100-2400), and Cluster 3 (high indicator levels; 3500->16000). At Cluster 3 the sites were at least 86% similar, while at clusters 2 and 1 the sites were at least 90% similar.

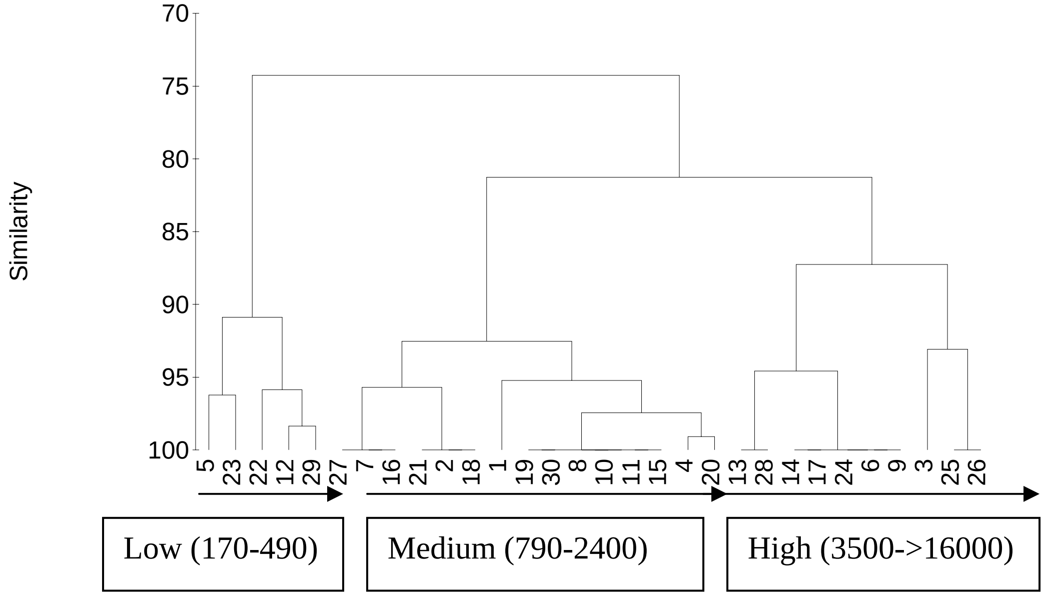

Figure 14: Dendogram showing similarity among stations on standardized mean feacal coliform indicator concentrations.

Cluster 1 consisted of stations far away from sewage outlets (5, 23, 22, 12 and 29), cluster 2 is moderately affected by sewage (27, 7, 16, 21, 2, 18, 19, 30, 10, 11, 15 and 4) and Cluster 3 (13, 28, 14, 17, 6, 9, 3, 25 and 26) showed the most sewage affected stations. It is noteworthy that even within these main clusters, there is further clustering down in the similar sites.

To evaluate and relate the feacal coliform levels observed with various standards, attempts were made to calculate percentage of the samples that met or failed to meet the required limits was calculated (Figure 15). None of the microbiological standards for various water uses were met as indicated by high percentage of the samples that had unacceptable feacal coliform counts.

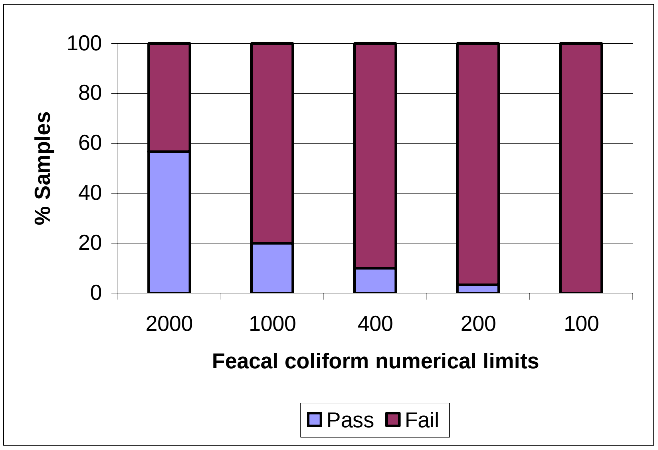

Figure 15: Percent samples in relation to different water quality standards.

