Safe drinking water:
Experience with Water Safety Plans and assessment of risk factors in water supply

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Dissertation submitted in partial fulfillment of a
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Abstract

Access to adequate and clean drinking water is one of the fundamentals of a good and prosperous society. A comprehensive regulatory framework as well as institutional guidelines and procedures are necessary to secure this at any time. Iceland was one of the first countries to categorize drinking water as food in legislation passed in 1995. According to the legislation water utilities are obligated to implement systematic preventive management, Water Safety Plan (WSP), to ensure good quality water in conjunction with the regular external control by the regulator. The aim of the research is to evaluate the effect of the legislation on the utilities and whether it has had a measurable effect on the quality of drinking water and on public health. Part of the research is to look at risk from microbiological pollution and how far it can travel with groundwater. This is accomplished by using a model that incorporates hydrological and geological factors and comparing the results with an actual faecal contamination of drinking water that caused a norovirus outbreak in Iceland. The results of the research confirm several quantifiable beneficial effects of WSP on water quality and public health as well as on operation of water utilities. It analysis what has to be in place for successful operation of WSP and what obstacles were significant.The study of mobility of microorganisms in groundwater and comparison with an actual outbreak showed the necessity to take into account that microorganisms live longer in colder water and that due to their smaller size viruses can travel further than other pathogens through coarse geological strata.

Útdráttur

Aðgangur að nægu og hreinu drykkjarvatni er ein af undirstöðum velferðar í hverju samfélagi. Mikilvægt er að tryggja að vatn njóti verndar bæði lagalega og í allri umgengi um vatnsauðlindina. Ísland flokkaði neysluvatn sem matvæli í matvælalöggjöf 1995. Með þeirri löggjöf voru lagðar skyldur á vatnsveitur að beita kerfisbundu fyrirbyggjandi innra eftirliti til að tryggja gæði neysluvatns samhliða lögbundnu ytra eftirliti heilbrigðiseftirlits og var þar meðal fyrstu þjóða til að lögleiða innra eftirlit. Markmið þessarar rannsóknar er að meta áhrif þessarar lagasetningar á vatnsveitur og hvort þeirra áhrifa gæti í gæðum vatnsins og í heilsufari íbúa. Einnig eru skoðaðir áhættuþættir lífrænnar mengunar og hversu langt hún getur borist með grunnvatni og notað líkan sem byggir á vatnafræðilegum og jarðfræðilegum aðstæðum og niðurstöður bornar saman við saurmengun neysluvatns sem olli nóróveirufaraldri hér á landi fyrir nokkrum árum. Niðurstöðurnar sýna tölfræðilega marktækan mun á bæði betri neysluvatnsgæðum og bættri heilsu íbúa þar sem vatnsveitur hafa sett upp innra eftirlit. Rannsóknin leiddi einnig í ljós ávinning af innra eftirliti í rekstri vatnsveitna, hvað þarf að vera til staðar til að það virki vel og hverjar hindranirnar eru. Athugun á ferðafærni örvera í grunnvatni og samanburði við raunverulegan faraldur sýndu að taka þarf tillit til þess þegar vatnsverndarsvæði eru ákveðin að örverur lifa lengur í köldu vatni og veirur vegna smæðar sinnar geta ferðast lengra en aðrar sjúkdómsvaldandi örverur í jarðvegi.

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International reviewed journals

Gunnarsdottir, M.J., Gissurarson, L.R. (2008). HACCP and water safety plans in Icelandic water supply: Preliminary evaluation of experience. *J Water Health* 6(3); 377-382. (Chapter 2). *Gunnarsdottir was responsible for about half of the data gathering, majority of the data analysis and majority of the paper writing.*

Gunnarsdottir, M.J., Gardarsson, S.M., Bartram, J. (2012). Icelandic Experience with Water Safety Plans. *Water Science & Technology* 65 (2), 277-288. (Chapter 3). *Gunnarsdottir was responsible for the data gathering, almost all of the data analysis and majority of the paper writing.*

Gunnarsdottir, M.J., Gardarsson, S.M., Elliott, M., Sigmundsdottir, G., Bartram, J. (2012). Benefits of Water Safety Plans: Microbiology, Compliance and Public Health. *Environ. Sci. Technol., 2012, 46 (14), pp 7782–7789* (Chapter 4). *Gunnarsdottir was responsible for the data gathering, almost all of the data analysis and majority of the paper writing.*

Gunnarsdottir, M.J., Gardarsson, S.M., Andradottir, H.O. (2012). Microbial contamination in groundwater supply in cold climate and coarse soil: Case study of norovirus outbreak at Lake Mývatn, Iceland. Submitted to Hydrology Research. (Chapter 5). *Gunnarsdottir was primarily responsible for gathering all site specific conditions and epidemiological data on the outbreak and conducting a thorough literature review on factors that may negatively impact viral removal rates in coarse volcanic pumice. She was co-responsible for the results of the microbial transport model and paper writing.*

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Abbreviations

HACCP	Hazard Critical Control Points
HPC	Heterotrophic Plate Counts
IDWR	Icelandic Drinking Water Regulation
ICD	International Classification of Diseases
IFVA	Icelandic Food and Veterinary Authority
LCA	Local Competent Authorities
PHCC	Primary Health Care Center
WHO	World Health Organization
WSP	Water Safety Plan

Acknowledgements

1 Introduction

Access to safe drinking water is essential for human survival and one of the fundamentals for a good and prosperous society. This was officially recognized internationally 28th of July 2010 when the UN General Assembly declared, "the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights" (UN Human Right Council, 2011). Hence, prevention of drinking water contamination is a public health issue. Systematic preventive management is the key to safe drinking water with a well run water supply whereas relying solely on end-testing is not sufficient (Hrudey et al. 2006; Vieira, 2011). Waterborne outbreaks are a reality even in developed countries and evidence on underlying enteric and sporadic incidence of water borne diseases are appearing (Payment et al., 1997; Payment & Hunter, 2001; Calderone & Craun, 2006; Colford et al., 2006; Craun et al., 2006).

Since 2004 the methodology of a water safety plan (WSP) has been recommended for preventive management of water supply in the WHO Guideline for drinking-water safety (WHO, 2004; 2011). It is built on the principle of risk assessment of all elements of the water supply from catchment to consumer and preventive measures that shall prevent hazard to occur and is based on the principles of hazard analysis critical control point (HACCP) that was developed for the food industry in the 1970s (Havelaar, 1994). It has been used by a growing number of water utilities around the world and in several countries it has been put into regulation as a mandatory requirement, for example in Australia, Iceland, New Zealand, Uganda and UK. WSP has also been advocated by the International Water Association (IWA) that among other things has launched a framework, the Bonn Charter for Safe Drinking Water (IWA, 2004) and is now actively promoting use of WSP in Africa through IWA Africa.

Icelandic drinking water has been classified in legislation as food since 1995 and shall comply with regulation on food using the HACCP principle or similar management system, to prevent contamination. This means that there is more than a decade of data available at water utilities of the impact of this approach. The findings from research on lessons learned could therefore be beneficial for the water sector and also be of relevance for other countries, both those that have, and those that have not, adopted this approach.

1.1 Background

1.1.1 Water supply in Iceland

In Iceland, as in the other Nordic countries, a decentralized public administration plays a central role in providing essential services such as water and sanitation to the inhabitants (Pietilä et al., 2009). Municipalities are obliged to supply water to their densely populated areas whereas in the rural areas water supply is most often private consumer-managed water supply. Water utilities were established by the municipalities in urban areas in Iceland in the early first half of the last century and often the motivation was reoccurring

outbreaks of typhoid fewer. The country has now had 100% piped water to all its residences for decades (WHO/UNICEF, 2010). The basic hydraulic of the water supply is untreated groundwater pumped to an elevated tank that gravity-feeds the system.

Iceland is rich in natural resources and one of the freshwater richest countries in the world, estimated with around 600 thousand m^3 per person per year (UNESCO-WWAP, 2006) and there is high availability of good quality groundwater. About 95% of the country's drinking water is untreated groundwater extracted from springs, wells or boreholes. Surface water used for drinking is less than 5% so access to clean drinking water is generally not a problem in Iceland (European Environment Agency, 2010). Groundwater is not treated unless if there is a danger of surface water intrusion and then UV treatment together with filtration is utilized. The utilities that rely on surface water use such treatment but residual disinfection is not practiced in Iceland.

1.1.2 Legal status

Iceland is not a member of EU but is a member of the European Economic Area (EEA) and as such has to adapt national legislation to EU environmental legislation. This has resulted in tighter pollution control requirements. New Icelandic Drinking Water Regulation (IDWR) (Ministry for the Environment, 2001a) was introduced in 2001 in accordance with the European Drinking Water Directive (European Council, 1998). There it is stated that water utilities and others that distribute drinking water shall ensure that drinking water complies with quality requirement in the regulation and is not hazardous to health. Responsibility of surveillance of water quality lays with the ten Local Competent Authorities (LCAs)[1] in the country and on a governmental level the Icelandic Food and Veterinary Authority (IFVA) has the role of the regulator. The Ministry of Fisheries and Agriculture is the overall regulating body. Regular monitoring of microbiological and chemical parameters is to be carried out according to IDWR at all water utilities over a certain size (serving more than 50 individuals or 20 dwelling houses/summerhouses or with food processing/commercial activity) and frequency of sampling is according to population. Regular surveillance on bacteriological status has been carried out for decades but regular audit monitoring of heavy metals and chemicals came first with the new drinking water regulation in 2001.

Summary of compliance to drinking water regulation is not readily available to the public although it has been stated in regulation since 2001 that the local LCAs shall deliver results from monitoring to IFVA that shall summarize the results and publish yearly accessible for users (Ministry for the Environment, 2001a, paragraph 16). A central list of all the water utilities in the country that shall be tested according to the IDWR is not available so exact number of water utilities that shall be tested is not known.

In order to protect drinking water, authorities shall ensure that a protection zone is determined around the water source. It shall include three protection zones; well zone, near-zone, and distance zone, all with different stringent requirements (Ministry for the

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[1] Referred to as Local Health Authority in Chapters 2 and 3. LCAs is now the translation used by the regulator IFVA.

Environment, 2001a & 2001b). According to legislation municipalities can also implement legal requirements to restrict access, land use and use of chemicals inside catchment areas to prevent contamination of drinking water (Ministry for the Environment, 2001b). The European Water Framework on water governance has recently been implemented into Icelandic legislation (Parliament of Iceland, 2011). The objective of the legislation is to protect water and aquatic ecosystems and also to restore contaminated water bodies to its original state. The legislation requires the Environment Agency to maintain a registry of protected areas for drinking water abstraction over a certain size (serving more than 50 individuals or with more than 10 m^3/day water abstraction).

In 1995, Iceland became one of the first countries to legislate the use of systematic preventive management to secure safety of drinking water. That year new legislation on food was implemented that categorized drinking water as food and water utilities as food processing companies (Parliament of Iceland, 1995). The year before a new regulation on foodstuff (Ministry for the Environment, 1994) had stated the same but taxing provisions need a legal back up and therefore the year 1995 is used as the reference point. According to this legislation all food processing companies, including water utilities, are to implement systematic preventive approach to secure water safety and HACCP or similar was pointed out as an appropriate method to accomplish this. This regulation has now been updated with new legislation that enforces recent EU directive on the hygiene of foodstuff but that does not change the requirement that the water utilities are to use preventive approach (Ministry of the Fisheries and Agriculture, 2010).

1.1.3 Systematic preventive management

Systematic preventive management is built on the principle of systematically preventing occurrence of unwanted events. This is accomplished by evaluating risk and then taking the necessary mitigation measures to prevent identified hazards to cause harm. As in all management systems this is a continuous process. It can be depicted with the quality control circle, sometimes referred to as the Deming cycle (Gryna, 2001). The quality control cycle is the concept of self-control to achieve various goals and continuous improvement of processes. It has a widespread use and is used for example in ISO 9001 quality control standards. It is to work complementary with the classic external controls as surveillance and external audit of the WSP conducted by the regulator.

This concept is used here to describe the WSP approach and is shown in Figure 1-1. The control process is depicted as "plan, do, check, act". The first step is to plan; starting with describing the water supply system, doing a risk assessment taking into account likelihood and severity of the hazard taking place in order to be able to plan preventive mitigation measures. The second step is to do what has been planned. The third step is checking or studying that everything is carried out and is working as planned. And the fourth step is the upkeep of WSP and acting on deviation incidents and improvements, which then leads into another round.
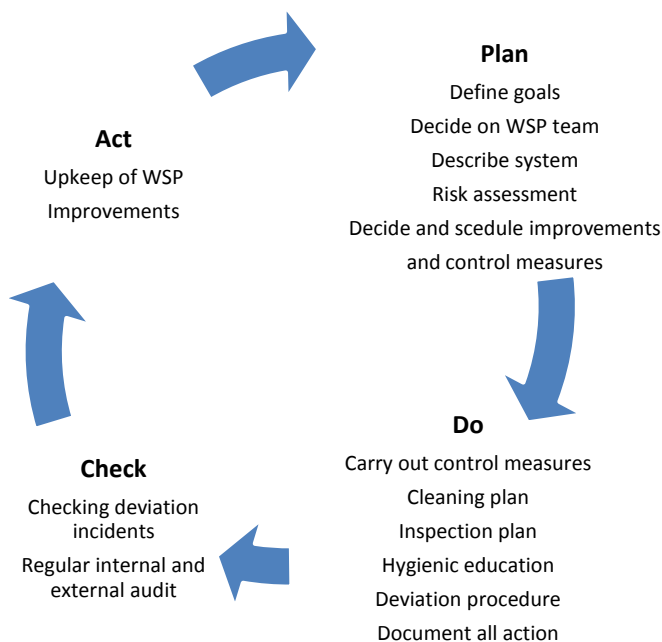
Figure 1-1 Quality Control Circle for a Water Safety Plan.

WSP is a management system that aims at identifying all risk to water safety from catchment to consumers tap and includes action to manage that risk (Bartram et al., 2009). This includes for example improved maintenance policies and procedures, systematic repair of pipes, cleaning plan and various improvements in the system. Such interventions shall reduce microbial growth in the system, prevent infiltration of contaminants and result in safer water unlike conventional approaches to drinking water quality that focus primarily on ensuring that drinking water meets governmental standards for biological and chemical parameters with end-point testing.

WHO has published two manuals on how to implement WSP; one aim for large utilities (Bartram et al., 2009) and also a manual for small supplies (WHO, 2012). Water Safety Plan Quality Assurance Tool has recently been launched by WHO to access the functionality of WSP and can be used as a part of internal audit (WHO, 2010). Many countries have published manuals on WSP and some of them can be accessed through WHOs WSPortal website on water safety plans (www.who.int/wsportal/wsp/en/).

1.1.4 Status of Water Safety Plans in Iceland

Between 1997 and 2009 preventive management was implemented in 31 water utilities in Iceland serving over 80% of the population as shown in Table 1-1. Reykjavik Energy was the first in the spring of 1997. Many of the larger utilities followed soon after and also many of the smaller ones. Samorka, the association of utilities, developed guidelines on HACCP for water utilities in 1996 (Palmadottir et al., 1996). It was clear quite early that

HACCP procedure was too complicated for the smaller utilities and therefore the water sector developed a simpler five step model in 2004 that has been used by many of the smaller water utilities as is shown in Table 1-1. The five step model is simpler than a standard HACCP, but nevertheless includes all the critical elements such risk assessment, procedures for maintenance, control at critical points, and deviation response. A template for the five step model is available on Samorka's website (Samorka, 2009).

Samorka has also offered support in the implementation process and encourages cooperation with meetings and training. Few years into the process the authorities decided on requirements that categorized WSP according to size. It states that a water supply serving more than 5000 inhabitants should have HACCP, those serving 500 to 5000 should have the five step model and those serving 100 to 500 as well as suppliers serving food processing companies such as milk farms should have a sanitary checklist. It is a prerequisite, according to the regulation, to have systematic preventive management for getting a working permit.

There are still some challenges though the legal requirements are in place. One is a lack of systematic external audit and approval of the functionality of the WSP system by the regulator. There is no official central list available of which water utilities have satisfied the regulatory requirements and implemented a preventive management. The regulator has put a legal requirement on the utilities on use of management system but without permission to follow up on compliance or guidelines on how to systematically test the functionality of the WSP.

Table 1-1 Icelandic water utilities that had implemented WSP by 2009 (Updated Table 2-1).

	Name of town	Date	HACCP	Inhab. of Iceland with WSP in 2009[1]
1	Reykjavík	May 1997	HACCP	118.665
2	Sauðárkrókur	Nov 1997	HACCP	2.601
3	Vestmannaeyjar	Nov 1997	HACCP	4.086
4	Gardabaer	March 1998	HACCP	10.358
5	Þorlákshöfn	Oct 1998	HACCP	1.582
6	Hveragerdi	June 1999	HACCP	2.315
7	Akureyri	Dec 1999	HACCP	17.355
8	Dalvík	Jan 2000	HACCP	1.412
9	Hafnarfjörður	June 2000	HACCP	25.850
10	Mosfellsbær	Oct 2000	HACCP	8.182
11	Seltjarnarnes	Oct 2002	HACCP	4.403
12	Akranes	April 2003	HACCP	6.609
13	Borgarnes	Nov 2004	HACCP	1.955
14	Hvammstanga	April 2005	5 step model	591
15	Stöðvarfjörður	April 2005	5 step model	235
16	Berglind Ölfusi	April 2005	5 step model	144
17	Hlíðarveita Biskupst	June 2006	5 step model	200
18	Bifröst	June 2006	5 step model	227
19	Hvanneyri	June 2006	5 step model	297
20	Grundarfjörður	Nov 2006	5 step model	853
21	Flúðir	Dec 2006	5 step model	377
22	Stykkishólmur	Jan 2007	5 step model	1.111
23	Egilsstaðir	March 2007	5 step model	2.716
24	Selfoss	April 2007	HACCP	7.650
25	Álftanes	June 2007	5 step model	2.518
26	Uppsveitir Borgarfj	June 2007	5 step model	180
27	Kópavogur	August 2007	HACCP	29.976
28	Fjarðarbyggð	June 2008	HACCP	4.334
29	Höfn	June 2008	HACCP	1.635
30	Vopnafjörður	June 2008	5 step model	534
31	Djúpavogur	Oct 2009	5 step model	363
SUM				4256.313[2]

1) Population of Iceland in 2009 was 319.368. 2) 81.2% of population with WSP

1.2 Challenges for water supply

There are some challenges facing water supply in relation to drinking water safety in Iceland. Twelve confirmed waterborne disease outbreaks have occurred in the last 28 years (Geirsdottir, 2011). Six were due to *Campylobacter* and six to norovirus. The last confirmed outbreak was in 2004 and at least one contamination event has been confirmed since 2004 but was not associated with adverse health impacts (HAUST, 2010). All of these outbreaks were at small water utilities. Absence of detected outbreaks of disease is, however, not a reason for complacency as endemic and sporadic cases of gastrointestinal illness and small waterborne outbreaks can be undetected by surveillance systems (Craun et al., 2006). The cause can for example be loss of pressure. Water supply system should be operated at high enough pressure to prevent contamination from entering the system but various types of events can cause transient pressure loss, e.g. a sudden large increase in water use, main breaks, or loss of power for pumps (Jung et al., 2007; Teunis et al., 2010). Water and sewage pipes are often in close vicinity in the same ditch and soil around water pipes can be contaminated with sewage. Therefore operation procedures, maintenance policy, and preventive measures in the water supply system are important to secure safe drinking water which the WSP methodology is expected to address.

Limited data, especially on septic systems is a challenge. About 8% of the population in Iceland is permanently served by septic systems and in addition many temporary residents such as tourists and summerhouse dwellers use such a system (Environment Agency of Iceland, 2011). Little is known of the condition of most of these systems and whether their condition and/or location are a threat to drinking water resources and limited data exists about travel and lifetime of pathogens in Icelandic groundwater. Usually the pathogens have a longer life span in cold water than in warmer water and viruses and parasites live longer than bacteria. The microbiological safety of drinking water relies on measuring the indicator bacteria such as total coliform and *E. coli* but it is not tested for viruses and parasites. Negative total and faecal coliform results can therefore not be taken as ensuring pathogen free water (Gleeson & Gray, 1996). This was for example the case in a waterborne norovirus outbreak in Iceland in 2004 where no indicator bacteria was detected in drinking water during the outbreak but test results was very strongly positive for norovirus of the same genotype as found in patients stools (Briem, 2005; Atladottir, 2006).

There are other challenges facing the sector as for example the fact that infrastructure of the water supply system is aging and little is known about the status of the systems and leakages. The largest groundwater resources are in the volcanic zone and high porosity of surface layers and bedrock characterize these areas often with thin layer of soil (Sigurdsson & Sigurbjarnarson, 1989). This requires increased protection with strict rules and special care on catchments to prevent contamination. Few municipalities have implemented the legal requirements to restrict access and rules on protection zones, as permitted in legislation. Due to global warming changes in rainfall-runoff patterns and in infiltration from highland areas presently covered by glaciers may alter the groundwater recharge and water level. Water level reductions have been observed and water scarcity reported in certain communities in summer months especially after dry winters and utilities have been forced to use less safe sources and turned to water treatment described above.

1.3 Objectives

The objective of this doctoral research is to evaluate measures by water utilities to prevent contamination of drinking water. The research is intended to reveal the importance of two factors; firstly, the impact of legislation requiring water utilities to implement and operate WSP methodology for water safety which is the main part of the research; and secondly, which factors influence travel of pathogens in coarse volcanic strata in cold climate.

The research questions are:

1. Are there benefits from WSP?
2. What has to be in place for successful implementation of WSP?
3. What has to be in place for continuous operation of WSP?
4. Are there measurable gains from operating WSP?
5. What are the similarities of operation of WSP in a developed versus a developing country?
6. Which factors influence travel of pathogens in volcanic strata in cold climate?