No sample met the limit of 100MPN/ 100 ml requirement in Iceland for recreational areas and waters in the vicinity of food industry. While 57% of the samples failed to meet the 2000 Feacal coliform limit for bathing waters (EU), only 20% of the samples were within the 1000MPN feacal coliform limit for waters outside dilution areas of sewage in Iceland. 90% and 97% of the samples failed to meet the 400 and 200 MPN/FC numerical limits for bathing waters set by the US and the WB, respectively.

5 DISCUSSION

Results showed that sewage disposal had a significant effect on the water quality, especially in terms of feacal coliform indicator bacteria for which well defined standards are at hand. This effect was well spread throughout the study area. Effects due to nutrients were only discernible in the vicinity of the sewage outfalls. There was, however, decrease in both levels away from the sewer points. Delille and Gleizon (2003) reported high bacterial levels in seawater close to the sewage outfall with rapid decrease in levels with increasing distance from the outfall in Antarctica Kerguelen Island.

Higher temperature observed near outfalls is most probably due to discharged hot water from households / industries flowing in together.

Low dissolved oxygen and under saturation observed at the sewage outfall is due to increased biochemical oxygen demand requiring oxygen to break down organic matter brought in by the sewage. It is also known that oxygen solubility in water is dependent on temperature and salinity, this factor is taken into consideration when relative oxygen saturation is computed. Oxygen concentrations will always be low when temperatures are higher (Horne, R.A 1969). The super saturation values for oxygen recorded for most of the stations could be explained on prevailing weather conditions which could have caused unstable conditions for oxygen to leave the water surface with the resulting super saturation effect.

The generally lower salinties recorded were due to either influence of freshwater, mainly from inflowing rivers or due to the fact that these values reflect the low tide situation when the freshwater influence is much spread into the area. Highest salinity recorded at station 27 which is off the harbour reflects the influence of pure sea water since the area is under relatively greater tidal influence. Noticable was the influx of freshwater from under the laval rocks in the southern part into Hafnafrfjordur resulting in relatively lower salinities as compared to oceanic water.

Lower feacal indicator bacteria levels were generally found in stations of relatively high salinity, that is, decrease with increased distance from freshwater influence. However, areas of higher salinity are under greater tidal influence and experience greater potential flushing and dilution than the shoreline and are therefore characterized by relatively low feacal indicator level. There may also be a direct negative response of indicator bacteria to high saline conditions reducing the die-off time. Though salinity seems to have an effect on feacal coliform counts, it is also evident from the results that the resulting levels depend also on how far or close the point is from the sewage outlet. It should be noted that the die-off time of 12 hours already established for bacteria indicators in coastal waters during winter (December-January) in Iceland is long time enough to raise concern. Since the study was done in winter, this can explain the elevated feacal coliform concentrations observed as it has previously been observed by other workers that low environmental temperatures reduce the metabolic activity of enteric bacteria and thus seem to be favorable to their survival (Delille, D and Gleizon, F, 2003, Baross *et al* 1975) as opposed to summer period when the solar radiation is reported to have detrimental effect on the pathogenic bacteria (Smith *et al*, 1994). Factors such as sunlight intensity and duration, temperature and salinity levels may influence the population of organisms in the sea water. Delille, D and Perret, E., 1989 reported that nutrient availability rather than low environmental temperature may limit the survival of feacal bacteria.

The distribution pattern and levels of nutrients in this study indicate that the infuence of sewage on nutrients concentration within the bay is confined to the vicinity of the outfalls. Hughes K.A and Thompson A., (2003) reported similar observation around a Maritime station in Antarctica. It seems that the spread in nutrient concentration is fairly low in winter except close to the sewage. Stations close to sewage outlets had the highest nutrient values because they are more influenced by the incoming proteinic matter and polyphosphoric products from detergent from the households, an observation that has been made by other workers (Young-Jin Suh and Rousseaux P., 2001). Concentration of silicates in sea water is known to be affected by both geological and biological processes (Horne, R.A, 1969) though a considerable amount of anthropogenic silicates also get into the coastal waters especially through sewage disposal. In winter the phytoplankton production is at its minimum and as these organisms die the silicates are regenerated and so the silicate uptake is also reduced to minimum. It should be noted that under natural condition silicate concentrations in seawater would be about 10 µmM. It should however, be noted that the silicate values at zero salinity (140.11µM) from observed values ((= 3.6403x S+140.11) from the sewage source was much lower compared to values observed at Reykjavik (= 25.251x S+878.4) during a similar study (Stefansson U. and Olafsson J., 1991). This can be attributed to the fact that only heated freshwater is used at the sewage plant (Mr. Tore, personal communication) and not water directly from hydrothermal vents with high levels of silicates as is the case in Reykjavik.

Using an equation derived from computed regression linear plot from observations in earlier studies on coastal waters (0-200 m), where; (NO_3^-N) =3.407 In (Si) + 5.2, (Stefansson U. and Olafsson J., 1991), comparisons were made on the nutrient relationship with the data from this study. With reference to expected nutrient concentrations along the coast indicated by previous work, phosphates, silicates and nitrates concentrations from this study were elevated thus indicating the whole bay is affected by anthropogenic or freshwater source of nutrients. All the silicate values from this study were above the expected concentration meaning the whole bay is affected as shown in Figure 16 (blue line –expected natural silicate concentration of sea water, red line-an extrapolation covering our data).

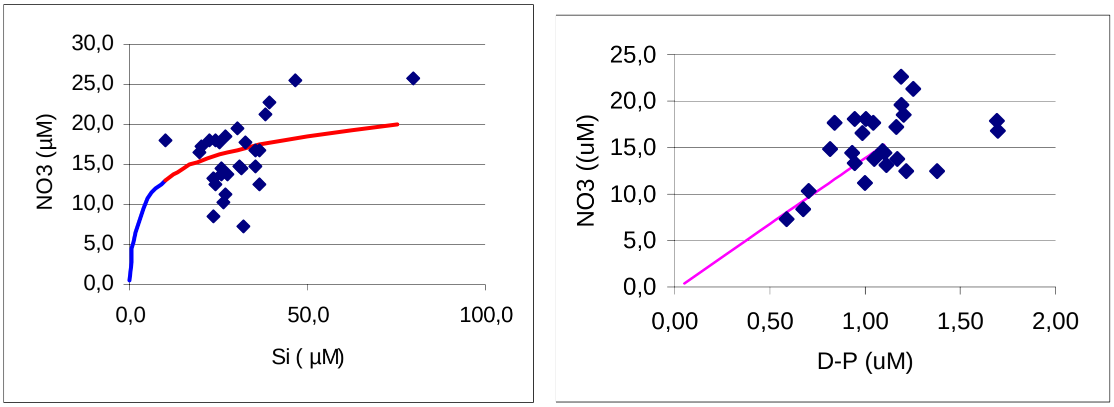

Figure 16: Relationship between NO3, Si. and PO4 (Regression line: coastal waters, Adopted from Stefansson U. and Olafsson J., 1991.

Most points except for stations 12 and 27 which are under influence of a stream of fresh sea water from the west deviated from the above relationship (Figure 16). Deviation from this relationship is therefore a clear pointer to external influence in all the stations sampled within the bay. Data for phosphates and NO_3 from this study when fitted using regression equation (slope line 14.21 ± 0.40, intercept,-0.33 ±0.27 µM) computed from observations made for Selvogsgrunn section which is closer to the study area fitted generally well, points considered normal fitted around the expected coastal water concentrations of these nutrients. Half of the sampled stations had higher phosphates and nitrates concentrations than expected thus deviated from the relationship. The points that deviated most from the relationship were as expected those more affected by the sewage (27, 3, 26, 6, 24 and 25).

The low D-P/ TD-P ratio observed in sewage affected stations as opposed to less affected stations, indicate that at these points only a small part of total phosphorus was available, which suggests that phosphate in such environmental state is organically bound and is therefore not found largely in free dissolved form. The phosphate is then gradually released into dissolved form during the mineralization process of the sea. This observation also gives an indication to the presence of high organic load in sewage impacted stations.