1.4 Organization of the Dissertation

The dissertation consists of seven chapters:

- Introduction in Chapter 1 gives background of water supply and status of water safety plans, challenges to safe water supply as well as the main objectives of the study and lists the research questions.
- Chapters 2 to 4 describe the research on WSP in Iceland in three journal papers; all of them have been published in ISI journals.
- Chapter 5 analysis a subsurface waterborne outbreak in cold climate coarse pumice by analyzing and modeling the data obtained during the outbreak. This paper has been submitted.
- Chapter 6 presents an evaluation of WSP in Uganda and comparison with results obtained in Chapters 2 to 4.
- Chapter 7 discusses and summarizes the main findings and provides recommendations for the water sector based on the research findings.

2 HACCP and Water Safety Plans in Icelandic Water Supply − preliminary evaluation of experience

Abstract

Icelandic waterworks first began implementing HACCP as a preventive approach for water safety management in 1997. Since then implementation has been ongoing and currently about 68% of the Icelandic population enjoy drinking water from waterworks with a water safety plan based on HACCP. Preliminary evaluation of the success of HACCP implementation was undertaken in association with some of the waterworks that had implemented HACCP. The evaluation revealed that compliance with drinking water quality standards improved considerably following the implementation of HACCP. In response to their findings, waterworks implemented a large number of corrective actions to improve water safety. The study revealed some limitations for some, but not all, waterworks in relation to inadequate external and internal auditing and a lack of oversight by health authorities. Future studies should entail a more comprehensive study of the experience with the use HACCP with the purpose of developing tools to promote continuing success.

Keywords: drinking water quality, five-step mini-HACCP, HACCP, water safety management, water safety plans.

2.1 Introduction

Safe drinking water is a very important contributor to good public health. Drinking water can be polluted at the source, during treatment, en route to consumers or in the household. Safe drinking water means water that will not jeopardize health and is reliable and available at all times. The World Health Organisation (WHO) has been promoting a systematic preventive approach, Water Safety Plans (WSP), as a means of promoting safe drinking water provision. Guidance on WSPs is given in the latest version of WHO's Guidelines for Drinking-water Quality *(*WHO, 2004*)* and further in the publication "Water Safety plans: Managing drinking-water quality from catchment to consumer" (Davison et al, 2005).

Since 1995 drinking water in Iceland has been classified in legislation as a food and waterworks as food processing plants. Subsequently the waterworks have had to implement a safety plan to secure the safety of the food (i.e. drinking water) that they

produce. Icelandic waterworks have been at the forefront of applying this approach to water safety by having implemented Hazard Analysis and Critical Control Points (HACCP) since 1997, ahead of other countries (Gunnarsdóttir, 2005).

Samorka, the Association of Icelandic Waterworks, has promoted the implementation of WSPs and a working group created guidelines both for HACCP in 1996 and later for a simpler WSP, mini-HACCP, for smaller waterworks in 2004. The first utility water supply to implement HACCP was the capital city Reykjavik, in May of 1997. Later that same year Reykjavik was followed by two towns: Sauðárkrókur and Vestmannaeyjar. By May 2007, 22 towns, representing 68% of the Icelandic population, had or where in the process of implementing HACCP or the simpler WSP (Gunnarsdóttir and Gissurarson, 2006) as shown in Table 2-1.

The waterborne diseases that have been reported in Iceland in the last twenty years have all been in small waterworks in fishing towns or at recreational areas (Gunnarsdóttir, 2005). It is, therefore, important to implement the concept of water safety and the preventive approach in smaller communities. From the early stages of HACCP implementation it became evident that a full HACCP system was too complex and time consuming for the smaller waterworks because of their lack of resources. Therefore, Samorka in cooperation with four small waterworks developed a simpler WSP in 2004, called the five-step plan, or mini-HACCP. There are now eight small waterworks with this simpler WSP. The simpler WSP is now being actively promoted for small waterworks and guidelines have been placed on Samorka's website for all waterworks to use.

WHO has recognized the need for attention to the special challenges of supplying safe water to small or remote communities and has initiated international cooperation on small community water supply management. Icelandic waterworks are participating in this work internationally and have been promoting this concept among the Nordic countries.

2.2 Evaluation

The ten years of Icelandic experience with the application of HACCP to water provides a body of experience that should be evaluated. A preliminary study of the improvements resulting from the implementation of HACCP indicates that overall the program has been a success for Icelandic waterworks (Gunnarsdóttir and Gissurarson, 2006).

HACCP has raised awareness of the importance of protecting water resources and many corrective actions and improvements have been implemented. However in some places the implementation revealed a lack of external audit, and inadequate internal self-regulation and control, by Health Authorities. Audit and back up from the Health Authorities has been limited because these authorities lack the resources to carry out what would logically be required of them. The lack of support could over time result in a decreased interest in good performance and improvement would fade out with time. External support and recognition is considered important to maintain support from management and staff motivation.

Reykjavik.

The preliminary study showed that implementing HACCP improved compliance with regulated drinking water quality standards in the town of Reykjavik as illustrated in Figure 2-1. The mean compliance value for bacterial count for 22°C improved from 94% for the

years 1991 to 1997 to 99% for the years 1998 to 2006. Drinking water in Reykjavik is mostly derived from borholes.
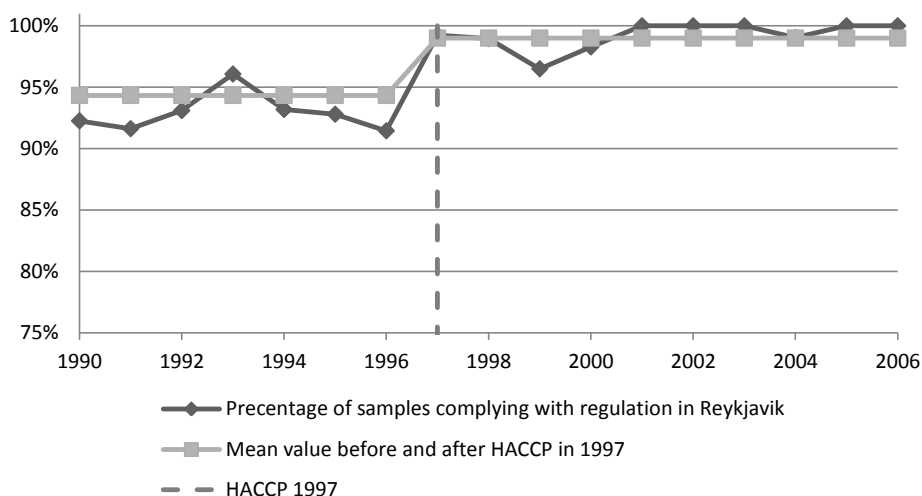
Figure 2-1 Percentage of samples complying with regulated drinking water quality standards in Reykjavík from 1990 to 2006 and mean value before and after HACCP in 1997.

A number of projects were started when implementing the HACCP system and completed as a result of the hazard analysis. In addition, when implementing HACCP in Reykjavik, some corrective actions were undertaken and additional control measures where applied at critical control points. A number of additional control measures introduced were as follows:

1. Thawing plan – during periods when snow is melting, shallow wells are closed down.
2. A program was introduced for cleaning out fire hydrants and dead ends twice per year.
3. Sanitary plan - cleaning of tanks 1-2 times per year and cleaning of pumping stations thoroughly once a year with a checklist for on-site quality and safety procedures.
4. Other control measures - regular preventive checking of well zones, fencing, status of gates and inspection of vehicles to verify that they are not leaking oil or other fluids.

Waterworks management identified the following as representing benefits of implementing HACCP:

✓ More thorough control resulting in higher product quality

- ✓ Greater system understanding and follow up so that if something goes wrong it is easier to trace and fix the problem
- ✓ All deviations are documented and reported as incidents
- ✓ More disciplined working methods
- ✓ Continuous improvement
- ✓ Stronger market position
- ✓ Good for business

They main water quality improvement in Reykjavík was thought to have arisen from closing down shallow wells during periods of snow melt. Regular cleaning of fire hydrants and dead ends is also considered to have led to significant improvements in water quality.

Akureyri.

In Akureyri HACCP was implemented in December 1999. Following implementation the proportion of samples complying with the regulated water quality standard increased, as in Reykjavik. The mean compliance value for bacterial counts for 22°C increased from 88% for the years 1992 to 1999 to 99% for the years 2000 to 2004 after implementing HACCP (*Árnason, 2005*). Approximately 86% of water for Akureyri is spring water and 14% is from boreholes.
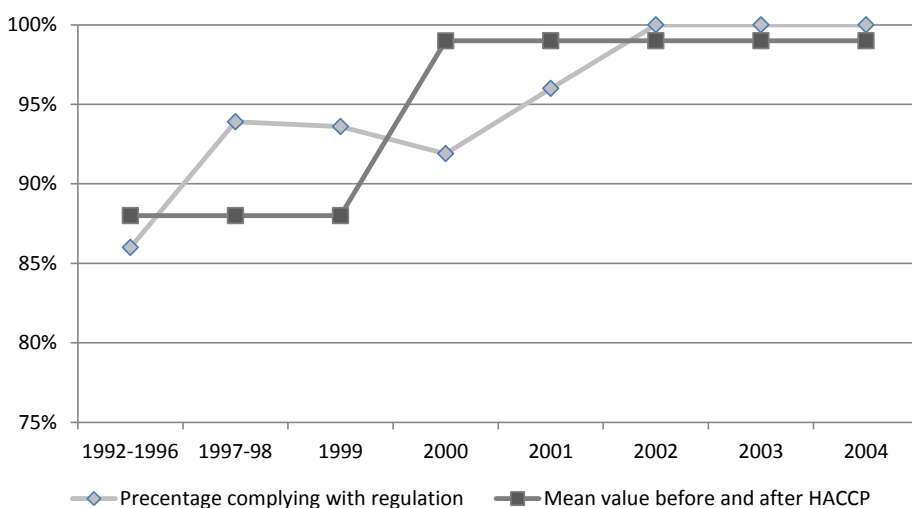
Figure 2-2 Percentage of samples complying with regulation in Akureyri 1992 - 2004 - HACCP in Dec.1999.

The improvements detected did not emerge immediately, but arose over time, following corrective actions being taken as a result of implementing HACCP. The corrective actions taken where as follows:

- ✓ Improved water intakes for spring water. These improvements were made in stages as there were 22 water intakes in total.

- ✓ Old distribution and connection pipes where renewed over a period of time in an area where water samples often had elevated bacterial counts.
- ✓ The pipeline to the airport was cleaned as the pipe was oversized which resulted in sedimentation. The pipe is now regularly cleaned twice per year.
- ✓ Fencing around the well protection zones was renewed.
- ✓ Signs for the catchment area, including map showing prohibited areas for vehicles, where installed.

The main detected improvements in water quality arose after the pipeline to the airport was cleaned. Control measures around the well zones included a sanitary plan, regular monitoring and a working procedure for protecting well zones. The procedure on well zones included strict rules for snow-cats as one of the three well zones is in a ski area. There were 23 critical control points identified that needed regular monitoring based around three well zone areas, each of which had many springs and boreholes.

Not many deviation incidents were recorded and very few in recent years. Most deviations recorded were related to the need to repair fences to keep out sheep, the need to repair lids on water tanks and the need to repair cracks in concrete tanks. At the beginning of 2007 there was a deviation incident on one of the well zones (Árnason, 2007). Snow scooters went into the well zone and one of them had an accident that resulted in injuries to the driver and an oil spill from the scooter. The spill was quickly cleaned up and measures were taken to promote the importance of protection of the water resource both by advertisements in local newspapers and in cooperation with the local snow scooter club.

2.3 Results and future studies

This results of this study are consistent with HACCP implementation leading to improved compliance with regulation for drinking water quality. Mean values for compliance for samples from all spring water supplies in Iceland is 89%. In contrast, samples from Akureyri, which is mostly supplied by spring water, had 99% compliance with regulated drinking water standards after implementing HACCP. Most of the water intakes in Reykjavik are from boreholes. For the country as a whole, borehole water samples showed 96% compliance with regulated water quality standards compared with Reykjavik which has 99% compliance (Gunnarsdóttir and Gissurarson, 2006). The main improvement in Reykjavík was observed after closing down shallow wells during periods of snow melt.

A study performed by the Environment and Food Agency showed that 90% of drinking water samples in Iceland for the period 1989 – 2001 complied with regulatory requirements for water quality (Georgsson, 2002). The same study showed that 96% of borehole water, 92% of treated surface water, 89% of spring water and 50% of untreated surface water samples complied.

An analysis of regular surveillance results undertaken by health authorities in south Iceland for the year 2004 showed that 85% of the drinking water samples in that area complied with regulatory requirements for quality (Guðmundsdóttir, 2006). This part of Iceland is a farming area with some eight towns and also some greenhouses and school centres, with a population of around 20,000. In this area there are three towns where HACCP has been implemented, (Vestmannaeyjar, Þorlákshöfn and Hveragerði), and in each case 100% compliance was achieved. Non compliance occurs mostly at small waterworks serving the

farming areas. It has also been shown that there is a significantly higher content of nitrate in drinking water from catchment areas in Iceland with agriculture, albeit at levels well below safety limits (Gunnarsdóttir et al., 2005).
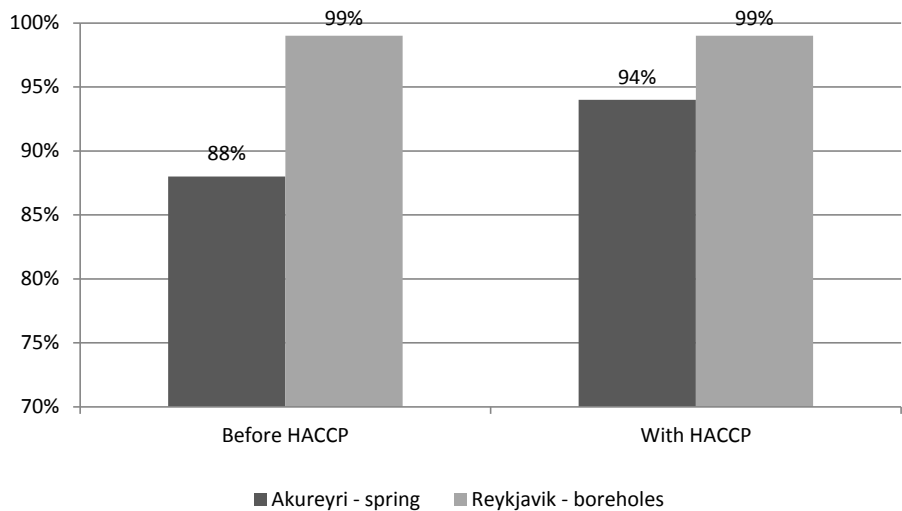
Figure 2-3 Improvement in compliance with regulated water quality standards after HACCP implementation in Akureyri and Reykjavík.

This preliminary study indicates that the implementation of HACCP by Icelandic waterworks has been a success as can be seen in Figure 2-3. The implementation of HACCP led to many corrective actions and improvements being made. The program appears to have improved drinking water quality and it is probable that these improvements in water quality have resulted in health benefits in the relevant towns. In addition, the use of HACCP has raised awareness of the importance of protecting water resources.

Our study revealed an inadequate auditing process as well as poor oversight by the health authorities in some areas. Scrutiny from audit, and back up from the health authorities, has been inadequate due to a lack of resources to carry out these functions. Over time, the lack of support from health authorities could result in decreased interest in good performance and a loss of the continuous improvement benefits of applying a rigorous HACCP approach. Support and recognition from health authorities is important to trigger support from management and for motivating staff.

There were some important exceptions to this problem. At Orkuveita Reykjavikur (OR) internal and external auditing is carried out regularly and was a fundamental component of the HACCP system. Reykjavik is an order of magnitude bigger than other waterworks in Iceland and therefore has relatively more resources to organise audits. OR has an integrated management system approach and has implemented ISO 9001, ISO 14001 and

OHSAS 18001 and HACCP, all in place since1997, for all its functions, drinking water, sanitation, district heating and electricity supply. Nordurorka, which is the waterworks in Akureyri, the town centre for the northern area, also supplies district heating and electricity, and has a good auditing process for its HACCP system makes great efforts to maintain the process. Nordurorka has implemented HACCP as part of its ISO 9001 system.

HACCP is a relatively new instrument in the water sector and, therefore, there has not been much evaluation of its value, the gains, the lessons learned and what is required for continual success. Critical review of the Icelandic experience has value for other countries as well as locally. The European Union is preparing a directive where a preventive approach is required and many waterworks in Europe are in the early stages of implementing systematic preventive approach. Iceland now has ten years of experience in this area and it is of value to share this experience.

In future there are plans to undertaken a comprehensive study of the implementation and operation of HACCP and WSP by Icelandic waterworks and an evaluation of the benefits compared with the cost and effort. The smaller waterworks five-step mini-HACCP approach will also be evaluated with a view to identifying what support has to be in place to realise implementation of the system to achieve safer drinking water in smaller communities. The long-term aim is to develop tools to keep the water safety process active so that the approach of preventive control and quality awareness will be firmly established in the water sector in Iceland. The major challenge in Iceland, as elsewhere, is to secure the safety of water from waterworks serving smaller communities with simpler systems and also to secure continuing success and quality awareness in waterworks that have already implemented HACCP and WSPs.

Table 2-1 Icelandic waterworks with HACCP and Mini HACCP in May 2007.

	Name of town	Date of approval	Number of inhab. Dec.2004	Accumulated population with WSP	% of Icelandic population	Type of town
1	Reykjavík	HACCP/May 1997	113.730	113.730	38%	Capital town
2	Sauðárkrókur	HACCP/Nov 1997	2.796	116.526	39%	Fishing town
3	Vestmannaeyjar	HACCP/Nov 1997	4.522	121.048	41%	Fishing town
4	Garðabær	HACCP/March 1998	10.471	131.519	44%	Sub town
5	Þorlákshöfn	HACCP/Oct 1998	1.372	132.891	45%	Fishing town
6	Hveragerði	HACCP/June 1999	1.766	134.657	45%	Green house and agriculture
7	Akureyri	HACCP/Dec 1999	16.800	151.457	51%	Town – centre of the northern area
8	Dalvík	HACCP/Jan 2000	2.040	153.494	52%	Fishing town
9	Hafnarfjörður	HACCP/June 2000	20.672	174.169	59%	Industry, fishing and sub town
10	Mosfellsbær	HACCP/Oct 2002	6.496	180.665	61%	Sub town to Reykjavik
11	Seltjarnarnes	HACCP/Oct 2002	4.654	185.319	63%	Sub town to Reykjavik
12	Akranes	HACCP/April 2003	5.342	190.661	65%	Industry, fishing
13	Borgarnes	HACCP/2004	1.730	192.391	65%	Service town for west area
14	Siglufjördur	Mini HACCP/2005	1.561	193.952	66%	Fishing town
15	Hvammstangi	Mini HACCP/2005	698	194.650	66%	Fishing town
16	Stöðvarfjörður	Mini HACCP/2005	276	194.926	66%	Fishing village
17	Berglind, Ölfusi	Mini HACCP/2005	144	195.070	66%	Farms and tourist area. Many more temporary residents
18	Hlíðarveita í Biskupstungum	Mini HACCP/ 2006	200	195.270	66%	Farms and summerhouses (mostly temporary residents)
19	Bifröst	Mini HACCP/ 2006	300	195.570	66%	Bifrost-University, farms and tourist area. Many more temporary residents, mostly students
20	Hvanneyri	Mini HACCP/ 2006	300	195.870	66%	Agricultural University. Many more temporary residents mostly students.
21	Flúðir	Mini HACCP/ 2007	536	196.406	67%	Greenhouse, farming, tourist centre and summerhouses. 600 more temporary residents
22	Egilsstaðir and Fellabær	Mini HACCP/ 2007	2364	198.770	67%	Town – service centre for the eastern area
	In all		5011.952		68%	

Note: Total population of Iceland in December 2004 was 293.291.

3 Icelandic Experience with Water Safety Plans

Abstract

The aim of this study was to investigate accumulated experience with water safety plans in one of the first countries to adopt systematic preventive management for drinking-water safety. Water utilities in Iceland have had legal obligation since 1995 to implement a systematic preventive approach to secure safety of drinking water and protect public health. The water utilities responded by implementing either an adapted HACCP (Hazard Analyses Critical Control Points) model for larger water utilities or a simpler five step model for smaller water utilities. The research was carried out at sixteen water utilities that serve about two thirds of the population of Iceland. Both qualitative and quantitative methods were used with the aim of analysing if and what benefits water safety plans bring for water utilities and what is needed for successful implementation and operation of such systems. The results of the study show that numerous benefits and even the process of going through the implementing process were considered to be of advantage and change the attitude of the staff and the utility culture. Some obstacles and shortcomings came to light, such as lack of documentation and lack of regular internal and external audit. There was little communication with the public although some mentioned that good public relations are important to succeed with water safety plans. Many important elements of success were revealed of which intensive training of staff and participation of staff in the whole process is deemed the most important. It is also important to have simple and well structured guidelines and good cooperation with the health authorities.

Keywords: drinking water, HACCP, risk management, water safety plan, WSP-scoring system

3.1 Introduction

Access to safe and reliable water is one of the fundamental requirements for a good and prosperous society. This emphasises the importance of well managed water utilities where in which the key is the attitude and skills of the people working in the sector. At the core of that is the commitment of all staff to the responsibility of securing public health above all else (Hrudey et al., 2006; Summerill et al., 2010a). An adequate regulatory framework and regular external surveillances are important in verifying safe water but the main responsibility lies within the water utilities in protecting drinking water quality from catchment to consumer at all times.

Episodes of microbiological and chemical contamination of drinking water lead to illnesses and fatalities all over the world demonstrate a need for new preventive approach (Hrudey & Hrudey, 2004; Kvitsand & Fiksdal, 2010). The systematic preventive management has been gaining acceptance as a methodology that can assist in safeguarding drinking water. World Health Organization (WHO) defined a Water Safety Plan (WSP) in its latest drinking water guideline (WHO, 2004) building on this principle and has recently published a manual on how to implement a WSP (Bartram et al., 2009). The objective of a water safety plan is to ensure safe drinking water through good water supply management and the main goal is to prevent contamination of raw water source, treat water to remove contamination and prevent re-contamination during storing and distribution (Davison et al., 2005). HACCP has been used in the food industry for decades (Hrudey & Hrudey, 2004). It was later adapted for the water sector and most water safety plans in use are based on HACCP (Havelaar, 1994; Hamilton et al., 2006).