Silicate concentrations in the bay seem not to have increased signifcantly over time since the study of 1988 was undertaken. Silicates distribution at the sea-surface in the bay in summer 1988 ranged between 5-76,5 µg/l, while nitrate concentrations were in the range of 0,4- 15,1µg/l. (Svend-Aage Malmberg 1989). The higher values in the study of 1988 were from sites located at the vicinity of the sewage. The poor correlation often found between the different nutrients in the study, is an indication that the nutrient input to the area is likely due to different sources of sewage of different strength and proportions, which results in cloudy distributions. In steady state, most of the nutrients would reflect good correlations between them. Additionally, Horne (1969) attributed the cloudy relation between silicates and other nutrients to geological processes that influence silicate dynamics in sea water.

Since the Hafnarfjordur area has several industries which release their waste into the same sewer system this could also explain the poor correlation. Other influences on nutrient distribution are for example from runoff and inflowing fresh waters. However, silicates on the other hand seem to have a homogenous source (freshwater) in the area and correlates very well with salinity. This is borne out by the fact that at zero salinity a silicate concentration of 140.11 µM is obtained close to the river water in Iceland of 197±16 µM. Silicate seem to be a better indicator of sewage influence than other nutrients in Iceland.

Waters within the study area showed overwhelmingly higher feacal coliform counts in almost all the stations than the recommended limits for recreation and bathing waters and may present potential risk to human health and therefore there is a need to strive for compliance. The bay is also affected by nutrients loads that may cause algal blooms and impairment of amenities at Hvaleyrartjörn. The sewage impact on the bacterial water quality at the time of the study are widespread and not limited to the vicinity of sewage outlets as observed with the nutrient which dissipates very rapidly away from the sewage source. Since the background level for feacal bacteria in the seawater is zero, this means that any input into sea it will always stand out as opposed to the nutrients (phosphates and nitrates) which are already in the seawater in high concentrations with the exception of silicate since freshwater contains about 40-50-fold higher concentrations than seawater (Stefansson U. and Olafsson J., 1991).

The relatively higher effect of sewage on water quality in terms of bacterial load and nutrient level observed at stations 24, 25 and 26 was a direct influence by the sewage compounded by the prevailing hydrographic conditions. The area is rather enclosed with low water exchange meaning that the effluent coming from the sewage plant is not flushed out fast enough. The study was conducted during low tide when the dilution influence of the seawater was low and this could have influenced the results in a way to make them higher. Another survey during high tide would have given a better description the situation.

6 CONCLUSIONS

The results form this study showed nutrient enrichment of the coastal water in Hafnarfjordur Bay and feacal coliforms were found at all stations.

- Pollution from the sewage outlets had significant enviromental impact as revealed by a similar trend of decreasing nutrient and microbilogical contamination with increasing distance from sewage outlets.
- Sewage discharge had significant effect on the water quality in terms of feacal coliform indicator bacteria levels. This effect was well spread throughout the study area.
- Feacal coliform counts in all the sampled sites were above the recommended limits for drinking and bathing and may present potential risk to human health.
- The influence of sewage on nutrient concentrations at Hafnarfjordur was mostly seen confined close to the sewage outlets (localised), but correlation with feacal coliforms indicating their widespread effects.
- Although nutrient concentrations were in some cases within reasonable limits as a result of dilution, there was however evidence of anthropogenic input especially in the lagoon.
- The poor correlation between the different nutrients in the results is an indication that the nutrient input to the area is likely due to different sources of sewage of different strength and proportions, which result in a cloudy distribution.
- Closer look at the relationships between different nutrients using established relationships from previous work, revealed deviations from natural seawater concentrations that are herein attributed to sewage effluent effects.
- Hafnarfjordur bay may, from the results of this study, be considered a sensitive area due to tendency of nutrient accumulation especially in the lagoon area meaning there is risk of eutrophication.

6.1 Management options

Waste-water treatment is hardly neccessary with regard to nutrients in the light of the study outcome, however feacal bacteria load needs to be looked into. However, since the existing regulations/ directives have restrictions on nutrients at sewage outlets, it is imparative that the sewage sludge undergoes primary treatment which would result in 20% reduction in BOD_5 and 50% of the total suspended solids.