In 1995 a new legislation for food was implemented in Iceland that categorised drinking water as food and water utilities as food processing companies (The Foodstuffs Act no. 93/1995). According to this legislation all food processing companies including water utilities are to implement a systematic preventive approach to secure water safety. HACCP was pointed out in accompanying regulation as an appropriate method to accomplish this. This regulation has now been updated with new legislation that enforces a recent EU directive on the hygiene of foodstuff but that does not change the requirements that the water utilities are to use a preventive approach (Regulation no 103/2010 on the enforcement of the EU directive (EC) no 852/2004 on the hygiene of foodstuffs). Drinking water quality is in the jurisdiction of the Ministry of Fisheries and Agriculture and is managed by the Icelandic Food and Veterinary Authority. At local level, Local Health Inspection Board and Health Inspectors on their behalf are responsible for water surveillance. In 2001 new drinking water regulation (536/2001) was implemented in Iceland according to European Union regulation (EU 98/83). In this regulation it is stated that water utilities are responsible for delivering safe drinking water. Despite this and the fact that risk management has been implemented to a large extent, accidents do still happen, and even in water utilities that have a WSP.

The first water utility in Iceland to implement HACCP, which was adapted to a water supply, was the water utility in Reykjavik City in the spring of 1997. Many of the larger utilities followed soon after and also many of the smaller ones. But it was clear quite early that HACCP procedure was too complicated for the smaller utilities and therefore the water sector developed a simpler five step model that has been used by many of the smaller water utilities (Gunnarsdottir & Gissurarson, 2008). The five step model simplifies HACCP, but nevertheless includes all the critical elements such risk assessment, procedures for maintenance, control at critical points and deviation response (Palmadottir et al., 1996; Samorka, 2009). Samorka, the association of utilities, has also offered support in the implementation process and encourages cooperation with meetings and training. A few years into the process the authorities decided on guidelines that categorized WSPs according to size. It states that water supply serving more than 5000 inhabitants should have HACCP, those serving 500 to 5000 should have the five step model and those serving 100 to 500 as well as suppliers serving food processors such as milk farms should have a sanitary checklist. It is a prerequisite, according to regulation, for getting a working permit to have some kind of systematic preventive quality control system.

There are forty water utilities serving population of more than five hundred in Iceland. By far the largest one is the water utility of Reykjavik City, being nearly an order of magnitude larger than the second largest. According to information from the ten local health authorities in the spring of 2008, thirty one water utilities serving 81% of the population were said to have WSP. Of these, fourteen used the five step model for smaller system while seventeen have adapted HACCP model.

WSP has been used for over a decade in Iceland so a systematic research on the performance is timely. In this research sixteen Icelandic waterworks with WSP are investigated. The objective is to investigate if there are benefits from a systematic preventive approach and what has to be in place for successful implementation and continuous operation of the WSP. Based on the results, a list of recommendations is developed that might assist water utilities in improving operation of current WSPs and/or assist water utilities in installing a WSP. The results and recommendations from the study should be applicable internationally to other utilities as the data collection; the analysis and the scoring system do not rely explicitly on Icelandic circumstances.

3.2 Methods

3.2.1 Utilities

The research is carried out by analysing sixteen water utilities that all have WSP. They serve around two third of the population of Iceland but are very different in size, serving from 270 to 120.000 residents and nine of them with less than five thousand residents. The main features for the utilities are shown in Table 3-1.

Table 3-1 Feature of the 16 water utilities.

	Unit	*Mean*	*Median*	*Range*
Size of water utility	no. of inhabitants	12,900	3,000	270-120,000
Number of Critical Control Points (CCP)	no. of CCP	9	6	1-24
Duration of WSP in use	year	6	7	0-12
Time it took to implement WSP	month	11	9	2-24
Work experience of the interviewed in the water utility	year	16	17	2-29

All of the interviewees were responsible for the WSP either as foremen or as senior managers. Most had a long experience working in the water utility and had taken part in the WSP implementing process. The average working experience was sixteen years. Only two of the interviewee had water supply as their main work function but others had multiple responsibilities either in combined utilities or elsewhere in the municipality. They are all male reflecting the fact that this is a male dominant profession.

3.2.2 Research methods

In the research both qualitative and quantitative methods are used. Qualitative research methods build on understanding the attitude and the situation from the viewpoint of individuals with firsthand experience. Sixteen semi-open interviews with staff that are responsible for WSP in the water utilities were carried out using a framework of questions on benefits, obstacles and key success factors. Some questions were designed to reveal the depth of understanding of the interviewee of the WSP methodology. The interviews lasted from one hour to three hours with an average length of one hour and fifty minutes and were all conducted in 2009. Two participant observations were carried out with staff on a regular WSP site visit and two interviews with health inspectors were carried out to get the view from the regulator side; one from a rural area and one from an urban area. The interviews were recorded, then documented and analysed according to the methodology of qualitative research, coding themes and relevant information. The interviewees and the water utilities are anonymous.

The quantitative part of the research is a question list with seventy nine parameters. The first twenty nine questions gather data on the WSP and how it was implemented. Then twenty three questions explore the motivation and support with the implementing process. Finally, there are twenty seven questions about the functionality of the WSP and the benefits and improvements.

Statistical methods are also used such as non-parametric Kendall's correlation test using the statistical tool SPSS 18 to analyse the connection between different parameters and the success factors.

3.2.3 Limitations of the study

The interviews were performed in a systematic way by the first author over a period of nine months. Care was taken in preparing, executing and post-processing the interviews in a consisting way. However, potential biases could be introduced due to the knowledge of the interviewer of the subject area, which is extensive; a former working relationship of the interviewer with some of the interviewee; and lack of knowledge on management issues which in some cases necessitated a second interview with a management person, sometimes during a second visit. In most cases the different structures of the utility were inspected, especially the water-intakes, pumping stations and storage tanks, but in few cases this was not possible. The authors believe that none of these issues introduce significant bias to the study.

3.2.4 WSP scoring system

Scoring system for rating the WSP performance of the water utilities was developed. The scoring system is also used to analyse correlation between different factors to examine what leads to a successful WSP. The WSP scoring system is divided into on four categories of performance, each with five items, in all 20 items, as is shown in Table 3-2. The categories are based on the principles of the well known PDCA (plan-do-check-act) cycle, which is sometimes referred to as the Deming Wheel (Chase et al., 2001) which expresses the continuous improvement process in quality management. The first category assesses the mapping of the hazards (plan), the second category assesses what action were implemented (do), the third category assesses the documentation (check), and the fourth category assesses the support actions that are used to maintain and improve the WSP (act).

Table 3-2 Scoring system of WSP performance.

	Category and items	Max scores
Category 1: Mapping and risk assessment		
1	Knowing your system	5
2	Risk assessment	5
3	Decide on action on CCP	5
4	Standard operational procedure	5
5	Improvement plan	5
Category 2: Action taken		
6	Regular control on CCP	5
7	Regular cleaning action	5
8	Procedure implemented	5
9	Decided improvements preformed	5
10	Contingency plan tested	5
Category 3: Documentation		
11	Control/checking	5
12	Cleaning actions	5
13	Complaints	5
14	Malfunctions	5
15	Yearly summation of deviation incident and report on action taken	5
Category 4: Support actions		
16	WSP steering group active	5
17	Internal audit	5
18	External audit	5
19	Training	5
20	Public relations	5
	SUM	100

Each item is evaluated and given a score between 0 and 5 based on the following rating:

0. No progress
1. Limited initial action
2. Moderate progress
3. Extensive but incomplete progress
4. Extensive progress
5. Completed successfully.

The four categories represent loosely a timeline of implementation of a WSP at a water utility, as the items in the first category are generally carried out first and so on. The maximum score for each category is 25, and combined maximum score is 100.

All sixteen water utilities are rated according to the system in Chapter 3.3.3.

3.3 Results and discussion

The results are divided into four parts. First, the results from the implementation process with discussion on motivation and support are presented in a quantitative way. The second part discusses what lessons can be derived from the interviews as a result of qualitative approach. The third part is a result derived after rating the sixteen water utilities according to the rating system developed for the purpose. The fourth part looks at correlation between different factors.

3.3.1 Implementation process

Table 3-3 shows summary of the most often stated reasons for implementing WSP according to the interviews within at the sixteen water utilities. The most common reason stated was to provide safe and reliable water supply as all the water utilities interviewed had that as one of the three most important purposes. Fulfilment of regulation was stated by 88% of the water utilities and thereby getting a working permit, though only 19% put that as the first priority. Improved service was also stated 88% of the time but never as a first priority. Only 12% mentioned decreasing complaints as one of the second and third main purposes of implementing WSP.

Table 3-3 Purpose for implementing WSP.

Purpose	Safe water	Fulfil regulation	Improve service	Decrease complaints
Nr. 1	81%	19%	0%	0%
Nr. 2	6%	50%	32%	6%
Nr. 3	13%	19%	56%	6%
	100%	088%	088%	012%

Table3-4 shows the stakeholders that were most commonly listed by interviewees for encouraging implementation of WSP. The interviewed most often stated that the important push to implement WSP came from the water sector, health authorities or local staff and in fact enthusiasm by staff was the most common first priority or 38%.

Table 3-4 Incitement for implementing WSP.

Incitement	Interest of staff	Water sector	Health Authority	Non-compliance	Pressure from board	Pressure from companies
Nr. 1	38%	25%	25%	6%	6%	0%
Nr. 2	0%	57%	25%	6%	6%	6%
Nr. 3	19%	18%	31%	6%	6%	19%
	057%	100%	081%	018%	018%	025%

Non-compliance of drinking water quality requirement was also mentioned as the reason for implementing a WSP or in 18% instances. Pressure from the board and from companies in the area was also mentioned by 18% and 25% of the utilities, respectively, as a reason. The latter would most often be food processing companies, exporting e.g. fish, that would need to be able to verify the purity and quality control of the water used in the process. This could also be influencing the local government as the water utilities boards are usually part of the local government structure.
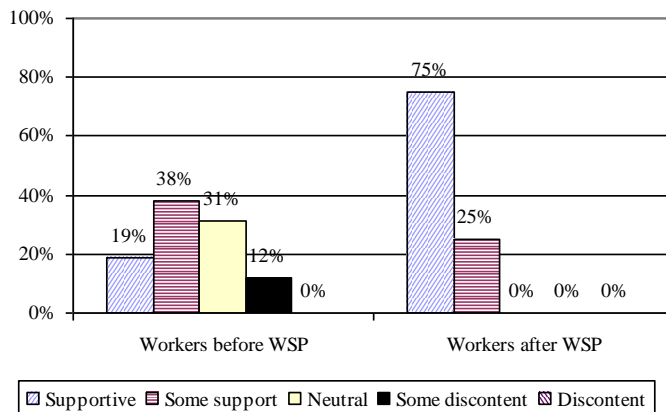
Figure 3-1 Attitude by staff towards WSP.

Figure 3-1 shows the change of attitude of staff before and after implementation. Attitude by staff was 19% supportive before WSP but increased to 75% support after WSP was implemented. Figure 3-1 also shows that the staffs are 100% supportive or somewhat supportive following the implementing process of WSP.

Table 3-5 shows the support from stakeholders during the implementing process. The table shows that the support came mainly from the water sector and the health authorities, 75% and 81%, respectively. Somewhat less support was received from the municipality and from the local government, or 44 and 56%, respectively. Some had experienced opposition to their plan to implement WSP from the municipality or companies in the area although that was rare. Companies and others in the area had mostly been neutral and shown little interest and 6% of companies had shown much support and had, as also revealed in Table 3-4, in some cases been pushing for implementation. But none had experienced objection to the plan of implementing WSP. The interest of the staff from the beginning highlights the importance of human capacity building. This is also emphasised by Summerill et al. (2010b) in a case study at two utilities which stated the importance of utility culture for success and longevity of WSP projects.

Implementing WSP in Iceland has been a long process and many water utilities have been granted a long adaption time to fulfil the requirement. The health authorities have continued to put pressure on the utilities and used work permits as a means for that. But still they have adopted a soft approach. "We have always tried to consult with the water utilities and inform about legal requirement" quoting one health inspector. The implementing process took from two to twenty four months and with average time being about 11 months. For the sixteen water utilities interviewed, some had only recently finished implementation but the oldest was 12 years at the time of the interviews and with the average time being six years since implementation of WSP.

Table 3-5 Stakeholders supporting WSP.

Supporting WSP	Water sector	Health authorities	Munici- pality	Local government	Companies	Others
Much support	50%	50%	38%	18%	6%	0%
Some support	25%	31%	6%	38%	0%	6%
Neutral	25%	19%	50%	31%	88%	94%
Wanted other solutions	0%	0%	6%	13%	6%	0%
Object to	0%	0%	0%	0%	0%	0%
	100%	100%	100%	100%	100%	100%

3.3.2 Lessons learned

The lessons learned from the data collected during the interviews are divided into three parts. First, benefits from implementation are discussed. Then obstacles and shortcomings in the operation of the WSP are analyzed and lastly discussions on what issues are important for successful implementation and operation of a WSP.

Interviewed waterworks

Benefit	Percentage
Change in attitude of workers- water is food	88%
Systematic procedure and traceability	81%
Safe water and reliable water delivery	63%
Improved management	63%
Financial gain	63%
Better service and feed-back on complaints	50%
Advantage for the community to have audied water	50%
Learn to know your system	44%
Staff less stressed about safety of water	31%
Good PR for waterworks	31%

Figure 3-2 Benefits from WSP.

Benefits

Figure 3-2 shows what the interviewed considered to be the benefits from implementing a WSP. The main benefit stated was the change in attitude by the staff. Fourteen out of the sixteen interviewed stated that as a benefit. The fact that water was classified as food in 1995 was a strong stimulation for change in attitudes. It changed e.g. the way tools are handled which resulted in better hygiene and different procedure, e.g. tools for sewage and water supply are separated…"and things used in the sewage works is not allowed into the premises now"… quoting one, or "we never take the pressure off a pipe before we have cleared away all earth as it could be contaminated with effluent from leaking sewage pipe in the same ditch"… quoting another. The process of going through risk assessment and training had a lasting influence on staff attitude and emphasis on health related issues. Many mentioned that regards for safety is now incorporated in all design and choice of material.

Another strong influence that was considered as a great benefit was that the process of implementing WSP had stimulated more systematic workmanship in all procedures. The staff had better knowledge of their water system after thoroughly going through it and many consider that to be of great importance. Also, with systematic approach, the management is improved which makes it easier to cope with stressful events.

Financial gain in some form was stated by 10 of the water utilities. It was considered easier to secure resources for improvements of the system after WSP implementation. Now there was an understanding that you were protecting public health which is a good argument. As one interviewer formulates it "is used to be no big deal if some insects were floating in people's bath but now it is not tolerated". One big water utility had lower interest rates on loans in international loan markets because of WSP. Many stated that it had in fact saved money through better management of assets although nobody had actually done any calculation or cost benefit analysis.

Figure 3-2 shows also that 50% mentioned that one of the benefits was better service to users and feed-back on complaints had improved. "We are always scoring highest in the municipality service surveys among the residents in our town"…said one interviewee. The benefits of knowing that you are doing your best in providing safe and reliable water were considered a great bonus. Also that the staff in charge are less concerned that something will go wrong and feel that they are in control of the situation and that makes the job less stressful. Better documentation and the resulting traceability improve workmanship. "This is the bible for the water utility on how to do things" was emphasised by two interviewees.

Several mentioned that it was of great advantage for the community to have audited water and that gives them better status among communities when competing for enterprises to move to the community. And it is considered by some to be good public relation for water utilities to have WSP.

Obstacles and shortcomings

Some shortcomings and obstacles came to light in the interviews as is shown in Figure 3-3. In 15 out of 16 water utilities some of the documentation was inadequate and in some cases even completely missing. Most frequently documentation of the action following incidents is lacking. Few perform yearly summations on incidents. Summation on complaints was also inadequate in many instances. Few water utilities have a steering committee that follows up on WSP though many had a team working on risk assessment during the implementing process.

About 80% had no account of training or any overview or a future plan for training of staff. However, many staff members pointed out that training was important and had participated, or someone at their utility, in the courses that had been available. The water sector has provided shorter courses in WSP and also, in cooperation with institute for adult learning (funded by labour unions), yearly extensive six weeks general training program, including WSP, aimed at workers at utilities.

In 75% of the water utilities there was no regular auditing of WSP either internal or external. In some cases the health authorities had never inspected the WSP after granting work permit while others did regular random inspections. And in two cases health authorities stated that there was a functioning WSP when inspection revealed that in fact there was none. Internal audit and follow up on results from audit reports are rare.

Many interviewees mentioned that the recent building boom has been difficult for the water utility. Too much emphasis had been on expansion of the distribution network and less on maintenance. Water utilities were forced to expand and invest for borrowed money. These loans have to be paid back but many of the buildings are still half build or empty and the distribution network underutilized with limited return on investment cost. Another aspect of the building boom was increased pressure for land use in water protection areas as contractors had put pressure on local government to allocate building sites in these areas.
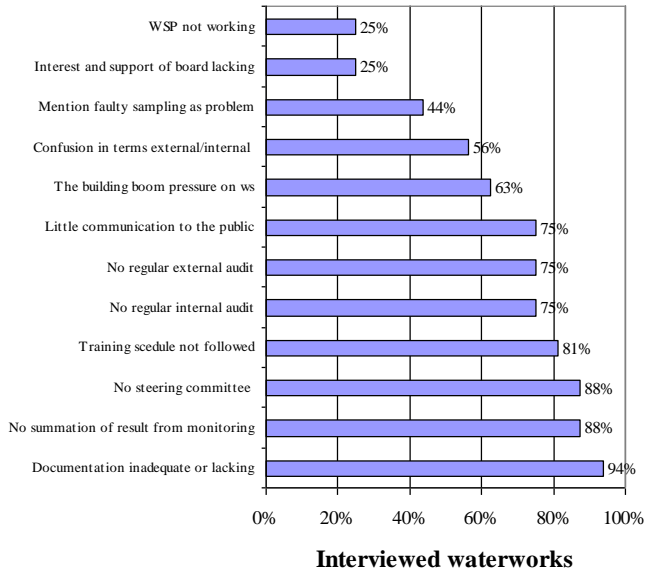
Figure 3-3 Obstacles and lacking in WSP.

Questions in the interviews were designed to reveal the level of understanding of WSP by the interviewee. The results showed that there was some confusion of terminology regarding WSP. Some mixed up external and internal control and e.g. thought that mandatory monitoring of water quality by health authorities was part of the WSP.

Some interviewees complained that local government is not supportive and had little interest or knowledge of the water supply. They also believed that users have little interest in the operation of a water works as long as water comes out at the tap. There is also little done within most water utilities to inform the public. It was even considered better not to highlight water issues as that would make the water utilities more in danger of vandalism. Little or no information about water was on the websites and only two had information about the water safety plan on their website. One water utility had just published a leaflet without any information about WSP.

Issues important for success

In order to evaluate lessons learned the interviewees were asked what issues were important for successful operation of a WSP. The questions are divided between internal and external matters and the results are shown in Figures 3-4 and 3-5.
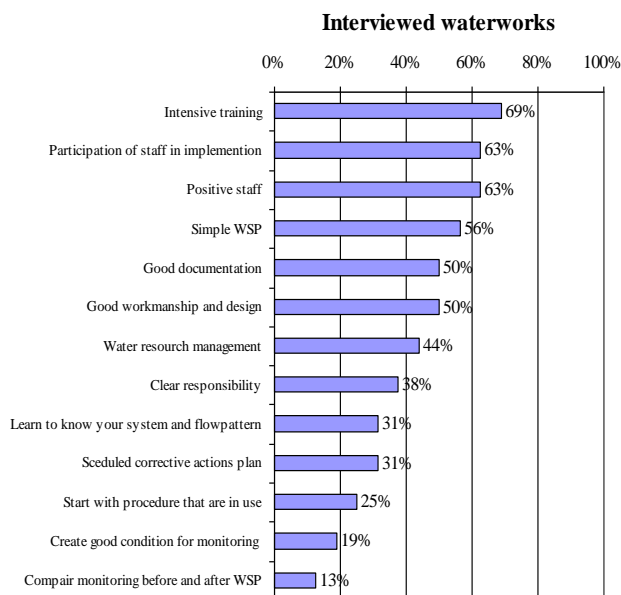
Figure 3-4 Important for success – internal.

The theme that was most often pointed out or in about 70% of the water utilities was training of personnel as training leads to a positive attitude. Some said that attending the comprehensive training program for workers had been a milestone for success. Staff came back from the course with a different attitude towards water safety.

It was also considered important to let staff, which is to carry out the work, participate in the implementing process. This was mentioned by over 60% of the water utilities. Some said that this had been done at their water utility, which they considered important. Others had failed to do that, had even just bought a readymade WSP from a consultant with no input from staff and had then realised that it was a mistake as the system was not working. It should be a team work and with as much input from staff as possible. This induces a kind of owner's responsibility.

Delegation of responsibility should be clear and some wanted to have one person responsible for all documentation. One of the smaller utilities had just at the time of the interview hired a worker to take care of all documentation. He is not to carry them all out but is responsible for following up, collect and summarizing the information gathered.

In 56% of the interviews it was pointed out that it was important that the guideline and layout for the WSP should be simple and as straightforward as possible. Documentation was considered important and it would increase traceability. Two mentioned that they had to create good working condition in the field for control and monitoring, with warmth and light at control stations otherwise no documentation was performed. Citation from an interview emphasising the importance of good conditions" the paper is wet… I can't find the pen… I am cold and my hands are wet…. and in the end no documentation is done".

Other issues mentioned were, e.g. that the output of the risk assessment should be a scheduled improvement plan and the staff should learn to know the system better, both with regard to assets and flow- and load patterns of water through the distribution network. Also to aim for best solutions and quality in all projects, e.g. choosing an asset that is easy to clean and maintain. Effective water resource management was considered important for a successful WSP as this was mentioned by 44% of the interviewed and land-use planning, protective measures and strict regulations are the key to good resource management. Some, or 25%, mentioned that it was helpful to start with the procedures that were already in use at the water utility.

Interviewed waterworks
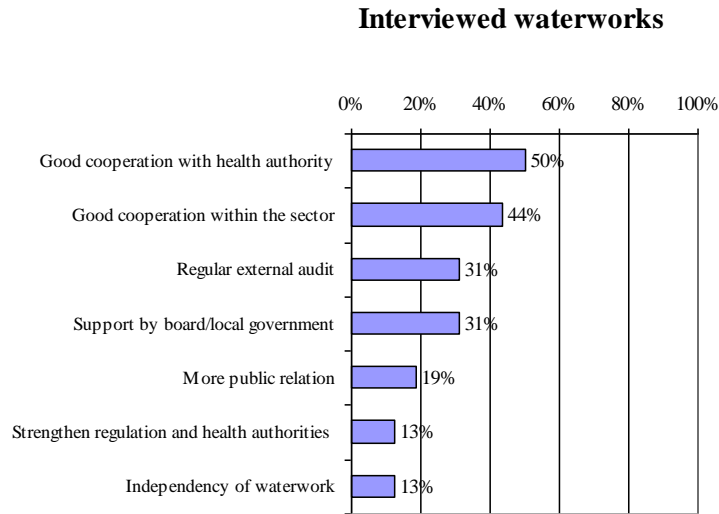
Figure 3-5 Important for success – external.

Figure 3-5 shows responses with regard to external matters that were considered important for success. The most important factors in implementing and running the WSP with respect to the external framework were to do it in good cooperation with the local health authorities and also with cooperation with other water utilities directly or through collaboration with Samorka, the association of water utilities.

A need to have a regular external audit was pointed out by one third as an important contributor to success. Some also mentioned that there was a need to strengthen the regulatory bodies for external control and the regulation for them to carry that out.

Support by the board or the local government is considered important as one third mentioned that as one of the keys to success. Also, to grant water utilities more independence within the municipality was considered important.

Some, or 19%, mentioned that it would be a good idea to do some more public relation work as for example to put on the website information about the water supply, history etc. as well as results from audit monitoring. It was also considered to be important to enlighten and inform the local government and the board of the water utilities. These are sometimes the same as in some places there is not a special board for the water supply but it is governed by the town council. Generally there are few complaints and that is the sign that everything is performing in a satisfactory way, was the attitude of the staff.

3.3.3 Performance of the water utilities

The scoring system introduced in Chapter 3.2.4 was applied to the sixteen water utilities. The outcomes are from 27 to 91 out of hundred with the average rating of 57. Most do well in mapping, risk assessment and in performing the action decided on but when it comes to documentation and support action many do not perform well. Seven water utilities have lower score than 50 mainly due to poor documentation, limited support actions such as external and internal audits and little communication to the public. It is noted that in case of limited documentations, system can hardly be classified as functioning WSP. Even if the interviewee state that actions described in the WSP are carried out it is unverifiable and can therefore not be classified as working systematic management system that can for example fulfil an external audit. Figure 3-6 shows the rating of the WSPs.
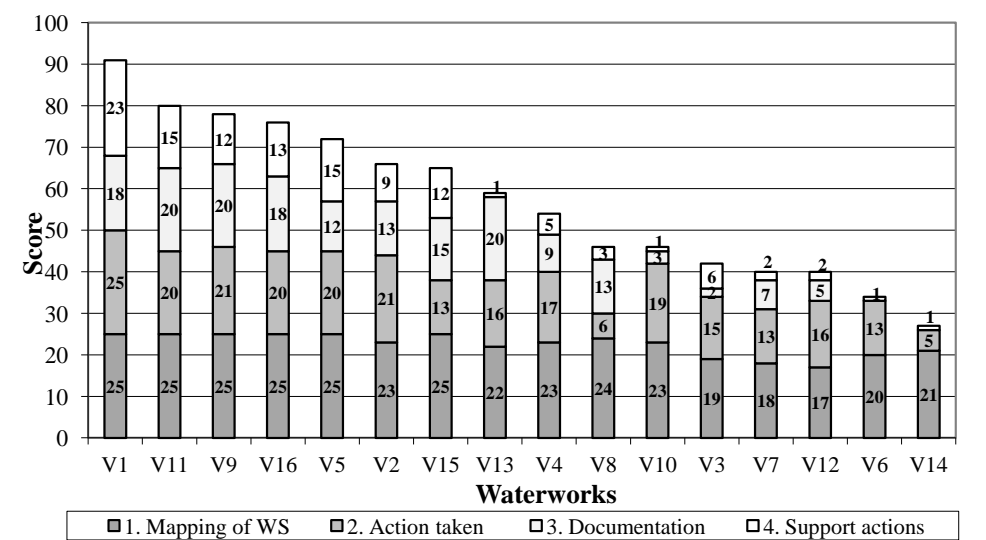
Figure 3-6 Results from WSP rating for the sixteen water utilities.

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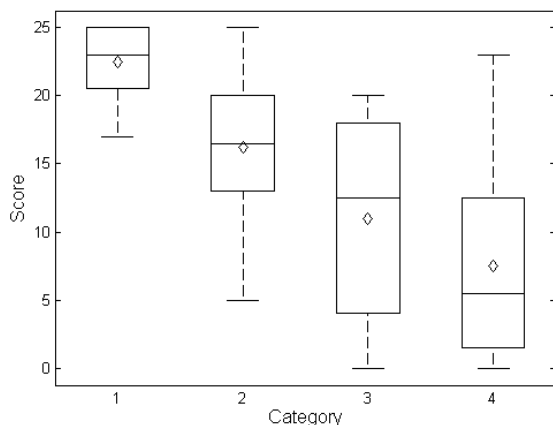
Figure 3-7 Distribution of WSP rating for each category.

Figure 3-7 shows the distribution for the WSP rating for the four categories as defined in Chapter 3.2.4. Shown are max and min values, 1st and 3rd quartile, median and the mean with a diamond. The plot shows clearly that the WSP rating decreases for each category. This could indicate that the implementation procedure was not carried to completion for many of the water utilities, as the categories indicate in a way how mature the WSP system is at each utility. The high WSP rating and a low scatter for the first category indicates a successful initial implementation of a WSP at the utilities. Category 2 represents a standard daily running of the WSP which get a lower rating than the first category with larger scatter indicating some difficulties in daily operation in some of the water utilities. The scatter for the latter two categories is much larger than for the first two potentially indicating increasing complexity (or confusion) in running the WSP system after an initially successful implementation. The result for the latter two categories clearly indicate a need for re-evaluation of the daily execution and documentation and especially with regard to audits which are crucial in maintaining and motivate continuous improvement for the WSP system at each water utility.

3.3.4 Correlation between different factors

Correlation between various water utilities parameters and the result from the scoring system were analysed to investigate what parameters were important in a successful WSP performance. In all 175 parameters, 79 from the quantitative part, 91 from the qualitative part of the research and 5 from the scoring system were analysed. Results for selected variables are shown in Table 3-6. The correlation between WSP rating and which system is used; adapted HACCP or simpler five step system, is negligible. This indicated that the WSP systems are equivalent.

Table 3-6 shows that larger water utilities score higher than smaller ones both in Category 2 which evaluates the actions taken and Category 4 which evaluates the support actions.

The larger utilities are more likely to have a WSP steering group, to have active cleaning plan and conduct audit and training and are therefore able to score higher. This reflects the difficulty of the smaller utilities. But this is not universal as some smaller water utilities score highly and of the top three two are small water utilities. The interviewees at the larger utilities expressed concern that the WSP needed to be simpler which indicates that the systems tend to get too complicated at larger utilities.

Water utilities that have a working WSP steering group are more likely to have internal audit and also put more emphasis on regular cleaning such as flushing of fire hydrants. They do better in all categories (not just Category 4 which includes a steering group). A training plan that is carried out, especially if employees had taken the comprehensive training program for workers in the field, results in higher scores in all categories (not just in Category 4 which includes training) except in Category 3 which is documentation. This shows that training is an important part of succeeding but there is a need to improve education in documentation.

Table 3-6 Example of non-parametric correlation (Kendall's tau, 2-tailed) between selected factors in WSP showing correlation coefficient R (upper number) and significant factor (lower number). Significant factor less than 0.05 are in bold.

	Size of water-work	Training program active	Steering group	Freq. of internal audit	Freq. of external audit	Regular flushing of hydrants	Good under-standing of WSP
Size of water-work	1						
Training program active	0.483 **0.032**	1					
Steering group	0.483 **0,026**	0.303 0.241	1				
Freq. of internal audit	0.297 0.153	0.176 0.476	0.503 **0.042**	1			
Freq. of external audit	0.401 0.052	0.471 0.054	0.285 0.244	0.566 **0.016**	1		
Regular flushing of hydrants	0.127 0,560	0.429 0.097	0.545 **0.035**	0.132 0.593	0.075 0.760	1	
Good under-standing of WSP	0.219 0.315	0.47 0.097	0.545 **0.035**	0.395 0.109	0.359 0.142	0.746 **0.004**	1
WSP rating	0.353 0.058	0.516 **0.018**	0.545 **0.013**	0.642 **0.002**	0.579 **0.005**	0.360 0.100	0.603 **0.006**
WSP Categ. 1	0.325 0.094	0.476 **0.038**	0.476 **0.038**	0.656 **0.003**	0.635 **0.004**	0.262 0.252	0.549 **0.016**
WSP Categ. 2	0.449 **0.018**	0.439 **0.049**	0.439 **0.049**	0.527 **0.014**	0.425 **0.045**	0.333 0.135	0.583 **0.009**
WSP Categ. 3	0.145 0.441	0.299 0.177	0.433 **0.050**	0.585 **0.006**	0.454 **0.031**	0.317 0.152	0.529 **0.017**
WSP Categ. 4	0.496 **0.009**	0.585 **0.008**	0.540 **0.015**	0.599 **0.005**	0.589 **0.005**	0.236 0.287	0.378 0.089

There is a correlation between WSP rating and good understanding of WSP as shown in Table 3-6. Good understanding of WSP is not included in the scoring system so this

correlation supports the usefulness of the scoring system and of course of the importance of well informed and positive staff. Good understanding gives significantly higher score in all categories of the rating system except Category 4, the support actions. There is also correlation between high WSP rating and mentioning the importance of having a good cooperation with the health authorities and local government. This indicates the importance of good cooperation between all stakeholders. Those who complained of poor support from senior management or the water board were more likely to have low scoring indicating the importance of support from management for success.

Generally it can be said that when the interviewees emphasised improved workmanship, better management, financial gain, improved competitiveness and better service to users as extra benefit of WSP there was a significantly higher scoring of WSP, indicating that when employees see multiple gain of having a WSP it will improve performance. There is no correlation between the duration of WSP and WSP scores, except for support actions, indicating that water utilities implement more support actions as time passes and more experience is gained. A long duration of WSP is also followed by more improvements in the system depicting that this is a step by step process.

3.4 Conclusions

In this study the effectiveness of WSP at sixteen water utilities in Iceland has been analysed. The analysis shows that the implementation has been beneficial for the water utilities. The study also reveals the difficulties in successfully installing a comprehensive system as well as in running and maintaining the WSP in a successful way. Based on the results from the analysis the following summary of recommendation might be useful for existing WSP users as well as for utilities that intend to implement a WSP system:

- Improve management of human resources. This includes: (1) provide intensive training during the implementation process and then with ongoing training plan; (2) include training in documentation; (3) secure participation of staff in the risk assessment and implementing process; (4) build up good utility culture among staff, e.g. in good workmanship; (5) encourage participation of staff in water sector activity and contact with colleagues in the water sector; (6) motivate staff and recognize in some way their contribution to secure public health in the community; and (7) recognize the importance of management support as essential for success.
- Secure improvements in running the WSP. This includes: (1) aim at having a simple WSP system with clear forms to fill out and work on improving and streamlining the WSP; (2) establish a WSP steering committee with a clear mandate; (3) improve and secure good documentation; (4) implement a scheduled improvement plan; and (5) perform a regular internal and external audit and recognize that audits are the backbone and driving force of successful WSP.
- Secure support and interest from outside stakeholders. This includes: (1) secure interest and support from water utility board and local government by stressing the importance of public health; (2) secure good cooperation with health authorities and encourage training of health officers in preventive management methodology; (3) improve communication to the public, for example with a website and public outreach stressing the importance of the quality of the water supply; and (4) provide information to the public on surveillance and new projects.

- Recognize that WSP is a process of continuous improvements, of implementing and adapting the utility to preventive management that can take some time.

Acknowledgments

4 Benefits of Water Safety Plans: Microbiology, Compliance and Public Health

Abstract

The Water Safety Plan (WSP) methodology, that aims to enhance safety of drinking water supplies, has been recommended by the World Health Organization since 2004. WSPs are now used worldwide and are legally required in several countries. However, there is limited systematic evidence available demonstrating the effectiveness of WSPs on water quality and health. Iceland was one of the first countries to legislate the use of WSPs, enabling the analysis of more than a decade of data on impact of WSP. The objective was to determine the impact of WSP implementation on regulatory compliance, microbiological water quality, and incidence of clinical cases of diarrhea. Surveillance data on water quality and diarrhea were collected and analyzed. The results show that HPC (Heterotrophic Plate Counts), representing microbiological growth in the water supply system, decreased statistically significant with fewer incidents of HPC exceeding 10 cfu per ml in samples following WSP implementation and non-compliance was also significantly reduced ($p<0.001$ in both cases). A significant decrease in incidence of diarrhea was detected where a WSP was implemented and furthermore, the results indicate that population where WSP has been implemented are 14% less likely to develop clinical cases of diarrhea.

Keywords: Water Safety Plan, drinking water, public health, water quality, water supply.

4.1 Introduction

The Water Safety Plan (WSP) methodology for ensuring the safety of drinking water supplies, with its approach to systematic preventive management and risk assessment, has been recommended by the World Health Organization (WHO) since its incorporation in the third-edition of the WHO Guidelines for Drinking Water Quality in 2004 and again in the fourth edition in 2011 (WHO, 2004; WHO, 2011). WSPs have become widely used and are incorporated into legal requirement for water utilities in several countries. However, systematic evidence for the effectiveness of WSPs in improving water quality and health is lacking and stakeholders recognize the need for research to strengthen the evidence base (CDC, 2011). In Iceland, the use of the WSPs by drinking water utilities was legislated in

1995 (Parliament of Iceland, 1995). Implementation has progressed steadily and by 2008 over 80% of the population was served by a water utility with a WSP (Gunnarsdottir et al., 2012a). The staggered implementation and long duration of WSP use in Iceland, as well as availability of water quality data and surveillance data on diarrhea in humans, provide a unique opportunity to evaluate systematically the impacts of WSPs on water quality and public health.

The WSP methodology is more comprehensive than conventional approaches to drinking water safety, addressing the whole water system from catchment to consumer with the goal of preventing contamination at each stage (Bartram et al., 2009). This is in contrast to conventional approaches to drinking water quality that focus primarily on ensuring that drinking water meets government standards for biological and chemical parameters with end-point testing. The WSP approach includes, for example, improved maintenance policies and procedures, systematic repair of pipes, cleaning plan (e.g. regular flushing of fire hydrants and cleaning of reservoir tanks) and improvements in the system (e.g. backflow prevention). Such interventions are expected to reduce microbial growth in the system, prevent infiltration of contaminants and result in safer water.

Iceland is a developed country with a population of 320 thousand inhabitants with well-run municipal water utilities and 100% piped drinking water supply(WHO/UNICHEF, 2010). Iceland is also one of the freshwater richest countries in the world, estimated at around 600 thousand m^3 per person per year (UNESCO-WWAP, 2006), with good access to quality groundwater. About 95% of the country's piped drinking water supply originates from groundwater. Groundwater is typically not treated prior to distribution unless there is a danger of surface water intrusion. Surface water (used by less than 5% of the population), and groundwater under direct influence of surface water, are typically treated by filtration followed by UV disinfection (European Environment Agency, 2010). Residual disinfection with chlorine or other disinfectants is not practiced in Iceland (Gunnarsdottir et al., 2012a). Local Competent Authority (LCA) is responsible for surveillance of drinking water protection and compliance. Legal requirements on protecting the sources of drinking water have been included in the Icelandic Drinking Water Regulation (IDWR) since 2001, obligating the LCA to define protection around water intakes. The Primary Health Care Centers (PHCCs) are required to collect and report data on diarrheal diseases to the Chief Epidemiologist at the Directorate of Health.

In 1995, Iceland became one of the first countries to legislate the use of WSPs (Parliament of Iceland, 1995); implementation began with Reykjavik Energy in the spring of 1997 (Gunnarsdottir et al., 2012a). Five years later, eleven utilities serving 63% of the population had implemented a WSP and by the end of 2008 thirty one utilities serving 81% had WSP in place (Gunnarsdottir et al.,2012a; Gunnarsdottir & Gissurarson, 2008). Preliminary evidence indicates that WSP implementation in Iceland has resulted in increased compliance with IDWR. A preliminary evaluation carried out in 2008 at two water utilities, City of Reykjavik and Akureyri town showed compliance increasing following WSP implementation, from 94% to 99% at Reykjavik and from 88% to 99% at Akureyri, respectively (Gunnarsdottir & Gissurarson, 2008). Research at sixteen water utilities in 2009 and development of a scoring system to evaluate performance of WSP showed that nine out of sixteen utilities got a satisfactory score, however the range in scoring was great (Gunnarsdottir et al., 2012a). Results from that research also indicated that the process of implementing a systematic preventive approach to water safety improved the utility culture regarding drinking water as a

public health issue. But the question of whether there are measurable benefits from having a WSP was unanswered.

Although waterborne disease is a much greater burden in developing countries, it is essential that the causes of both endemic and epidemic diarrheal disease from drinking water supply be addressed in wealthy countries like Iceland. There were 12 confirmed waterborne disease outbreaks in Iceland between 1984 and 2011. Six were due to *Campylobacter* and six to norovirus (Geirsdottir, 2011). The last confirmed outbreak was in 2004 and at least one contamination event has been confirmed since 2004 but was not associated with adverse health impacts (HAUST, 2010). All of these outbreaks were at small water utilities. However, absence of detected outbreaks of disease is not a reason for complacency (WHO, 2004; Payment et al., 1997; Payment & Hunter, 2001) as endemic and sporadic cases of gastrointestinal illness and small waterborne outbreaks can be undetected by surveillance systems (Craun et al., 2006). Research also indicates increased risk for gastrointestinal illness during pressure loss in a distribution system. A cohort-study among recipients of water from seven larger water utilities in urban areas in Norway during the years 2003-04 showed that breaks and maintenance work in the distribution systems was associated with an increased risk for gastrointestinal illness among water recipients (Nygaard et al., 2007); and a similar study in England and Wales showed a strong association between self-reported diarrhea and reported low water pressure at the faucet (Hunter et al., 2005). These examples indicate that addressing health risk from drinking water in developed countries requires an approach like WSPs that can address risk at all stages of supply, particularly in the distribution system, and establish appropriate procedures for maintenance and operation.

The aim of this study was to determine the impact of WSP implementation on: a) regulatory compliance; b) microbiological water quality; and c) incidence of clinical cases of diarrhea, using comprehensive surveillance data.

4.2 Materials and methods

4.2.1 Design of study

The design of this study is an observational retrospective cohort study. The uptake areas without WSP were considered risk exposed (non-intervention) and the uptake areas with WSP were non-risk exposed (intervention). The following indicators were compared in water utilities before and after implementing WSP: 1) percentage of annual compliance with drinking water regulation in Heterotrophic Plate Counts (HPC), Total coliform and *E. coli* bacteria; 2) the number of colony forming units (cfu) by HPC in water; and 3) incidence of diarrhea per 1000 inhabitants per month.

For 1) and 2) five utilities were chosen for analysis of water quality and compliance data based on the following criteria: a) available data for water quality and compliance; b) at least two full years of data with and two full years of data without WSP; and c) at least 100 regular water quality compliance samples reported during the study period.

For 3) the inclusion criteria for the PHCCs were: a) data availability of reported monthly number of cases of diarrhea during the study period (defined below); b) that the entire population in the uptake area for the PHCC had received piped drinking water from a single water utility; and c) the geographic boundary of service for the PHCC was stable over the

period of study (e.g. two community clinics were not consolidated into one during the study period). These criteria eliminated 42 of the 60 PHCCs, leaving 18 for inclusion in the study, whereof 7 could be tested for before and after WSP.

4.2.2 Data collection for water quality

Regular monitoring of microbiological and chemical parameters is carried out according to Icelandic Drinking Water Regulation (IDWR) (Ministry for the Environment, 2001a) and the European drinking water directive (European Council, 1998) at all water utilities over a certain size (> 50 users) with frequency of sampling according to population. To be in compliance with IDWR the HPC in a water sample must contain less than 100 cfu per ml at 22°C and zero value for both Total coliform and *E. coli* in 100 ml.

Data for compliance of HPC, Total coliform and *E. coli* were collected from five water utilities, either from the LCA or from the utility, where sufficient data and period before and after WSP implementation were available. Results from 1562 regular monitoring samples were included. Repeated monitoring that was carried out because of deviation incidence, real or suspected, and monitoring after complaints from users were excluded to increase conformity between cases and avoid bias. The five water utilities serve around 24% of the population of Iceland. WSP were implemented in the five water utilities between 1998 and 2007 and data on water quality extended from 8 up to 13 years before implementation and 3 to 10 years after. Time of implementation was based on the month when the WSP was certified by the LCA. In some of the water utilities the frequency of sampling was reduced as regulatory compliance improved, as permitted in the IDWR since 2001. Scope of data available for the five water utilities as well as the periods before and after WSP implementation is shown in Supporting Information in Tables 4-4 and 4-8. In no case were electronic data available. In subsequent analysis the water utilities are labeled with V followed by a number for simplification and in order to keep them anonymous.