The three options available would be: to treat the sewage in order to reduce the pollutants to background concentrations that are acceptable by regulation, collect the sewage to one long pipeline and direct it out to the deeper sea away from habited areas and greater dilution rate. The latter option should be done whether the sewage is treated or not. And lastly, the waste sludge could be reused especially in agriculture though this would depend on opinion.

Several workers in environments more or less similar to Iceland have recommended that sewage receive treatment before discharge (Halton and Nehlsen, 1968; Hughes and Blenkharn, 2003). Though relocation of sewage outfalls farther into the sea would be safer to the immediate public health, deep sea disposal is not the first panacea to be envisaged as raw sewage will always cause environmental problems wherever it is discharged. It is possible that prevailing hydrographic conditions could result in sewage slick from long outfall returning to the shore. Although the bacterial indicators may well have been eliminated by the adverse sea environment, other pathogens with longer die-off time like viruses may still be present. It is becoming increasingly evident that such micro-organisms can remain in seawater and especially in sediments where they can be found even though they are not found in the seawater (Elliot.M., 2003).Therefore elimination of the pathogens, including bacteria, by treating the sewage before disposal through appropriate technology available is the surest way out. Therefore primary treatment would always be necessary.

There are three sewage treatment processes that can be applied. Primary treatment entails treatment of sewage waste by a physical and/or chemical processes involving settlement of suspended solids, or other prececsses in which the BOD5 of the incoming waste is reduced by 20% before discharge and the total suspended solids reduced by 50% (CEC 1991). Secondary treatment is done by treating waste-water by a process involving biological treatment with a secondary settlement to meet the required limits. And finally tertiary treatment including nitrogen removal involves a treatment process that allows the recieving water to meet the relevant objectives and criteria.

The management approach should recognize that technology alone is not enough to sustain waste-water management systems. It also should give more attention to user's preferences, and ability and willingness to pay.

The managers should foster appropriate action with true patnership with the private sector. The existing management practices should be flexible enough to incoroporate changes arising from the scientific world. Regulations should also be put in place to enforce that polluters pay the principal cost and also foster a willingness to pay among all polluters through provision of better and efficient services. This would ensure operational sustainability of the services.

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LIST OF REFERENCES

Armstrong, F.A.J., 1963. Determination of Nitrate in Water by Ultraviolet Spectrophometry.

Baron RC, Murphy FD, Greenberg HB, Davis CE, Bregman DJ, Gary GW, *et al* 1982. Norwalk gastrointestinal illness: an outbreak associated with swimming in a recreational lake and secondary person-to-person transmission. Am J Epidemiol 115:163-172.

Cabelli VJ, Dufour AP, McCabe LJ, Levin MA 1982. Swimming-associated gastroenteritis and water quality. Am J Epidemiol 115:606-616.

Baross, JA, Hanus, FJ, Morita, RY, 1975. Survival of human enteric and other sewage microorganisms under simulated deep sea conditions. *Appl. Microbiol. Vol. 30, no. 2, pp. 309-318. 1975.*

Cabelli, V.J., Levin, M.A., Dufour, A.P and McCabe, L.J. 1975. The development of criteria for recreational waters. In Discharge of Sewage from Sea Outfalls. A.L.H. Gameson (ed.). Pergamon Press, Oxford. Pp.63-73.

Cabelli V.J. 1979. What do water quality indicators indicte? Presented at: Aquatic Microbial Ecology Conference; Clearwater Beach, FL (USA); 7. Feb. 1979. In: Aquatic microbial ecology. Proceedings of the conference sponsored by the American Society for Microbiology. Publ. by Maryland Univ,: College Park, MD (USD)., [1980]., p. 305-336., Tech, Rep. Md. Univ. Sea Grant Program.

Cabelli, V.J., Dufour A.P., Levin M.A. and McCabe, L.J. 1982. Swimming-associated gastroenteritis and water quality. Am. J. Epidemiol. 115, 606-616

Canter L.W., 1996. Prediction and Assessment of Impacts on the surface-Water Environment. 2nd Edition. University of Oklahoma. Mc Graw-Hill Inc.