4.2.3 Data collection on diarrhoea in humans

The Chief Epidemiologist for Iceland at the Directorate of Health is responsible for maintaining a register of communicable diseases according to Act no. 19/1997 on Health Security and Communicable Diseases. Diarrhea is a notifiable disease with monthly reporting of number of cases from the PHCCs to the Chief Epidemiologist. The reporting is based on the International Classification of Diseases (ICD-10) (WHO, 2007) for standard diagnostic classification of diseases, which is used almost for the entire health care in Iceland. For every patient seeking health care one or more ICD-10 codes are selected by the physician and entered into each patient record. For this study data from the monthly reporting for the two following ICD-10 codes representing diarrhea were selected and collected from the Chief Epidemiologists register on communicable diseases:

- A09 - Diarrhea and gastroenteritis of presumed infectious origin.
- A05 - Other bacterial food-borne intoxications, not elsewhere classified.

These codes are notifiable without personal identification. All data available from individual PHCCs on the above ICD -10 codes were collected from January 1997 to the end of 2009. Over the thirteen year (156 month) period of the study, the total number of clinic-months of data available were 2408 (see Supporting Information Table 4-5). Delivery of data for these eighteen PHCCs was approximately 90%. Non-conformity and missing data were observed at each PHCC and rectified with the help of Chief Epidemiologist and regional or local PHCC if

possible. Adequate data on diarrhea in humans were available for PHCCs with uptake areas served by seven water utilities before and after the implementation of WSP; of these two also provided adequate water quality data. The seven water utilities are sufficiently localized so minimal commuting exist between the service areas. Additionally, data for eleven PHCCs were collected; four had an uptake area served by water utilities with a WSP during the entire study period and seven had uptake areas that were served by water utilities without a WSP at any time during the study period. The uptake areas for these eighteen PHCCs covered approximately 38% of the population of Iceland. Scope of data and population for the PHCCs where data on diarrhea were obtained is shown in Supporting Information in Table 4-5 and Table 4-8.

Data on population in the uptake areas for the PHCCs were obtained from the website of Statistics Iceland (Statistics Iceland, 2011) and from the Administration Office of PHCC in the Capital Area. The population served by the PHCCs is generally connected to postal codes in the uptake areas; one exception is in the capital area where people can more easily choose between PHCC. There are nineteen PHCCs in the greater capital area, five of which were included in this study.

4.2.4 Testing for confounders and strength of the data

Correlation test between diarrhea and pneumonia was conducted at three PHCCs (V1, V16 and V17). The three PHCCs selected had significant difference in incidence of diarrhea before and after WSP implementation and sufficient months of data that coincided. The correlation test examines other factors than WSP that could affect these diseases simultaneously, such as changes in definitions or methods for reporting/registering. Pneumonia was selected as it is a common disease, which is notifiable to the Chief Epidemiologist and reported in the same way as diarrhea using the ICD-10 codes J12 to J18, with sub-codes for pneumonia. While associated with water supply through the impact of water availability on hygiene there is no evidence to suggest an association of pneumonia with water quality.

In addition the correlation between interventions in water utilities and diarrhea incidence was investigated. This was assessed by testing the correlation between the WSP scoring of sixteen water utilities, and the diarrheal incidence in the PHCCs uptake areas that the water utilities were serving. Ten of the water utilities had implemented a WSP and were rated according to the WSP scoring system reported in a previous study[5] and six were without WSP and were given a score of zero. Surveillance data on diarrhea from the Chief Epidemiologists register were available for all PHCCs uptake areas served by these sixteen water utilities. In the Supporting Information data availability is given in Table 4-6.

4.2.5 Statistical analysis

Statistical analysis was conducted with SPSS 19. For all datasets, mean, median, 5th and 95th percentiles and range was calculated before and after WSP implementation. Statistical significance was set as two tail and at 5% (p=0.05).

The binary logistic regression test was used when analyzing the relative frequency of two possible outcomes (e.g., compliance vs. non-compliance). It tests if non-compliance to drinking water regulation in the parameters HPC, Total coliform and *E. coli* was significantly more frequent before than after WSP implementation. The binary logistic regression test was also used to examine if there was difference in HPC before and after the WSP implementation; this comparison was based on an HPC concentration of 10 cfu per ml.

When analyzing the difference in numerical values (e.g., bacterial concentration or diarrheal incidence), two tests were used: the t-test was used for parametric analysis and the Mann-Whitney U test for non-parametric analysis.

Univariate two-way ANOVA test was used to compare diarrheal incidence before and after WSP implementation in all seven PHCCs. The difference in mean before and after WSP implementation at each of the seven PHCCs was then tested with a post-hoc t-test. To adjust for multiple comparisons, the Bonferroni correction was used; accordingly, the significance level was divided by number of tests conducted (n=7) p=0.00714 (0.05/7). For the supporting evidence of correlation between; diarrhea and pneumonia a non-parametric Kendall`s tau test was used, and Persons correlation for WSP scoring and incidence of diarrhea.

4.3 Results

4.3.1 Compliance with drinking water regulation

Surveillance data for drinking water showed a decrease in non-compliance with IDWR requirements following WSP implementation (p<0.001) as shown in Table 4-1. Mean annual non-compliance declined following implementation of a WSP at four of the five water utilities investigated, as shown in Figure 4-1. Mean non-compliance across all five utilities declined approximately 80% (from 7.7% of samples to 1.5%).

Table 4-1 Results from binary logistic regression test for water quality (n=1562)

	B	S.E.	Wald	df	Sign.	Odds ratio	95% C.I. Lower	Upper
Non-compliance	1.315	0.280	22.056	1	.000	3.725	2.152	6.448
HPC > 10 cfu per ml	0.789	0.127	38.340	1	.000	2.202	1.715	2.827
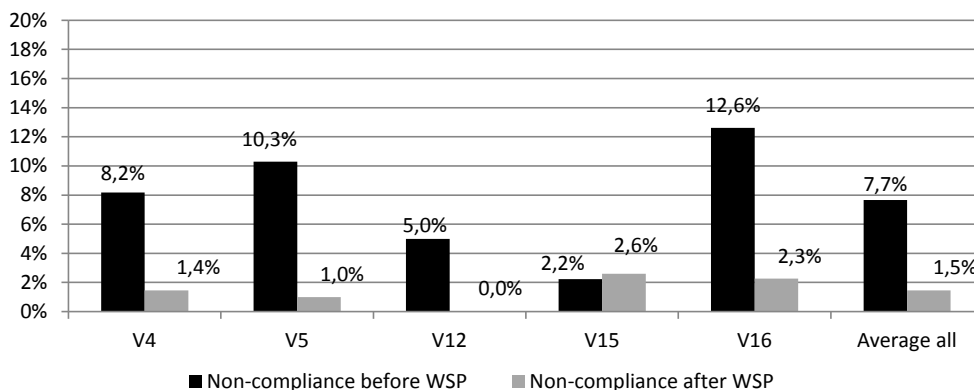
Figure 4-1 Mean annual non-compliance with IDWR at five water utilities before and after WSP

Non-compliance can result from a violation in any or all of the three following parameters: HPC, Total coliform or *E. coli* bacteria (as described in Methods and Materials). The total number of incidents of non-compliance decreased from 85 (out of 955 samples) before WSP implementation down to 16 (out of 607 samples) after WSP in all five water utilities combined. HPC violations were the most common cause of non-compliance, both before and after WSP implementation; see Table 4-9 in Supplementing Information for details.

According to IDWR water samples should be obtained at both the source (e.g., at the borehole or a well from which groundwater is pumped) and from the piped distribution system. For the 1562 samples 33% were taken at the source and 67% from the distribution network. Samples from the source were in compliance more often than those from the distribution network. Non-compliance at the source reduced from 4.8% to 2.3% following WSP implementation while the reduction was from 10.7% to 2.8% in the distribution network.

4.3.2 HPC in drinking water

In Figure 4-2 HPC is plotted for the five utilities before and after WSP implementation. The figure shows that number of HPC that were above the upper cut-off level 10 cfu per ml at all five utilities, decreased following a WSP implementation. A binary logistic regression test showed that the decrease was significant ($p<0.001$) as shown in Table 4-1.

Table 4-2 shows that the median is higher before than after WSP implementation at all water utilities except at V15, although at V15 there were only 2 non-compliance before WSP (during 8 years) and 2 after WSP (during 7 years) and low HPC both before and after WSP, yielding unreliable results. However the difference in the median is only significant for two of the five utilities, V5 and V16, according to non-parametric test. Table 4-2 shows also that when all sample results were combined, and also when samples at the source and in the distribution system were compared separately, the median HPC was significantly lower after WSP implementation (p<0.001 for all three comparisons).

41
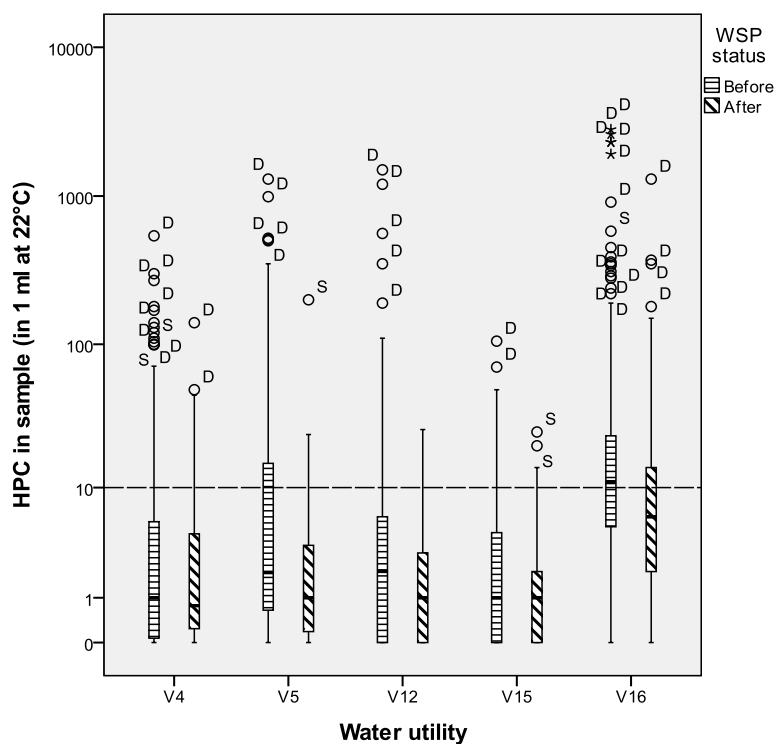
Figure 4-2 Boxplot of HPC before and after WSP implementation at five water utilities showing sampling site of outliers (S=water source, D=distribution network). The broken line shows 10 HPC in samples.

Table 4-2 provides detailed information on HPC bacteria in samples taken before and after WSP implementation at the five water utilities. A significant decline in median HPC bacteria following WSP implementation was found overall, at the source and in the distribution system. Additionally, HPC concentrations were more consistent following WSP implementation, with a decreased range and a decrease of the 95th percentile value as can be seen in Table 4-2. Most outliers were recorded before WSP implementation and more often in the distribution network than at the source as can be seen in Figure 4-2.

Table 4-2 Statistical summary of HPC in water samples at five water utilities before and after WSP

Water-utilities	Status	No. of water samples	Mean*	Median*	Percentiles* 5th, 95th	Range* min, max	P_non-param. 2 tail
V4	Before WSP	159	19.7	1	0, 121.5	0, 540	0.617
	After WSP	96	5.4	0.8	0, 21.0	0, 140	
V5	Before WSP	250	33.0	2	0, 146.7	0, 1300	0.001
	After WSP	103	5.1	1	0, 18.8	0, 200	
V12	Before WSP	100	45.0	2	0, 206.0	0, 1500	0.104
	After WSP	35	3.7	1	0, 21.3	0, 26	
V15	Before WSP	51	7.5	1	0, 57.4	0, 105	0.082
	After WSP	78	2.2	1	0, 13.1	0, 25	
V16	Before WSP	395	61,2	11	1, 182	0, 2800	<0.001
	After WSP	295	21.4	6	1, 84.6	0, 1300	
All samples	Before WSP	955	42.3	5	0, 144.0	0, 2800	<0.001
	After WSP	607	12.6	3	0, 45.0	0, 1300	
All samples at source	Before WSP	294	16.0	2	0, 74,4	0, 580	<0.001
	After WSP	218	6.7	1	0, 21.0	0, 200	
All samples in distribution network	Before WSP	657	54.0	6	0, 181.0	0, 2800	<0.001
	After WSP	393	15.9	4	0, 54.3	0, 1300	

*cfu/ml: HPC colony forming units per milliliter in water sample

4.3.3 Incidence of diarrhoea

Figure 4-3 and Table 4-3 show the difference in diarrheal incidence before and after WSP implementation. The mean incidence of diarrhea for all the surveillance data set studied here, which covers about 38% of the population of Iceland, is 1.7 per 1000 inhabitants per month or 0.02 per person year as shown in Supporting Information Table 4-7. When data from all seven PHCCs were combined, univariate two-way ANOVA indicated an overall significant reduction of diarrheal incidence ($F_{(1,982)}$ =232, $p<0.001$, η_p^2=0.19); this test also indicated that there was a significant interaction between PHCC and WSP status (e.g., that the difference in diarrheal incidence varied between PHCCs) (F $_{(6,982)}$ =53, $p<0.001$, η_p^2=0.24). Diarrheal incidence was significantly reduced at five out of seven PHCCs (Table 4-3); this finding was confirmed using the Bonferroni correction to account for the problem of multiple comparisons (tested at significance level α/n of $p<0.00714$).
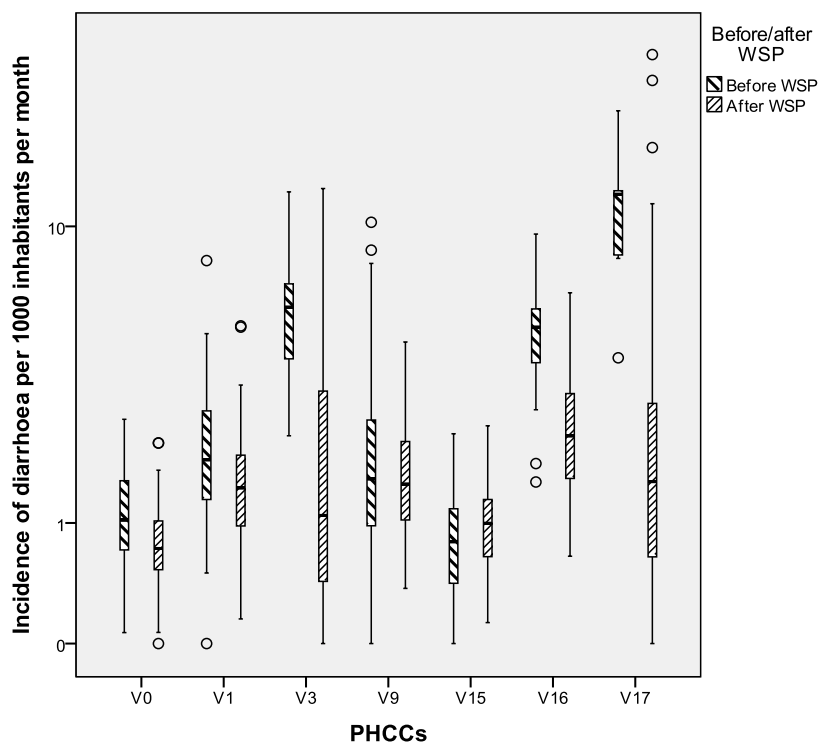
Figure 4-3 Incidence of diarrhea before and after WSP at seven PHCCs

Table 4-3 Statistical summary of incidence of diarrhea per month per 1000 inhabitants at seven PHCCs before and after WSP

PHCCs	Status	No. of months with data	Mean*	Median*	Percentiles* 5th, 95th	Range*	$p_{post-hoc}$
V0	Before WSP	68	1.12	1.04	0.30, 2.13	2.56	<0.001
	After WSP	87	0.84	0.73	0.25, 1.66	2.17	
V1	Before WSP	48	2.16	1.88	0.50, 4.76	8.04	0.005
	After WSP	93	1.59	1.45	0.49, 2.78	5.06	
V3	Before WSP	17	6.01	5.91	2.30, 10.99	10.11	<0.001
	After WSP	103	2.15	1.09	0, 7.27	12.67	
V9	Before WSP	117	2.07	1.58	0.29, 5.95	10.26	0.362
	After WSP	32	1.76	1.50	0.46, 4.55	4.29	
V15	Before WSP	53	0.84	0.80	0.10, 2.12	2.34	0.056
	After WSP	80	1.02	1.00	0.27, 2.05	2.37	
V16	Before WSP	34	5.22	5.16	1.74, 9.40	7.99	<0.001
	After WSP	116	2.48	2.30	1.06, 4.50	5.86	
V17	Before WSP	21	11.19	12.22	4.57, 20.00	16.21	<0.001
	After WSP	127	2.59	1.54	0, 7.61	28.52	
All	Before WSP	358	2.74	1.60	0.30,9.37	20.37	<0.001
	After WSP	638	1.88	1.37	0, 4.90	28.52	
Sum		1992					

* Monthly incidence of diarrhea per 1000 inhabitants served by the PHCC

Table 4-7 in the Supporting Information shows diarrheal incidence for both those groups of PHCCs that experienced a change in WSP status during the study and those with and without WSP for the entire study period; both the mean and the median rate of diarrhea were lower when WSP were in use and 95% percentile was reduce by half.

4.3.4 Confounders and strength of the data

It was hypothesized that decreases in diarrheal incidence over time could possibly be attributable to changes in the Iceland health care system or broader improvements in population health. To test whether the decline in diarrhea was not attributable to these factors, but rather to WSP implementation, data for pneumonia for three PHCCs were collected as a control variable. A non-parametric correlation test between pneumonia and diarrhea for these three PHCCs did not show significant relation between the rate of the two diseases (V1: r=0.094, p=0.119, n=129; V16: r=0.053, p=0.363, n=135; V17: r=-0.053, p=0.377, n=144),

providing further evidence that the reduction in diarrheal incidence was attributable to WSP implementation.

Figure 4-4 shows the incidence of diarrhea as a function of WSP scoring for sixteen water utilities for 2009 (Gunnarsdottir et al., 2012a). The figure shows a trend suggesting a lower incidence for water utilities with high WSP score, but the trend is not significant according to parametric test (r= - 0.443, p=0.086, n=16).
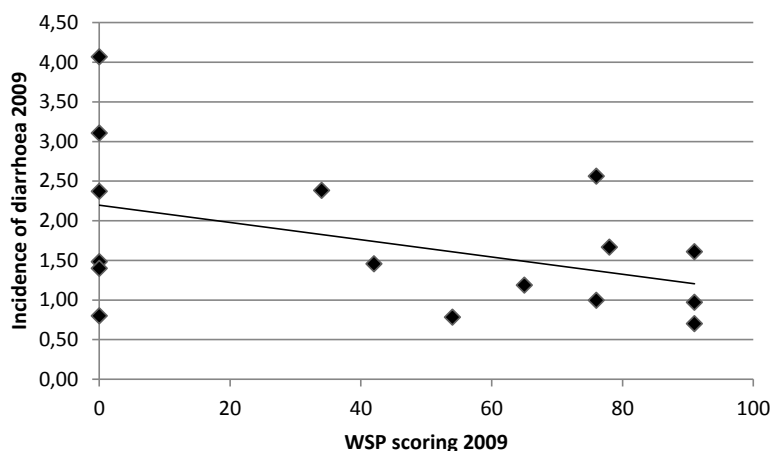
Figure 4-4 Incidence of diarrhea per 1000 inhabitant per month versus WSP scoring at 16 water utilities, Iceland, 2009

4.4 Discussion

This study provides systematic evidence of the positive impacts of WSPs on drinking water quality and health. These data indicate that WSP implementation in Iceland resulted in substantial and measurable reductions in drinking water non-compliance, amount of HPC in water (both at the source and in the distribution system) and incidence of diarrhea in communities served by utilities implementing WSP.

The strength of the study is that it covers a large proportion of a national population: well over one third of the population for diarrhea incidence and nearly one fourth for water quality. Therefore, there is a substantial amount of data behind the results. The uniformity of the Icelandic society, both socially and culturally is a further strength. Additionally, both consumers and health workers were unaware of the WSP implementation and were therefore effectively blinded to the intervention. These results are further supported by the fact that there is no correlation between incidence of diarrhea and pneumonia, indicating that the findings on diarrheal disease incidence were not influenced by broader trends in the Icelandic health care system. Using a previous analysis that scored the strength of WSP implementation at various utilities in Iceland revealed a possible correlation between better functioning WSP and lower diarrheal incidence; however, limited data were available and the trend was not statistically significant.

There were some limitations that could have influenced the results obtained. There was some non-conformity in delivering and recording data from the PHCCs into the national surveillance system. There was a variation in how the physicians use the ICD-10 codes, different physicians use different ICD-10 codes for same diseases and symptoms. Additionally physicians change frequently in some areas while in others there was greater staffing stability. To control for this potential bias, data from all PHCCs were reviewed in detail and additional data were pursued if they were abnormal or large gaps. If these gaps could not be rectified, the associated PHCC was left out of the analysis. In addition to this, usual disadvantages of an ecological study apply, such as lack of control for confounding factors (partly addressed with the comparison with pneumonia in result section), and the study addresses population, as data on individuals was not available.