CEC, 1976. Council Directive of 8 December 1976 concerning quality of bathing water (76/160/EEC). http://www.europa.eu.int/eur-lex/en/search/search_lif.html

CEC, 1991. Council Directive of 21 May 1991 concerning urban wastewater treatment (91/271/EEC). http://www.europa.eu.int/eur-lex/en/search/search_lif.html

Danulat E, Muniz P, García-Alonso J, Yannicelli B. Fist assessment of the highly contaminated harbour of Montevideo, Uruguay. Mar Pollut Bull 2002; 44-554-65.

Delille, D and Perret, E.,1989. Influence of temereature on the growth potential of southern polar bacteria. Microbial Ecology18.117-123.

Delille, D and Gleizon, F., 2003. Distribution of enteric bacteria in Antarctic seawater surrounding the Port-aux-Francais permanent station (Kenguelen Island). *Marine Pollution Bulletin [Mar. Pollut. Bull.]. Vol. 46, no.9, pp.1179-1183. Sep 2003.*

Elliot M., 2003. Biological pollutants and biological pollution- an increasing cause of concern. *Marine Pollution Bulletin* 46, 275-280.

EPA (U.S. Environmental Protection Agency) 1986. Ambient *Water Quality Criteria for Bacteria*. Office of Water Regulations and Standards, Criteria and Standards Division. EPA 440/5-84-002. January 1986.

Erin K. Lipp E.K., Farah S.A. and Rose J.B., 2001. Assessment and Impact of Fecal Pollution and Human Enteric Pathogens in a Coastal Community. *Marine Pollution Bulletin* Vol.42, No. 4, pp 286-293.

Geldreich, E.E. 1965. "Origins of microbial pollution instreams." In: *Transmission of Viruses by the Water Route*, edited by G.Berg, Interscience Publishers, NY.

GESAMP 2001. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) and Advisory Committee on Protection of the Sea. 2001. A sea of troubles. Rep. Stud. GESAMP No. 70, 35 pp.

GESAMP 1999. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). 1999. Report of the Twenty-Ninth Session, London, United Kingdom, 23-26 April 1999. Rep. Stud. GESAMP No.67, 60pp.

Gareth, Rees.1993. Health Implications of Sewage in Coastal Waters-the British Case *Marine Pollution Bulletin* Vol.26, No. 1, pp 14-19.

GPA 2001. National Report for the Intergovernmental Review of the GPA 2001. Kenya. 18 September 2001.

Hafnarfjarðarbær, Staðardagskrá 1995, Lög nr.53, 8.mars1995. {Hafnarfjarðarbær, Local Agenda 21. Act No.53/1995},

Halton, J.E. and Nehlsen, W.R**.** (1968). Survival of *Escherichia coli* in zero degree centigrade seawater. Journal of the Water Pollution Control Federation 40: 865-868.

Hill, A.R. 1996. Nitrate Removal in Stream Riparian Zones. J. of Env. Qual., 25(4), 743-755.

Horne, R.A 1969.Marine Chemistry: The structure of water and the chemistry of Hydrosphere. Wiley-interscience. John Wiley and sons, New York, London.

Hughes K.A. and Thompson. A., 2003. Distribution of sewage pollution around a maritime Antarctic research station indicated by faecal coliforms, *Clostridium perfringens* and faecal sterol markers. *Environmental Pollution.* 127 (2004) 315- 321. Available online at www.sciencedirect.com.

Hughes K.A. and Blenkharn N. 2003. A simple method to reduce discharge of sewage microorganisms from an Antarctic research station. Marine Pollution Bulletin [mar. Pollut. Bull.]. Vol. 46, no. 3, pp. 353-357. Mar 2003.

NPA 2001. Iceland National Programme of action for the protection of the marine environment from land-based activities. 2001. Printed in Iceland. http://www.hollver.is/np

Kashefipour, S. M., Lin, B., Harris, E. and Falconer, R.A. 2002. Hydro-environmental modeling for bathing water compliance of an estuarine basin. Water Research 36, 1854-1868.