The mean incidence of diarrhea for the surveillance data set studied here is 1.7 per 1000 inhabitants per month with sample variance of mean 4.5 and range 28.52. This gives 0.02 per person per year, but the proportion seeking medical care and the true incidence of diarrhea in the community is not known in Iceland. Cross-sectional telephone surveys in Australia, Canada, Ireland and United States found that approximately one in five with diarrhea sought medical care (Scallan et al., 2005). A similar result is reported from a study in Norway, with 17% consulting a physician (Kuusi et al., 2003). If the situation is similar in Iceland it could be concluded that incidence of diarrhea in Iceland is around 0.10 per person per year. This is low compared to other countries, for example in Norway the rate is 1.2 per person year (Kuusi et al., 2003); in Ireland 0.44 per person year, 0.83 in Australia and 0.99 in Canada and United States (Scallan et al., 2005). FoodNet in USA has estimated a rate of 0.65 per person year of acute gastrointestinal illness based on 33 studies (Roy et al., 2006). There is insufficient information to enable estimation of the global burden of water-borne disease, which has proven complex because of the complex relationships among sources of hazards and routes of transmission. Estimates suggest that 6.6% of the total global burden of disease (measured in Disability-adjusted Life Years or DALYs) could be prevented through well-recognized interventions in drinking-water supply and quality, sanitation and hygiene (Bartram & Cairncross, 2010; Pruess-Ustun et al. 2008). Hunter et al. (2005) concluded that up to 15% of gastrointestinal illness in the United Kingdom could be associated with contamination of drinking water in the distribution system. Colford et al. (2006) estimated attributable risk percent (AR%) of acute gastrointestinal illness to drinking water by reviewing five household drinking water intervention trial, two in Canada, two in USA and one in Australia, with the median estimate of AR% of 12%. The US Environmental Agency (EPA) has estimated the mean incidence of acute gastrointestinal illness attributable to drinking water to be 8.5% of all cases in the population served by community water system (Messner et al., 2006). The median value of incidence of diarrhea between the seven PHCCs before and after WSP (shown in Table 4-7 in the Supporting Information) obtained in the present study, yields a conservative estimate of AR% of about 14% for Iceland, which can be attributed to drinking water and cause endemic or sporadic cases of diarrhea.

Residual disinfection is not used in Iceland, due to high availability of good quality groundwater, which provides insight into what happens in the distribution system. Non-compliance was higher in the network than at the source and the main decrease of HPC following WSP implementation was in the network. This indicates that it may be possible to keep water safe by preventing contamination and bacterial growth in the pipe network rather than with disinfection. In some countries in Northern Europe disinfection of drinking water with chlorine is not used or used in a limited way. These are countries, where the dominant source is groundwater as in Iceland, such as the Netherlands, where chlorine is not used at all,

neither for primary disinfection or to maintain a residual disinfectant in the network (Smeets et al., 2009), and Denmark where most systems are not chlorinated (Neimann et al., 2003). The reason for higher non-compliance in the distribution network than at the source in this study could be the fact that water and sewage pipes are most often in the same ditch. In all pipe system there are some leaks and soil will become contaminated around sewage pipes. A common theory is that this contamination does not enter the water pipes if sufficient internal pressure is maintained in the water pipe system. But some pressure events may cause low or negative pressure that result in intrusion of pathogens (LeChevallier et al., 2003; Teunis et al., 2010; Besner et al., 2011). These events can be because of pipe break, pump shutdown or sudden increase in water demand. They can be short-lived and still cause many incidents and that risk is greater where there is no residual disinfection.

The results from this study show significant benefit from WSP implementation in the form of improved regulatory compliance to drinking water standard, water quality and reduced disease risk. It indicates that there are measureable benefits from implementing water safety plan in water utilities. The general conclusion of the study is that WSP is an important instrument in improving water quality and reducing the occurrence of waterborne illnesses and as such improves public health.

Acknowledgements

4.5 Supporting Information

Table 4-4 Scope of data for HPC and compliance at five water utilities

Water utilities						Total
Entire study period in no. years	17	12	23	18	24	94
No. of years before WSP	9	9	11	8	14	51
No. of years after WSP	8	3	12	10	10	43
Total no. of samples	129	135	255	690	353	1562
No. of samples before WSP	51	100	159	395	250	955
No. of samples after WSP	78	35	96	295	103	607

Table 4-5 Scope of data on diarrhoea from 1997 to 2009 (from 1998 in comparison two)

			Number of PHCCs	Population served in year 2009 Sum (range)	Available data on diarrhea 1997-2009 no. of months
Comparison	one	Before implementing WSP	7	59,957 (1,573-19,942)	358
		After implementing WSP			638
Comparison	two	Without WSP the entire study period	7	23,727 (625-17,554)	895
		With WSP the entire study period	4	36,581 (4,086-12,24)	517
Sum			18	120,265	2408

Table 4-6 Scope of data for testing for confounders and strength of the data

	Number
Data on diarrhea versus incidence of pneumonia	
Number of PHCCs	3
Number of months including both pneumonia and diarrhea data	277
Data on diarrhea versus WSP scoring in year 2009	
Number of PHCCs/ water utilities	16
With WSP	10
Without WSP	6
Available data months January to December 2009	190

Table 4-7 Statistical summary of incidence of diarrhoea at eighteen PHCCs

PHCCs combined		No. month data	Mean*	Median*	Percentiles* 5th and 95th	Range*
Comparison one	All 7 PHCCs before WSP	358	2.74	1.60	0.30, 9.37	20.37
	All 7 PHCCS after WSP	638	1.88	1.37	0, 4.90	28.52
Comparison two	All 7 PHCCs without WSP	895	1.63	1.23	0, 5.16	16.78
	All 4 PHCCS with WSP	517	0.94	0.80	0.11, 2.25	4.29
Total 18 PHCCs		2408	1.71	1.16	0, 5.35	28.52

*Incidence of diarrhea per 1000 inhabitants per month

Table 4-8 Overview of health and water quality data and results

PHCCs or utility	Population 2009‡	Water source	Treatment type	Implement. duration Months	Incidence of diarrhoea - without WSP PHCCs without WSP					Incidence of diarrhoea with WSP PHCCs with WSP					Water Quality Result before WSP Non-compliance†				HPC before WSP			Water Quality Result with WSP Non-compliance†				HPC after WSP		
					Year	Months	Mean	Median	Range	Year	Months	Mean	Median	Range	Years	Sampl.	n-compl	%n-comp	Mean	Median	Range	Years	Sampl.	n-compl	%n-comp	Mean	Median	Range
V101*	12000	Ground		6						12	143	0.583	0.511	2.042														
V102*	10000	Ground		6						12	117	1.201	1.118	3.859														
V103/V4	11000	Ground		12						12	133	0.926	0.788	4.289	11	159	16	8.18%	19.7	1	540	12	96	2	1.45%	5.4	0.8	140
V104	4000	Ground		NK						12	126	1.146	0.935	3.615														
V201	18000	Ground		NA	12	126	1.283	1.234	3.382																			
V202	1000	Ground		NA	12	138	1.036	1.000	6.211																			
V203	1000	Surface	Filtr & UV	NA	12	123	2.512	1.998	14.317																			
V204	1000	Surface	Filtr & UV	NA	12	136	1.287	1.332	6.150																			
V205	1400	Surface	Filtr & UV	NA	12	102	1.917	1.403	7.161																			
V206	1000	Surface	Filtr & UV	NA	12	131	2.455	1.395	16.783																			
V207	1500	Ground		NA	12	139	1.084	0.678	8.500																			
V0	15000	Ground		NK	13	68	1.12	1.04	2.56	8	87	0.84	0.73	2.17														
V1*	7000	Ground		6	13	48	2.16	1.88	8.04	10	93	1.59	1.45	5.06														
V3*	2000	Ground		9	13	17	6.01	5.91	11.11	11	103	2.15	1.09	12.67														
V9*	4000	Ground		18	13	117	2.07	1.58	10.26	3	32	1.76	1.5	4.29														
V15*	10000	Ground		18	13	53	0.84	0.8	2.34	8	80	1.02	1	2.37	9	51	2	2.22%	7.5	1	105	8	78	2	2.60%	2.2	1	25
V16*	20000	Ground		18	13	34	5.22	5.16	7.99	11	116	2.48	2.3	5.86	8	395	40	12.61%	61.2	11	2800	10	295	11	2.22%	21.4	6	1300
V17	1600	Ground		NK	13	21	11.19	12.22	16.21	12	127	2.59	2.59	28.52														
V5*	29000	Ground		24											14	250	21	10.29%	33	3	200	10	103	1	1.00%	5.1	1	200
V12*	7000	Ground		3											9	100	6	4.99%	45	2	1500	3	35	0	0.00%	3.7	1	26
All	157500					1253	2.870				1157	1.481				955	85	7.68%	33.280				607	16	1.46%	7.560		

* Part of the research on WSP at 16 water utility (Gunnarsdottir, Gardarsson, Bartram, 2012)

‡ Ca. 49% of the Icelandic population in 2009 (157500/332000).

† Percentage of non-compliance is the average of annual compliance

NK = not known

NA = not actual

Table 4-9 Incidents of non-compliance at source, in distribution network and all before and after WSP

At source before WSP

	No. samples	Non-compliance			
		HPC	T.colif	E.coli	All*
V4	32	2	0	0	2
V5	101	0	0	0	0
V12	15	0	0	0	0
V15	19	0	1	1	1
V16	127	7	5	3	11
SUM	294	9	6	4	14

In distribution network before WSP

	No. samples	Non-compliance			
		HPC	T.colif.	E.coli	All*
V4	127	11	4	2	14
V5	149	19	2	0	21
V12	85	6	1	0	6
V15	32	1	0	0	1
V16	268	21	8	6	29
SUM	661	58	15	8	71

All before WSP

	No. samples	Non-compliance			
		HPC	T.colif.	E.coli	All*
V4	159	13	4	2	16
V5	250	19	2	0	21
V12	100	6	1	0	6
V15	51	1	1	1	2
V16	395	28	13	9	40
SUM	955	67	21	12	85

At source after WSP

	No. samples	Non-compliance			
		HPC	T.colif	E.coli	All*
V4	31	0	0	0	0
V5	40	1	0	0	1
V12	6	0	0	0	0
V15	72	0	1	1	1
V16	69	2	1	0	3
SUM	218	3	2	1	5

In distribution network after WSP

	No. samples	Non-compliance			
		HPC	T.colif.	E.coli	All*
V4	65	1	1	0	2
V5	63	0	0	0	0
V12	29	0	0	0	0
V15	6	0	1	1	1
V16	226	8	0	0	8
SUM	389	9	2	1	11

All after WSP

	No. samples	Non-compliance			
		HPC	T.colif.	E.coli	All*
V4	96	1	1	0	2
V5	103	1	0	0	1
V12	35	0	0	0	0
V15	78	0	2	2	2
V16	295	10	1	0	11
SUM	607	12	4	2	16

* All does not have to be the sum of non-compliance as sometime HPC and coliform do coinside

5 Microbial contamination in groundwater supply in cold climate and coarse soil: Case study of norovirus outbreak at Lake Mývatn, Iceland

Abstract

This paper explores the fate and transport of microbial contamination in cold climate and coarse aquifers. A confirmed norovirus outbreak in small rural water supply late summer of 2004, which is estimated to have infected over 100 people, is used as a case study. A septic system, 80 m upstream of the water intake, is considered to have contaminated drinking water. Water samples tested were negative for coliform and strongly positive for norovirus. A modeling predicts that a 4.8-$\log_{10}$ removal was possible in the 8 m thick vadose zone, while only a 0.7-$\log_{10}$ and 2.7-$\log_{10}$ removal in the aquifer for viruses and *E. coli*, respectively. The model results support that the 80 m setback distance was inadequate and roughly 900 m aquifer transport distance was needed to achieve 9-$\log_{10}$ viral removal. Sensitivity analysis showed that the most influential parameters on model transport removal rate are grain size diameter and groundwater velocity, temperature and acidity. The results demonstrate a need for systematic evaluation of septic systems in rural areas in lesser studied coarse strata at low temperatures and thereby strengthening data used for regulatory requirement for more confident determination on safe setback distances.

Keywords: norovirus outbreak; septic system; groundwater; microbial transport, coarse soil.

5.1 Introduction

Availability and access to safe drinking water are critical components of public health. Groundwater resources are generally considered to be the safest for drinking water supplies because of the protected layer of soil above the aquifer. The soil has a natural ability to filtrate out water pollution and therefore disinfection is generally not conducted in groundwater supplies serving rural communities. Yet, groundwater resources are vulnerable to sewage pollution, stemming from septic tanks, broken sewer lines and land application of sewage effluent (Woessner et at., 2001; Kvitsand & Fiksdal, 2010).

Drinking water contamination, leading to waterborne diseases, is a recurrent event worldwide. A recent study established that more than one out of every three waterborne outbreaks in affluent nations was caused by sewage contamination in groundwater (Hrudey and Hrudey, 2004; 2007). Generally, multiple mechanisms were found to have contributed to the outbreaks and adverse conditions had often been in place for a long time (Hrudey and Hrudey, 2007). In addition, evidence of sporadic incidence of waterborne diseases is also appearing (Payment et al., 1997; Payment and Hunter, 2001; Calderone and Craun, 2006; Colford et al., 2006; Craun et al., 2006).

Half of the world's population lives in rural areas and many rely on septic systems (WHO/UNICEF, 2010). In the USA over 20% of households are served by septic systems (Motz et al., 2012) and in Europe around 30% of the population lives in rural areas and many use septic system for disposal of wastewater effluent (WHO/Unicef, 2010). At the same time, 10% of Europeans rely on small and very small water supply for drinking water (Hulsmann, 2005). This widespread use of septic tanks can pose a significant threat to groundwater supplies. This risk is especially great in rural communities, which rely on untreated groundwater for drinking water supply. Therefore, it is imperative to protect groundwater resources, and provide easily adapted guidelines for local rural communities, such as safe setback distances. However, this approach is not without challenges, as the determination of safe setback distances requires a thorough knowledge of local strata and groundwater properties.

Many factors are known to influence the fate and transport of microorganism in groundwater aquifers. A recent literature review suggests that pumice sand may be the most efficient soil type in removing microorganisms (Pang, 2009). Specifically, the low pH often present in such soils and high surface areas contribute to the sorption of microbes to the solids. Pang et al. (2003) concluded from laboratory experiments and groundwater modeling that a 48 m setback distance was enough to meet the Drinking Water Standards of New Zealand 2000 for enteric viruses in pumice sand aquifers (pH ~ 7) with groundwater speeds <7 m/day. This distance was estimated to allow for 10-$\log_{10}$ removal of viruses. However, this setback distance was established in uncontaminated aquifers. Wall et al. (2008) suggest that viral removal may be significantly lower in contaminated pumice sand aquifers compared with uncontaminated, leading to greater setback distances. Furthermore, viruses are known to be highly persistent and travel long distances in groundwater, and more so

in cold water (Yates et al., 1985;WHO, 2004; Pedley et al., 2006; Borchardt et al. 2011).

Until recently, limited research has been conducted on microbial transport in cold water in highly permeable coarse aquifers although such conditions are common (DeBorde et al., 1999, Woessner et al. 2001, Kvitsand and Fiksdal, 2010). Icelandic water supplies provide a good basis for such studies, both because they serve 95% of the population and many of them are located in the active volcanic zone with basaltic lava with high permeability (Sigurdsson and Sigurbjarnarson, 1985) and temperature usually between 3-6°C (Sigurdsson and Einarsson, 1988). Groundwater is not treated unless there is a danger of surface water intrusion. Ultraviolet (UV) irradiation treatment together with filtration is practiced in Iceland, while residual disinfection is not (Gunnarsdottir et al., 2012b). Although Iceland is sparsely populated country and the water supplies are generally considered safe, twelve confirmed waterborne disease outbreaks have occurred in the last three decades, all at small water utilities, whereof, six were due to *Campylobacter* and six to norovirus (Geirsdottir, 2011). The last confirmed outbreak was in 2004 and at least one contamination event has been confirmed since 2004 but was not associated with adverse health impacts (HAUST, 2010). Some of the largest of these outbreaks were in groundwater supply systems where contamination originated from septic systems.

The goal of this research was to explore the fate and transport of microbial contamination in cold climate and coarse aquifers. The 2004 norovirus outbreak in rural Lake Mývatn area, which involved a large number of disease cases and the first time norovirus was detected in drinking water in Iceland (Atladottir, 2006), was used as a case study. A thorough literature search on the local conditions at Lake Mývatn, combined with groundwater model simulations, was used to explain why the outbreak occurred. Model results were compared to observed viral removal rates from a collection of aquifers with different site-specific properties. A sensitivity analysis on major model input parameters was performed to investigate what factors contributed to the occurrence (and timing) of the outbreak, and what factors would make water supplies especially vulnerable for viral outbreaks. Lastly, implications on regulatory environments are briefly discussed.

5.2 Lake Mývatn site

Lake Mývatn (36.5 km^2) is a protected nature reserve and one of Iceland's most popular tourist destinations. The lake is situated in the neovolcanic zone in Northern Iceland (65°35'), with geological formations from the last ice age (Pleistocene) and Postglacial times. The area surrounding the lake includes groups of pseudocraters formed through steam explosions when lava plunged into the lake about 2300 year ago (Thorarinsson, 1979; Saemundsson, 1991). The lake is predominantly groundwater fed (Figure 5-1) with moderately warm subsurface springs entering the lake at the Eastern side, and cold springs at the southern side (Olafsson, 1979).

The study site, marked in Figure 5-1 and shown in Figure 5-2, is located in one of group of pseudocraters on the south shore of the lake. The soils are heterogeneous permeable pumice. The mean particulate size diameter in four pseudocraters 4 km

north east of the study site is d_{50} = 8.3 (4.7-13) mm and d_{10} = 1.05 (0.8-1.4) mm with porosity of 42%. The soils are poorly to very poorly sorted, from medium gravel to sandy fine gravel (Dolvik and Höskuldson, unpublished data). The 5-10 m thick unconfined aquifer has transmissivity of 0.25 m^2/s and 7 m/day seepage velocity, established from groundwater modelling (Vatnaskil, 2007). The groundwater is 6 °C and basaltic, with pH 8.8, determined at well 4.5 km east of the study site (Kristmannsdottir and Armannsson, 2004).

Water well, 1.2 m deep, was installed in the 1960s, approximately 3-4 m from the lake shore (Figure 5-2), directly in the path of a large volume groundwater stream that flows to the lake from south. A plastic barrier was installed between the lake and the well to prevent lake water to penetrate into the well. In addition a concrete coating was constructed around and on the edges of the well (Geirsson 2007; 2010).The well supplies water to a seasonal summer hotel and six dwelling houses west of the hotel at Álftagerði, connected to the well with separate pipes (Figure 5-2). In 1996, a 20 thousand litre three chamber septic tank, with a 20 m drainage bed, was installed 80 m directly upstream of the water well (Björnsson, 2010; Sigmundsson, 2008). The septic tank was located in an area on a sill with limited vegetated cover. A sharp 8-9 m vertical drop in land elevation occurs between the sill and the lake, indicating a minimum 8 m vertical separation between the disposal depth and the groundwater table.

5.3 The 2004 waterborne outbreak at Lake Mývatn

In the beginning of August 2004, an outbreak of gastrointestinal illness was reported by a group of tourists travelling in an organized bus-tour around Iceland. The group had dined at a hotel on the south shore of Lake Mývatn in the evening of July 31st (Figure 5-2). The first case of illness was reported in the evening of August 1st, when the group was in the nearby town of Akureyri in Northern Iceland. The group consisted of 26 individuals of whom 21 became ill. In the period of July 31st to August 3rd, individuals from three other tourist groups dining at the same hotel were reported ill (Atladottir, 2006). Simultaneously, residents in nearby summer houses were reported ill. A boil advisory was issued on August 4th after which no case of illness was reported. It is estimated that at least 100 people became infected this summer from that same water supply. A norovirus outbreak had occurred at the same hotel in late summer 2001 when at least 117 people became ill and food contamination was suspected as the culprit but later recognized to have the same cause as the outbreak in 2004 (Briem, 2005). Local residents also reported illness and that illness was a reoccurring event in late summer (Atladottir, 2006). However, when water analysis in 2004 showed that drinking water at the Lake Mývatn hotel was contaminated with the same genogroup (genogroup II) of norovirus as was found in patient stools, the outbreak was confirmed as waterborne. The owner of the hotel was requested to make the necessary improvement to the water supply. The following spring a UV treatment was installed and drainage from the septic tank was moved away from the direction of the groundwater stream (Brynjolfsson, 2008).

5.3.1 Bacteriological testing results

Water samples were taken by the Local Competent Authority to identify the source of the 2004 outbreak. Three samples for bacteriological testing were taken on August 4th, one from the hotel tap, one from a dwelling house and one from the lake near to the well. They were analyzed by the laboratory of the Environmental Agency of Iceland for HPC (Heterotrophic Plate Counts) at 37°C and at 22°C, total coliform, faecal coliform (if coliform was found), *Salmonella* and *Campylobacter*.

Results of bacteriological testing are displayed in Table 5-1, along with analysis of routine samples taken in spring of 2004 before the outbreak, and in summer 2005, nearly a year after the outbreak and when mitigation measures had been taken. For comparison, the values in the last line of the table represent the water quality limits set by the Icelandic Drinking Water Regulation (IDWR). All water samples from the water supply satisfied bacteriological requirements for IDWR except samples taken in the drinking water well before treatment, a year after the outbreak, where HPC was just above IDWR limits and turbidity was also higher than usual, although below limit. This indicates that some organic contamination was present in the groundwater, but successfully UV treated before supplied to users.

5.3.2 Viral testing results

Five stool samples were taken from people reported sick and were tested for viral contamination at the University Hospital Laboratory, four of which were found to be positive of norovirus of genogroup II (Atladottir, 2006).

Seven water samples were taken and tested for norovirus at the Firrst Life Science Laboratory in Finland (Atladottir, 2006): First two samples were taken August 4th; one from the tap at the hotel and one from a summerhouse in the neighbourhood where illness had been reported. Twelve days later, August 16th, five samples were collected; one from each tap, the same as August 4th, and three from Lake Mývatn near the well.

Results for viral testing, shown in Table 5-2, demonstrate that norovirus was present in the drinking water of the same genogroup as was found in stool from patients. It registered as very strong positive on August 4th and positive on August 16th. Norovirus was found both at the hotel tap and at the dwelling house August 4th but only at the hotel August 16th. The dwelling houses are connected to the well but with separate pipes. Samples from the lake tested negative for norovirus. This indicates that the water well was contaminated by the sewage from the upstream septic tank and not the lake although it could be too diluted in the lake for detection.