Klaus Koop and Pat Hutchings 1996. Disposal of sewage to the ocean'a sustainable solution? Marine Pollution Bulletin, Volume 33, Issues 7-12, 1996, Pages 121-123.

Luger M. and Brown C., (1999). The impact of Treated Sewage Effluent on Urban Rivers. An ecological, Social and Economic Perspective. www.southernwaters.co.za.

Mclntyre S., Wanninkhof R., and Chanton J.P. 1995. Trace gas exchange across the air-water interface in freshwater and coastal marine environments. In *Measuring Emissions from Soil and Water* (ed. P.A. Matson and R.C. Harriss). Blackwell Science Ltd.

Methods of Seawater Analysis. 1999. Edited by K.Grsshoff, K. Kremling and M., Ehrardt. 3RD Edition.

M.N.Byappanahalli and R.S. Fujioka 1998. Evidence that tropical soil environment can support the growth of Escherichia coli. Water Science and Technology, Volume 38, Issue 12, 1998, Pages 171-174.

Nelson,S.M., Atwell, R.W. and M.M., Smith, C.A. 1996. The effect of temerature on the viability of carbon and nitrogen starved *Escherichia coli.* Microbial Ecology 32, 11-21.

Nemerow, N.L and A.Dasgupta 1991. Industrial and Hazardous Waste Treatment. Van Nostrand Reinhold, New York, N.Y. 743pp.

Peter Matthiessen and Robin J. Law 2002. Contaminants and their effects on estuarine and coastal organisms in the United Kingdom in the late twentieth centurey. *Environmental Pollution, Volume 120, Issue 3, December 2002, Pages 739-757.*

Prieur D. G. Mevel, Nicolas J, L., Plusquellec and Vigneulle, M. 1990. Interaction between bivalve mollusks and bacteria in the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* **28**, 277-352.

Russo, R.C. (2002). Development of Marine water quality criteria for the USA. *Marine Pollution Bulletin* **45**:84-91.

Svend-Aage Malmberg 1989. Hita, seltu og straummælingar á Hafnarfirði sumarið 1988. Skýrsla til Bæjarstjórnar Hafnarfjarðar í júní 1989. Viðauki: Tafla um næringarefnamælingar frá Jóni Ólafssyni. Skýrsla frá Hafrannsóknastofnuninni.

Smith, P.,M. Hiney and O.B.Samuelson, 1994. Bacterial resistance to antimicrobial Agents used in fish farming: a critical evaluation of method and meaning. Annual Review of Fish Diseases 4: 273-313.

Stefansson U. and Olafson J.,1991. Nutrients and fertility of Icelandic waters. Journal of Marine Research Institute, Reykjavik, VOL.XII NO.3.

Thomann RV, Muller JA. 1987. Principles of surface water quality modelling control. New York: Harper Collins.

Tyrrel, S.F. 1999. The Microbiological Quality of Water Used for Irrigation. *Irrigation News* **27**, 39-42.

UNESCO/WHO/UNEP, 1992.Water quality Assessments-Aguide to use Biota,Sediments and Water in environmental Monitoring-Second Edition.

WHO (World Health Organization), 1993. Guidelines for Drinking Water Quality 2nd edition

WHO (World Health Organization), 2003. Looking back: looking ahead: five decades of challenges and achievements in environmental sanitation.

WHO (World Health Organization), 1999. *Health-Based Monitoring of Recreational Waters: the Feasibility of a New Approach (The "Annapolis Protocol")*. WHO. Geneva.

Wider Caribbean Region (WCR) 1998. UNEP. http://www.unep.ch/regionalseas/regions/car/carhome.htm.

World Bank, 1998. Pollution Prevention and Abatement Handbook. General Environmental and Manufacturing guidelines. Water Resources and Environment Technical Note D.1

World Bank, 2003. Water Quality: Assessment and Protection.(eds. Richard Davis, Rafik Hirji). The World Bank Washington, D.C.

Young-Jin, Suh and Rousseaux P., .2001. An LCA of alternative wastewater sludge treatment scenarios. Resource, Conservation and Recycling. (Elsevier Science).

Zabel T., Milne I. and McKay G., 2001. Approaches adopted by the European Union and selected Member States for the control of urban pollution. Urban Water 3 (2001) 25-32. Elsevier,publication.