5.4 Microbial transport model

5.4.1 Simple transport model

Microbial removal rates in the unsaturated and saturated zones are often described by the means of simple transport models (Pang, 2009). For a continuous release of sewage, microbial concentration will ultimately reach a steady state, which represents the highest possible microbial content downstream of the point of contamination release. Neglecting dispersion and dilution, the governing equation for microbial transport in groundwater with kinetic sorption is

$$u\frac{\partial C}{\partial x} = -\lambda C \qquad (1)$$

The term on the left hand side represents transport via advection, where u is the groundwater seepage velocity. The term on the right hand side combines the removal associated with inactivation of free and sorbed microorganisms, μ_l and μ_s respectively, as well as the attachment k_{att} and detachment k_{det} of microorganisms on solid strata, i.e.

$$\lambda = \mu_l + k_{att}\left(1 - \frac{k_{det}}{k_{det} + \mu_s}\right) \qquad (2)$$

Eq. (2) suggests the total removal rates is bounded on one hand by the free microbes inactivation rate, i.e. $\lambda = \mu_l$ if $k_{det} \gg \mu_s$. On the other hand, if detachment rates are slow ($k_{det} \ll \mu_s$) as suggested by field and modelling studies in dune sand (e.g. Schijven et al. 2006; Schijven et al. 1999), Eq. (2) reduces to

$$\lambda = \mu_l + k_{att} \qquad (3)$$

This scenario represents the maximum removal due to sorption. The solution of Eq. (1) is an exponential decay of groundwater contamination with distance from source, x, from which the $\log_{10}$ removal rate, is determined as

$$\log_{10}\left(\frac{C}{C_0}\right) = -\frac{\lambda}{u \cdot 2.3} x \qquad (4)$$

The slope of the curve $\lambda/(u\,2.3)$ is referred to as the total $\log_{10}$ removal rate and is expressed in the unit of $\log_{10}/m$. If this removal rate is a constant, independent of x, the removal is linear. Pang (2009) found that 70% of the 87 datasets investigated were better described by a linear law and 30% with a power law implying reduced removal rate with distance. Eq. (4) is generally used to describe microbial removal, both in the vadose zone as well as in aquifers.

Eq. (4) implies that safe setback distance is linearly correlated with $\log_{10}$ removal and inversely correlated with removal rate $\lambda/(u\,2.3)$. As an example, for 9-$\log_{10}$ removal requirement, Eq. (4) yields the safe setback distance

$$X_{9-log} = \frac{9}{\left(\dfrac{\lambda}{u \cdot 2.3}\right)} \qquad (5)$$

5.4.2 Sorption-filtration within groundwater aquifers

Sorption is when chemicals or organisms become attached and detached to rock material. If detachment rates are small, the dominant process is that of irreversible sorption, also referred to as filtration. Filtration theory for colloids in packed beds suggests that the attachment rate constant, k_{att}, can be described based on soil and microorganisms properties as Harvey and Garabedian (1991)

$$k_{att} = 3\frac{(1-n)}{2d_c}\alpha\eta u \qquad (6)$$

where d_c represents the average soil diameter of the single collector, n the porosity, u the groundwater seepage velocity, η the single collector efficiency and α collision efficiency. Pang et al. (2005) and Harvey and Garabedian (1991) suggest using d_{10} instead of d_{50} as effective particle size d_c when variation in grain size is large.

The single collector efficiency is found to depend on three different mechanisms: Brownian diffusion, interception and sedimentation. For viruses, brownian diffusion is found to dominate (Penrod et al, 1996) simplifying the attachment rate equation to

$$k_{att} = 6\frac{(1-n)}{d_c}\alpha A_s^{1/3}\left(\frac{D_{BM}}{d_c n u}\right)^{2/3} u \qquad (7)$$

Here $A_s = 2(1-\gamma^5)/(2-3\gamma+3\gamma^5-2\gamma^6)$ is Happel´s porosity dependent parameter with $\gamma = (1-n)^{1/3}$. The molecular diffusion coefficient $D_{BM} = K_B(T+273)/(3\pi d_p\mu)$ is based on water temperature, T, Boltzmann constant, K_B, diameter of viruses, d_p, and dynamic viscosity of water, μ, as described by Schijven et al. (2006).

MS2 bacteriophages have a similar size ($d_p = 26$ nm) as noroviruses and are commonly used to represent norovirus sorption (Penrod et al., 1996; Schijven 2006). Studies suggest that the collision efficiency of MS2 is affected by the pH of the groundwater. When water pH is below the isoelectric point of the virus and porous medium, the electrostatic attraction between the virus and opposite charge porous media promotes adsorption (Guan et al., 2003). Within the pH range of 3.5 to 7, Schijven and Hassanizadeh (2002) found that the following empirical relationship applies

$$\alpha = \alpha_0 0.9^{\left(\frac{pH-pH_0}{0.1}\right)} \qquad (8)$$

The collision efficiency, α, is generally back calculated from tracer experiments in the field. In the absence of tracer experiments, the reference values for the Lake Mývatn study area were chosen from previously published studies with similar groundwater and strata properties. In particular, basaltic aquifers (pH > 7) were chosen in order to eliminate the influence of pH, given that Eq. (8) is only valid for acidic environments. In addition, the selection criteria included sufficient groundwater speeds ($u > 1$ m/day) and lateral distances ($x > 30$ m). For norovirus modelling, $\alpha = 2.7 \times 10^{-4}$ was chosen based on Schijven et al. (1999) MS2 tracer experiments in a contaminated sand dune ($d_c = 0.2$ mm, $u = 1.2$ m/day) aquifer with similar pH (i.e. pH = 7.8, range 7.3-8.3) and distance ($x = 30$ m). This corresponds to a conservative value for collision efficiencies in coarse alluvial gravel aquifers (Pang et al., 2005) and accounts for contamination build-up in the aquifer which may undermine sorption according to Wall et al. (2008). For *E. coli* modelling, $\alpha_0 = 4.5 \times 10^{-3}$ based on field experiments by Mutsvangwa et al. (2006) with same bacteria group in a sand aquifer ($d_c = 0.7$ mm, $u = 1.3$ m/day, pH = 8.5, $x = 500$ m).

Accounting for the grain diameter ($d_{10} = 1.05$ mm) in the poorly sorted strata and groundwater seepage velocity ($u = 7$ m/day) at Lake Mývatn, Eq. (7) yields $k_{att} = 0.06$ day^{-1} for MS2 transport. For *E. coli*, the single collector efficiency was found to be dominated by Brownian diffusion based on the corrected Rajagopalan and Tien (1976) version as presented by Mutsvangwa et al. (2006) and Logan et al. (1995). The attachment rate for *E. coli* ($d_p = 0.5$ μm) was estimated as $k_{att} = 0.14$ day^{-1} based on Eq. (7).

5.4.3 Inactivation

Inactivation rate, μ_l, of free pathogens is related to many physical and chemical factors, temperature of the water being one of the most important. Inactivation rate for viruses can be one order of magnitude higher at 25°C than at 5°C (Pedley et al., 2006). Temperature of spring water south of Lake Mývatn is about 6°C and independent of season (Olafsson, 1979; Kristmannsdottir and Armannsson, 2004).

MS2 bacteriophages have been found to be good surrogates for norovirus inactivation (Bae et al., 2008; Collins et al., 2006). Yates et al. (1985) measured the free inactivation rate of MS2 in five different groundwater aquifers at three different temperatures, 4°C, 12°C and 23°C. This data, plotted in Figure 5-3, shows a clear dependency of temperature, but also a significant spread between different groundwater aquifers, implying that site specific conditions may play an important role. The mean die-off values at each temperature were fitted with a log relationship, in order to account for the levelling of die-off rates at low temperatures. The fit yields a free inactivation rate of 0.08 day^{-1} for the 6°C cold groundwater at the Lake Mývatn site, in line with for example to 0.083 day^{-1} at 5°C used by Schijven et al. (2002).

Inactivation rates for the bacteria *E. coli* is estimated to be 0.4 day^{-1} using mean rates from Pedley et al. (2006) as the limited data for *E. coli* does not show dependency on temperature.

5.4.4 Log removal rates in the vadose zone

Few studies have been undertaken to assess the microbial removal occurring within the unsaturated vadose zone as opposed to the saturated groundwater. Pang (2009) summarizes and compares removal rates of MS2 bacteriophages and faecal coliforms in the vadose zone from various studies. She argues that microbial removal rates for viruses (and virus indicators/phages) appear to be of the same order as for bacteria in the same soil media. In addition, microbial removal rates appear to increase with infiltration rates. The sewage effluent released to the hotel septic tank at Lake Mývatn site is estimated as 35 m^3/day based on standard usage guidelines in Iceland and number of residents (Environmental Agency, 2004), which corresponds to a hydraulic loading rate of approximately 1 m/day. For a similar hydraulic loading rate, Gerba et al. (1991) found a MS2 removal rate of 0.53-log_{10}/m in a vadose zone composed of sandy gravel and coarse sand. The same rate was found for faecal coliforms, representing bacterial removal in a 3 m thick sand vadose zone with varying hydraulic loading. Sinton et al. (2000) studied septic tank effluent in coarse gravels and found that faecal coliform removal rates ranged from 0.27-0.5 log_{10}/m, with mean of 0.44-log_{10}/m. Hence, a representative removal rate for both viruses and bacteria within the vadose zones of coarse gravel and sand aquifers is within 0.44-0.53-log_{10}/m, which will be used as a base for the Lake Mývatn study site.

5.4.5 Microbial removal requirements for safe drinking water

Since the IDWR does not specify any requirement for viruses, the drinking water requirements in other countries were consulted. The Drinking-Water Standards for New Zealand 2000 (DWSNZ) requires less than 1 per 100 l for enteric virus corresponding to a 10-log_{10} removal (Pang et al., 2003). Alternatively, the requirements used in a recent Dutch study are 9-log_{10} removal (Schijven et al., 2006). For the present study, a 9-log_{10} removal is used as a minimum requirement for enteric viruses.

The IDWR for *E. coli* is zero in 100 ml (Table 5-1). Medema et al. (2003) reported typical *E. coli* concentration in the order of $10^5 – 10^7$ n/100 ml, 10^7 will be used in this study. This means, that in order to satisfy the IDWR a minimum 7-log_{10} removal is required for *E. coli*.

5.5 Results and discussions

5.5.1 Removal at Lake Mývatn groundwater well

The groundwater transport model with the site specific conditions discussed in Chapter 4 suggest that a 3.5-log_{10} to 4.8-log_{10} viral and bacterial removal may be possible within the 8 m thick vadose zone at Lake Mývatn, corresponding to observed log removal rates of 0.44-0.53 log_{10}/m for coarse sand and gravel media (Pang, 2009). Within the 80 m lateral travel distance in the saturated zone, between the sewage discharge point and the drinking water well, however, the model estimates a 0.7-log_{10} removal for MS2, representing norovirus, and a 2.7-log_{10} removal for *E. coli*. The modelled removal within the groundwater aquifer accounts only for a small portion of that achieved in the vadose zone.

Combined, the removal of viruses after infiltrating the vadose zone and travelling within the groundwater to well is estimated at best as 5.5-log$_{10}$, which does not satisfy the minimum 9-log$_{10}$ removal for safe drinking water. However, the combined removal of *E. coli* at the drinking water is estimated as 7.5-log$_{10}$, which conforms to the minimum 7-log$_{10}$ bacteria removal discussed in Section 4.5. Therefore, the simple groundwater model adapted to the Lake Mývatn site supports the observation during the outbreak of strongly positive drinking water with norovirus (Table 5-2), while bacteria free (Table 5-1), indicating that the 80 m setback distance was insufficient.

5.5.2 Comparison to observed viral removal rates

Table 5-3 compares the simulated MS2 removal rates at Lake Mývatn with observed removal rates at different sites with various groundwater strata and water properties, summarized in Pang (2009) and references used in that paper. The safe setback distances, derived from Eq. (5), represent solely the viral removal within the different aquifers and neglect removal in the vadose zone. The field observations show a clear dependency of groundwater log removal, and hence safe setback distances, on soil type: the safe setback distance for 9-log$_{10}$ removal in sand aquifers, with d_{50} smaller than 0.4 mm, is less than 50 m. This same distance is, however, on the order of several hundred meters in more course strata (sandy gravel, sand and gravel), with d_{50} exceeding 5 mm. The model prediction for coarse gravel pumice at Lake Mývatn, top row in Table 5-3, conforms to these field studies in that it predicts low viral removal. The modelled removal rate of 0.009-log$_{10}$/m is, however, on the order of 2 to 3 times lower than observed in the coarse gravel aquifer studied by Sinton et al. (2000). The derived safe setback distance is slightly less than 1 km as opposed to several hundreds of meters. This difference cannot be entirely explained by the different groundwater temperature and pH because those effects are counterbalanced by the different groundwater seepage velocities. Hence, this may be an indication that model predicts conservative removal rates, which can be explained in several of the underlying model simplifications. The sorption module does for example not account for specific features of pumice strata, such as their high surface areas which promote removal (Pang, 2009). The model excludes the dispersion of pollutants and dilution of fresh water in the well. Lastly, the uncertainty in model input data may play a role as well, which will be explored further in the following section.

5.5.3 Groundwater model sensitivity

The groundwater transport model is dependent on selected site specific model input parameters, including grain size, groundwater seepage velocity, temperature, pH and collision efficiency. Figure 5-4 presents the log removal rate, $\lambda/(2.3\ u)$ (Eq. 4), for a range of input variables, which was based on observed values in sand, sand and gravel, and coarse gravel aquifers (Table 5-3). The vertical lines represent the result of the Lake Mývatn study, with modelled MS2 removal rate of 0.009-log$_{10}$/m.

First consider the model sensitivity on grain size diameter. Eq. (7) shows that the attachment rate, k_{att}, scales as $d_c^{-5/3}$. This means that strata with a ten times greater diameter may have approximately 50 times lower attachment rate, and removal rate if attachment dominates inactivation, $k_{att} \gg \mu_l$. In most aquifers, die-off contributes

substantially to viral removal, which in turn, would moderate the impact of grain size. At Lake Mývatn, where $k_{att} \approx \mu_l$, the characteristic grain size d_{10} ranged from 0.8 to 1.4 mm in four different samples taken at the site (see horizontal line, Fig. 5-4a). The model suggests that the removal rate may vary 20% from the mean, corresponding to 0.011 $\log_{10}$/m and 0.007 $\log_{10}$/m respectively. While this is a significant range, it does not alter the previous result that 80 m travel distance was not sufficient to achieve a 9-$\log_{10}$ removal at the Lake Mývatn drinking water well.

Next, consider the model dependency on groundwater seepage velocity. According to Eq. (7), $k_{att} \sim u^{1/3}$, so the removal rate, $\lambda/(u\ 2.3)$, scales between $u^{-2/3}$ if $k_{att} \gg \mu_l$ and u^{-1} if $k_{att} \ll \mu_l$. This suggests, for example, that a tenfold groundwater velocity may reduce the removal rate anywhere from five to fifteen times, all other parameters being equal. Since coarse strata is typically characterized by large grain size and seepage velocity (Table 5-3), the combined effect would generally be additive. The model thus conforms with the field observations in Table 5-3, that removal rate is on the order ten times lower for coarse (gravel) than fine (sand) aquifers. At the Lake Mývatn site, Figure 5-4b shows that log removal may vary 20-30% from the mean if the uncertainty in the seepage velocities were ±2 m/day.

The model sensitivity to groundwater temperature is predominantly associated with the exponential dependency of inactivation rate, μ_l, on water temperature. Figure 5-3 shows, for example, that when groundwater temperature drops from 15°C to 10°C, the inactivation decreases by a factor of two. An additional drop to 5°C, decreases the die of rate by a factor of 4. If viral inactivation dominates grain attachment, i.e. $\mu_l \gg k_{att}$ the total log removal would be linearly correlated with inactivation. In such cases groundwater temperature could greatly influence the log removal rate, and the consequently, the safe setback distance. This strong influence of temperature has gotten limited attention in contamination studies nor have many studies focused on a low temperature environment (John and Rose, 2005).

Figure 5-4c portrays the potential influence of water temperature for strata at the Mývatn site. The solid line represents the mean relationship, and the dot-dashed lines the range, derived from Yates et al. (1985) experiments on soils from 5 different aquifers portrayed in Figure 5-3. Figure 5-4c suggests that removal rate in cold climate, like Iceland, where groundwater temperature originating from melting glaciers can be as low as 2°C (Adalsteinsson et al., 1992), may be ten times lower than for similar strata in Mediterranean climates, where temperatures may exceed 20°C. Figure 5-4c also indicates that the log removal rate may vary from 0.005 to 0.013 $\log_{10}$/m depending upon whether the upper or lower limits of the Yates et al. (1985) data are used. This high uncertainty associated with site dependent characteristics demonstrates the need for conducting more microbial inactivation studies to better understand the role of local strata (other than temperature) on inactivation rate .

Lastly, the collision efficiency, α, is generally derived from tracer experiments in the field and is affected by groundwater acidity. The reference for Lake Mývatn was taken from Schijven et al. (1999) study of basaltic contaminated dune sand aquifer. Figure 5-4d portrays the possible impact of groundwater acidity on removal rate

based on Eq. (8). The figure suggests that neutral groundwater (pH = 7) might have 60% higher log removal rate or 0.014 $\log_{10}$/m. Another point of consideration is that increasing coarseness and water cleanliness may improve the collision efficiency, which in turn increases the viral removal rate. For example, Pang et al. (2005) derived $\alpha_{mean} = 1.9\times10^{-3}$ based on six well tests performed by Sinton et al. (2000) in the clean, more coarse gravel and neutral aquifer (Table 5-3) than Lake Mývatn. This higher α serves as to counterbalance the impact of high seepage velocities (u>80 m/day, Figure 5-4b).

To conclude, the high sensitivity to four of the model input parameters (Fig.5-4) highlights the need of conducting field experiments to reduce the uncertainty of results and calibrate the groundwater model. It also indicates that coarse, permeable and cold climate groundwater environments may be especially susceptible to microbial contamination.

5.5.4 Groundwater viral removal potential of gravel pumice and regulation implications for Iceland

Pang (2009) and Pang et al. (2003) argue that pumice sand may be the most efficient soil type in removing microorganisms. High surface areas and low pH contribute to the sorption of microbes to the solids. A safe setback distance of 48 m was established for enteric viruses in such pumice sand. A similar distance can be derived based on sand aquifer studies in the Netherlands (see Table 5-3).

The norovirus outbreak in Lake Mývatn, where a septic tank located 80 m upstream of a drinking water well, is evidence that a 48 m setback distance is not sufficient for gravel pumice in cold climate. A groundwater model incorporating general filtration theory and studies of inactivation rates of viruses suggest that a larger grain size, higher groundwater seepage velocity, cold and basaltic groundwater may all contribute to undermine the removal rate in coarse gravel pumice. This may have significant implications for groundwater supplies in coarse strata and cold climate. The greatest risk is likely to occur in small, and less regulated, rural water supplies, supported by the number of waterborne outbreaks reported in supplies in Iceland during the last decades. Many of rural water systems serve a large number of tourists during summer months as well as farms producing agricultural products. Yet, few studies on transport of microbes in cold coarse strata have been carried out. This highlights a need for research on hydraulic parameters and travel of pathogens in coarse strata, both with respect to geological conditions and temperatures, to underpin regulations governing determination of water protection zones for rural groundwater wells. Our initial effort suggests that the safe setback distances for achieving a 9-$\log_{10}$ viral removal might be up to 1 km for site specific condition at Lake Mývatn (Table 5-3), neglecting initial removal in the vadose zone. This is more in line with 4 km safe setback distances for 7-$\log_{10}$ viral removal reported in alluvial gravel aquifers (Pang et al., 2005). Yet, with the data available at hand today, it is impossible to assess whether the safe setback distance is indeed several hundreds of meters, or up to or more than a kilometre.

Another question worth considering is what type of measure would be most appropriate for determining water protection zones. Table 5-3 lists safe setback

distances, an approach taken in many countries. Consulting Eqs. (3), (5) and (7), however, it can be seen that safe setback distances scale linearly on u if $\mu_l >> k_{att}$ and $u^{2/3}$ if $\mu_l << k_{att}$. This undermines the use of setback distances for defining protection zones for different groundwater supplies. This dependency may be reduced by using travel times, X_{log}/u, as a measure for protection zone. The travel time between the septic tank and well at Lake Mývatn is estimated as 11 days, which is shorter than the 50 day travel zone used in some regulations indicating that the setback distance is significantly too short.

Lastly, the severity of the Lake Mývatn outbreak discussed in this article and the inadequate setup of the septic system demonstrate a need for systematic review of existing septic systems in Iceland and comprehensible regulatory guidelines for installation of such systems. This could be included in a systematic preventive management system, such as water safety plan, that have been or are currently being implemented by many utilities (Gunnarsdottir et al, 2012a; Gunnarsdottir and Gissurarson, 2008). A possible outcome of a review would be installation of UV treatment where needed or even a reconfiguration of the septic system if the risk is deemed unacceptable.

5.5.5 Factors contributing to the timing and occurrence of outbreaks

The contamination at the Lake Mývatn study site originated from a septic tank serving predominantly summer dwellings and a hotel. The tourist season starts late May or beginning of June. Norovirus outbreaks in 2001 and 2004 were reported in late July and beginning of August. Upon interviewing, a summerhouse dweller claimed that illness was a recurrent event in late summer.

The late season timing of outbreaks may be explained by the experimental findings of Wall et al. (2008). The addition of dissolved organic carbon were found to progressively reduce removal and retardation of phages in saturated pumice sand aquifers, suggesting that less removal may be achieved in contaminated as opposed to uncontaminated aquifers. At Lake Mývatn, sewage contamination starts building up in the aquifer at the beginning of the tourist season. The outbreak timing, at end of July, may indicate that a critical build up of contamination is reached after roughly 2 months of operation.