APPENDIX 1. DISTRIBUTION OF NUTRIENTS (µM), SALINITY, % SATURATION, DISSOLVED OXYGEN AND FEACAL COLIFORM IN HAFNARFJORD,DEC.2003.

In Appendix 1, comma is used for decimal point.

Appendix I

Distribution of nutrients concentration (µM), Salinity, % oxygen saturation,dissovlved oxygen and Feacal colifc

Stations	Position X	Y	Depth(m)	Si(µM)	TD-P, µM	**	D-P, µM	D-NO3,	Sa
1	453114,61	7104833,16	6,7	22,3	1,18	0,03	0,95	18,1	
2	452650,18	7105195,68	9,8	31,5	1,23	0,24	1,10	14,4	
3	452720,20	7105484,13	8,1	36,5	3,11	0,80	1,38	12,5	
4	452572,27	7105322,85	9,7	24,0	1,28	0,02	1,00	18,1	
5	452335,98	7105153,14	10,6	26,8	1,16	0,05	1,20	18,5	
6	452546,69	7105628,02	9,4	36,3	1,94	0,04	1,70	16,8	
7	452359,49	7105463,56	10,4	39,1	1,16	0,01	1,19	22,6	
8	452103,77	7105335,68	10,6	19,8	1,21	0,01	0,98	16,6	
9	452397,78	7105785,81	8,4	27,2	1,33	0,06	1,17	13,8	
10	452278,29	7105939,82	6	38,4	1,14	0,05	1,25	21,3	
11	452098,11	7105703,50	11,9	32,8	1,25	0,01	1,04	17,7	
12	451903,25	7105473,02	12,2	14,8	1,28	0,14	1,11	14,4	
13	452083,70	7106107,74	1,8	23,9	1,33	0,05	1,18	13,1	
14	451896,29	7105897,32	5	30,1	1,46	0,08	1,19	19,6	
15	451711,35	7105691,88	12,8	25,6	1,16	0,04	0,93	13,8	
16	451430,17	7105892,15	13,5	24,4	1,51	0,11	1,22	12,5	
17	451777,47	7106196,86	4	30,9	1,05	0,05	0,82	14,9	
18	451652,04	7106370,20	5	35,3	1,19	0,09	1,09	14,6	
19	451405,83	7106175,45	9,2	25,5	1,18	0,03	0,84	17,7	
20	451634,62	7105254,99	9,9	20,2	2,83	0,00	1,16	17,9	
21	451441,68	7105440,70	13,2	25,6	1,30	0,05	1,05	17,2	
22	451175,50	7105704,08	15,2	23,4	1,13	0,24	0,67	8,4	
23	450992,10	7105907,20	15,2	26,4	1,04	0,24	0,70	10,3	
24	452032,06	7104399,65	0,5	35,2	3,48	0,22	1,45	16,8	
25	452258,88	7104643,89	1	79,9	5457	0,00	276,00	25,6	
26	451923,53	7104803,40	1	46,7	93	3	53,00	25,4	
27	451451,09	7105044,29	3,6	10,1	2,21	0,09	1,69	11,2	
28	451182,34	7105215,29	8,8	27,1	1,23	0,24	1,00	13,3	
29	450975,12	7105496,20	15,8	31,8	0,90	0,02	0,59	7,3	
30	450989,70	7104936,17	4,9	23,4	1,42	0,03	0,95		

	1	453114,61	7104833,16	22,3
	2	452650,18	7105195,68	31,5
	3	452720,20	7105484,13	36,5
	4	452572,27	7105322,85	24,0
	5	452335,98	7105153,14	26,8
	6	452546,69	7105628,02	36,3
	7	452359,49	7105463,56	39,1
	8	452103,77	7105335,68	19,8
	9	452397,78	7105785,81	27,2
	10	452278,29	7105939,82	38,4
	11	452098,11	7105703,50	32,8
	12	451903,25	7105473,02	14,8
	13	452083,70	7106107,74	23,9
	14	451896,29	7105897,32	30,1
	15	451711,35	7105691,88	25,6