Another factor known to contribute to increased microbial contamination is precipitation, which increases the soil saturation and enhances infiltration to the groundwater table. The removal capacity of the vadose zone is found to be inversely correlated with infiltration rates (Pang, 2009). Waterborne outbreaks have been associated with extreme precipitation (Taylor, 2004; Curriero et al., 2001). The septic tank was present in an area with limited vegetation cover and pumice soils. Hence the vast majority of the rain infiltrates the ground and reduces the travel time in the vadose zone. However, the rain pattern in Iceland is generally characterized by low intensity and long duration events. The rain record at the local meteorological station at Lake Mývatn indicates that the summer 2004 was relatively dry (Gisladottir, 2007). A prolonged three day rain event with maximum of 6 mm/day occurred 10 days prior to the reported cases of illnesses, which matches closely the

travel time of 11 days. While it is possible that the rain may have accelerated the groundwater recharge, its intensity was much lower than the estimated sewage infiltration rate of 1 m/day. Rain may therefore have played a minor role in the occurrence of the outbreak. Peak occupancy at the hotel, and the fact that septic tank at Lake Mývatn was inadequately sized according to design criteria given in the 2003 guidelines of the Environmental Agency of Iceland probably played a larger role than rain.

5.6 Conclusions

This study takes a first step in reviewing the potential of microbial contamination in groundwater supply in cold climate and coarse soil. Sensitivity of microbial groundwater transport, explored by a model and tabulation of results from various studies, shows that microbial transport is particular sensitive to temperature and grain size, directly influencing safe setback distances and regulatory environment. These results were further collaborated by a case study of a documented waterborne norovirus outbreak at Lake Mývatn in Iceland. The model was applied to the site and results confirm field observations that a 80 m setback distance (11 day groundwater travel time) between a septic tank and drinking water well was inadequate for achieving a 9-$\log_{10}$ viral removal, but sufficient for a 7-$\log_{10}$ bacterial removal. The model highlights that aquifers with large grain size, high seepage velocity, cold temperatures and high pH, contribute to adverse conditions for microbial removal. In addition, contamination build-up associated with seasonal septic tank discharge may play an important role in reducing the filtration capacity of the volcanic strata. The vadose zone is found to play an important role in initially removing the microbial contamination, and needs to be considered. These results highlight the need for further studies on microbial removal rate in saturated and unsaturated volcanic strata in cold climate. Results from such studies should then be used to reinforce regulations regarding safe setback distances for septic tanks in rural areas that take into account local hydrogeologic settings.

Figure 5-1 Lake Mývatn area and the location of the study site. The arrows show the direction and magnitude of the groundwater flow according to groundwater model by Vatnaskil (2007).

Figure 5-2 Study Site. Map of the study area (adapted from Jonsson, 2006). The water well and the septic tank are marked. The hotel and six dwelling houses are served by the well, four at Alftagerdi and two close to the hotel.
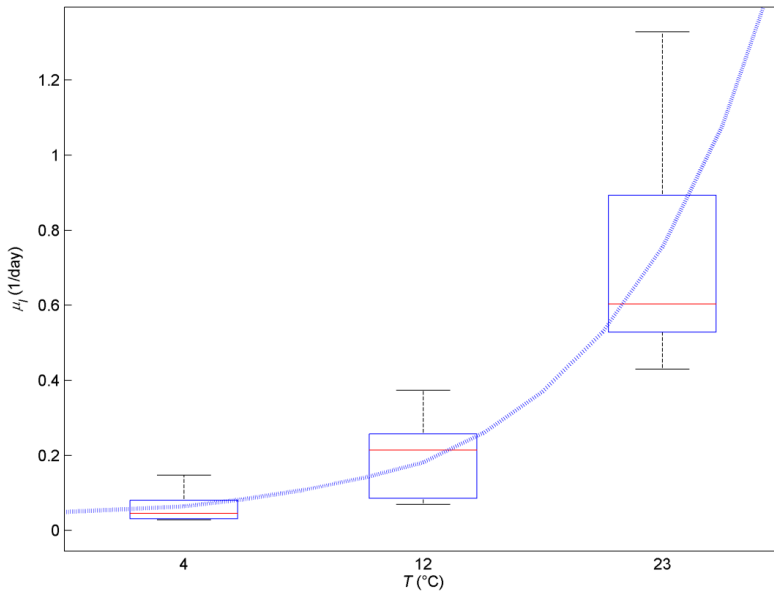
Figure 5-3 Free inactivation rate of MS2 as a function of groundwater temperature based on experiments from Yates et al. (1985). The central mark is the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend to the most extreme data points not considered outliers. The dotted line represents the best log fit through the data, $\mu_l = 0.0384e^{0.1295T}$.
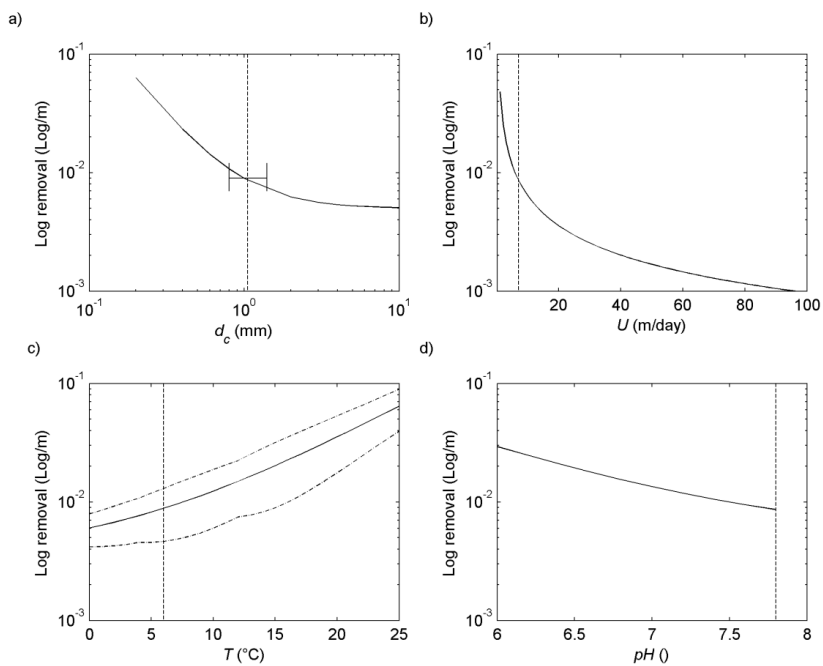
Figure 5-4 Model sensitivity for four parameters Modelled log removal rate as a function of a) grain size, b) groundwater seepage velocities, c) water temperature, and d) pH. The vertical broken lines represent the base simulation for Lake Mývatn, and the dashed dotted lines in c) ranges.

Table 5-1 Results from general water sample monitoring 2004-2005 at Lake Mývatn (The Environmental Agency of Iceland, 2004, 2005)

Sampling date.	Sample site	Turbidity NTU	Conductivity µS/cm	HPC at 37°C in 1 ml	HPC at 22°C in 1 ml	Coliforms in 100 ml	Faecal coliform in 100 ml	*Salmonella* in 400 ml	*Campylobacter* in 400 ml
25.5. 2004	Hotel tap – routine inspection	0.1	190	N.D.	19	0	N.D.	N.D.	N.D.
4.8. 2004	Hotel tap	N.D.	N.D.	1	25	0	N.D.	Neg.	Neg.
4.8. 2004	Dwelling house	N.D.	N.D.	0	33	0	N.D.	Neg.	Neg.
4.8. 2004	Lake near well	N.D.	N.D.	990	2100	990	990	Neg.	Pos.
4.7. 2005	Well (untreated)	0.27	190	N.D.	110	0	N.D.	N.D.	N.D.
4.7. 2005	Hotel tap (treated)	<0.1	190	N.D.	9	0	N.D.	N.D.	N.D.
	IDWR	<1.0	<2500	N.R.	<100/ ml	0/100 ml	0/100 ml	0	0

N.D. = not done. Test for Faecal coliform are not done if Coliform is not detected.

N.R. = no requirements

Table 5-2 Results from norovirus tests of water samples taken August 4th and 16th 2004 at Lake Mývatn (Firrst Life Science, 2004)

Water sampling site	Water samples from August 4th, 2004	Water samples from August 16th, 2004
Network – hotel tap	Very strong positive – (genogroup II)	Positive – (genogroup II)
Network – private house tap	Very strong positive – (genogroup II)	Negative
Lake/A202	N.D.	Negative
Lake/A203	N.D.	Negative
Lake/A204	N.D.	Negative

N.D. = not done

Table 5-3 Comparison of modelled MS2 removal rates at Lake Mývatn with previous field observations in groundwater aquifers. Adapted from Pang (2009).

Location	Aquifer	d (mm)	n	u (m/day)	T (°C)	pH	x (m)	Removal Rate (log_{10}/m)	$X_{9\text{-}log}$ (m)	Reference
Mývatn, Iceland	Gravel pumice	8.26 (d_{50}) 1.05 (d_{10})	0.42	7	6	8.8	80	**0.009**	960	
Castricum, Netherlands	Dune sand	0.2-0.24 (d_{gm})	0.35	1.2-1.7	2-5	7.3-8.3	30	0.187	48	Schijven et al. (1999)
Netherlands	Coarse sand	0.4	0.32	0.33-0.56	NA	7.5	37.7	0.188	48	van der Wielen et al. (2006)
Rotorua, New Zealand	Pumice sand	0.15 (d_{50})	0.2	0.9-1	13	6.2	2	1.85	5	Wall et al. (2008)
Montana, USA Frenshtown High School	Sand and gravel	2.4 (d_{mean})	0.2	1-2.9	9-12	6-6.4	6.6-17.4	0.392	23	Deborde et al. (1998)
Montana, USA Erskine Fish Access	Sandy gravel	1.25 & 12 (d_{mean})	0.15	22-30	10.3	7.2	7.5-40.5	0.0994	91	Deborde et al. (1999)
Montana, USA Erskine Fish Access	Sand and gravel	1.25 & 12 (d_{mean})	0.15	129	10.3	7.2	21.5	0.0358	250	Woessner et al. (2001)
Burnham, New Zealand	Coarse gravel	18 (d_{50}) 0.9 (d_{10})	0.2	88-112	12	6.92	87	0.025	360	Sinton et al. (2000)

*NA = not available

6 Uganda Experience with Water Safety Plan

The information on WSP in Uganda was gathered with two interviews with Sarah M. Tibatemwa and with carrying out an external audit of the WSP in Kampala Water during a visit by Maria J. Gunnarsdottir. At the time of the first interview Sarah was quality manager for all drinking water supply run by the National Water & Sewerage Corporation (NWSC) in Uganda and responsible of the WSP implementation in all its water utilities. At the time of the later interview Sarah is the director of the Africa Regional Office of the International Water Association (IWA Africa) that is in the process of advocating WSP in Africa. The interviews were conducted on 21st of November 2008 and 4th of August 2011, respectively.

The external audit of Kampala Water was carried out 1st and 2nd of December 2008 following an invitation letter from Kampala Water. The auditor received a report on the reaction to the audit late summer 2011 (see Appendix 4). Some of the defects have been rectified but others still remained a challenge. The issue of inadequacy for NWSC to have control or mandate over catchment management and source protection remains a big challenge. It was also reported in the letter that the Ministry of Water and Environment has in the last two years taken a keen interest in WSP which is an improvement. In the new version of the National Standards for drinking water quality from 2008 WSP is a mandatory requirement. So Uganda is now among the pioneers in the world in legalizing a WSP methodology.

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6.1 Water Safety Plan in Uganda

6.1.1 Background

Uganda belongs to the East Africa region and is situated north of Lake Victoria. Population was estimated in 2008 to be around 32 million and 13% or about 4 millions live in urban centers. According to WHOs and UNICHEFs Joint Monitoring Programme (2010), data for 2008 show that 67% of the population of Uganda have access to improved water source and 48% have access to improved sanitation. In the urban areas 91% have access to improved water source either public stand-pipes (72%) or piped to the premises (19%), while 9% have no access to improved source. In the rural areas the situation is worse as only 64% have access to improved source and mainly that is access to stand-pipes. Nearly 11 million of the 32 million people of Uganda had in 2008 only access to unimproved drinking water resource. When looking at sanitation the situation is even worse as 17 million do not have access to improved sanitation and over 3 million have to rely on open defecation and the biggest threat to drinking water safety is poor sanitation (WHO/UNICEF, 2010). The situation in Uganda is somewhat better than the average in Sub-Saharan Africa where 60% have access to improved water resource and 31% have

access to improved sanitation, but there is a big task ahead for the authority of Uganda to facilitate improved access for all its citizens.

6.1.2 Interviews with Sarah M. Tibatemwa

Kampala Water

NWSC is a nationally owned company and runs water supply and sewerage in 22 urban centers serving around 1.8 million people in Uganda in 2007 with the targeted population of 2.5 million (NWSC, 2008). Water supply is in the jurisdiction of Ministry of Water & Environment while the water quality is under Ministry of Health and public health inspectors on their behalf are responsible for surveillance of drinking water. There are around 1.5 million permanent residents in Kampala and 2 million during the day. Kampala Water serves residents from public stand-posts or with house connection. Around 80% of the water is metered. There are water vendors that are responsible for the stand-posts. They buy water from the utility and sell to customer. Because of this intermediary water from stand-posts is much more expensive than from house connections. The water source is Lake Victoria and the water is subject to conventional treatment; screening, flocculation, filtration and disinfection with chlorine gas. The water source is a challenge as the quality of water in the lake has deteriorated and Kampala Water has no jurisdiction over the catchment protection. The catchment includes Kampala and the lake receives sewage contaminated water from the area. The catchment of the lake is also in three countries; Uganda, Kenya and Tanzania and an agreement across boundaries is also needed as well as legal framework on catchment protection. Turbidity, color and nutrient content are on the rise and causing algae blooming and eutrophication.

Cholera has been a persistent problem in Kampala in the low income high populated areas. This can occur when people are using the so called protected springs that are free of charge and not a part of the Kampala Water supply system. These sources often get contaminated after heavy rains especially in low lying areas with poor sanitation. Illegal connections to the water pipes and vandalism of the infrastructure by local people are also a problem. Sewage and water pipes are in the same ditch and that poses risk to contamination but as sewage system are mostly in the centre of town, the risk is limited to certain area where the risk scores are high because of this, especially in low lying areas.

Kampala the torchbearer of WSP

The water utility in the capital town of Kampala was the first water utility in Africa to implement a WSP (Davison et al., 2005). In 2002 WEDC (Water, Engineering and Development Centre) at Loughborough University UK initiated a project together with the Department of Civil Engineering at Makerere University in Uganda and Kampala Water. It was also attempted to have a representative from the Ministry of Health but without success. Later when the project was finished a local team from the headquarters of the NWSC and Kampala Water took over. This project was funded by the UK Department for International Development (DFID) and the goal was to try out the newly advocated water safety plan that WHO was about to publish in its third edition of the Guideline for drinking-water (WHO, 2004). The aim was to test if this new approach would work in a developing country. It took 24 months to complete and a functioning WSP was in place by

the end of 2004. Now all the 22 urban centers served by NWSC are with or in the process of implementing WSP.

The WSP was based on the WHO manual including system assessment on intake, treatment and distribution. Then follows identification of risks and how to stop or decrease the risk. The team came up with a process of assessment of water quality at different points and how to classify the risk according to population, altitude, pipe, discontinuity, main burst, and leakage. Critical control points where located and documentation procedure implemented. New procedures were introduced and some old ones improved. Procedure for complaint was already in place as the utility had been certificated for ISO 9001 some years back. Training was also a part of the implementing process. An important part of WSP is external and internal audit but the external one is more of a problem in Uganda as there has not been anyone outside the utility who is knowledgeable about WSP. But NWSC has tried out the new WHO self assessment tool for WSP and it has proven to be very helpful in the internal audit process (WHO, 2010). The only external audit conducted is the one depicted in Chapter 6.2. Since the initial implementing process some public relation activities have been added such as weekly information on water quality on the utility website and a program made by NWSC with guide on how to conserve water is shown on local TV.

The main obstacle in the implementing process was financial when the utility had to take over and no budgetary plan was in place. That revealed the need to have a separate budget for WSP. Prior to WSP there was a rapid expansion of the distribution network and updated block maps were lacking. There was also the issue of the laboratory at the utility that could not cope with the requirement of testing all the parameters e.g. *Clostridium perfringens*. This was a challenge as staff had to change working procedures which had been used for a long time. There was also the need to involve other members of staff as is needed in all new projects and there is always some resistance to change. As this was a first time in a developing country there was no one to refer to and see how problems had been solved elsewhere and that was a challenge.

Benefits from WSP

Benefits of WSP have been many. Better service and water safety was the main incitement for implementing WSP. Many of the staff, from operators to managers, have stated that it has been very beneficial to have this increased knowledge of the system and felt that they ended up knowing the system very well. People have also come to understand the system and the issue of contamination. The WSP systematic approach is also very useful to locate where funding is needed e.g. if there is a continuous leakage in one place it can be used to justify a claim with data to support the request. When doing budgeting the data can also reveal where investments are most needed.

Analysis of bacteriological status was achieved with relying more on measuring residual chlorine. If that is measured there is no need to test always for bacteria. Overall when monitoring is rightly done it will save money in the long run as sampling is more focused. Now it is done at critical control points and not according to number of users as recommended in the WHO Guidelines. Raising the awareness of the safety issues and giving it a higher profile and not let it be just the business of the quality people came out very clearly as a benefit from WSP. But operators were to measure residual chlorine but they refused as there was no compensation for the extra work. WSP has also proofed to be

good in time of crises for example...”during the time of the Common Wealth Meeting here in Kampala some years back it was in the news that there was faeces in the water and of course the press came after us. The manager could announce that this could not be as we had WSP and everything was regularly checked and could be verified”. It later came out that the papers were referring to the protected springs mentioned before and those are not a part of Kampala Water supply system. After that information on water quality were added weekly on the utility website.

Obstacles and challenges

What was lacking in the process was more involvement of other stakeholders. The public health inspectors leave all surveillance to NWSC in urban areas while only attending to the rural area and that has not changed. There is also a lack of involvement of the consumers and the community and that is still a challenge. It would be beneficial to have some involvement of the municipality for example when there is a water pipe break, as it is a water quality issue and should concern the community. To fully succeed with WSP there is a need for involvement of all these stakeholders and support from top management. The attitude of the staff other than the quality people was partly skeptical. But the staffs of the quality control department were positive except that there was still some opposition to adapt to the new way in measuring water quality.

The remaining risk for water quality is discontinuity in water supply. The system has been expanded too much without providing for the supply of water in the mains. This has resulted breaks of delivery at peak hour. This can be very hazardous to water safety and cause intrusion of contamination into pipes when low or negative pressure. Another obstacle has been turnover of staff and then training has to start all over again as they can only get training and teaching within the company. Training should be ongoing so the new employee can be updated and knowledgeable on the methodology of WSP. If you neglect continuous training you will end up with only the quality department people trained and if they leave there is no one. Top management should always be kept well informed to secure their continuous support. Documentation is also a problem as people get lazy with filling out the forms.

Work on WSP for East Africa

In 2008 Sarah did assessment of use of WSP in Sub-Saharan Africa for International Water Association (IWA) and discovered that it was only Uganda and South Africa that were using the system. Then IWA decided to work on facilitating use of WSP in East Africa and this work is supported by the Environmental Protection Agency (EPA) in USA. The East Africa region includes ten countries; Uganda, Kenya, Tanzania, Ethiopia, Eritrea, Rwanda, Burundi, Sudan, Somalia, and Djibouti. IWA has initiated work on WSP in the region and wants to make them the champions for the developing world building on the experience of Uganda. “We are also trying to interest the governments of these countries” was stated by Sarah.

The first goal is to make a network. It started with a workshop were representatives from each country were invited and the aim is to establish a network based on the already established network WOP Africa (Water Operator Partnership). The same model for cooperation will be used as in WOP where some water utilities preferably at least one from each country are working together in the process of implementing a WSP. Second goal is to facilitate WSP training in an already established training centre in Kenya. This will be a

weeklong training program for water operators in WSP and water quality issues. It is expected that the countries will send at least three people each for the first training week.

The problem in the other East African countries is a lack of a reliable laboratory for monitoring water quality. Good laboratory in the utility or access to one is essential for success. One of the reasons for the success in Uganda is that NWSC had a good lab from the start. Others will have to start from scratch and in the beginning with relying on chlorine residual. Some of the countries are very much behind in water quality surveillance and some are not even using the third edition of the WHO Guideline published in 2004. The big challenge in these countries is poor sanitation and hygiene, the "step sister" of water supply. WSP in the urban centers is not helping much in the UN Millennium Development Goals (MDG) as it is the rural areas that are most behind in improved water sources. To work on the MDG there is a need for many initiatives as pictorial manual on WSP for the rural areas as has been done in Bangladesh with good result (Mahmud, 2007). One issue that often is mentioned is if a similar tool as WSP could be developed for sewage- a sewage safety plan. That could be very beneficial together with the water safety plan. There is also a need for cost benefit analysis for WSP. It would help in the advocacy of WSP and in convincing management and others of the benefits of WSP. "The important thing is to keep on pushing for progress and not give up" was emphasized by Sarah M. Tibatemwa director of Africa Regional Office of IWA.

6.2 External audit of the Water Safety Plan at Kampala Water

Gunnarsdottir, M.J. (2008). External audit of the Water Safety Plan at Kampala Water. Report delivered to Kampala Water and Icelandic International Development Agency.

6.2.1 Introduction

The external audit of the Water Safety Plan (WSP) of Kampala Water was carried out by an invitation from National Water & Sewerage Corporation (NWSC) by letter dated 29th October 2008 (see appendix 1). The external auditor was Maria J. Gunnarsdóttir from Samorka the Association of Icelandic Water Supply. It was carried out on 1st and 2nd of December 2008 in cooperation with Godfrey Arwata, Senior Laboratory Technician in distribution and Richard Oyoo, Quality Assurance Manager of Kampala Water.

First phase was to go through the WSP structure and results. The auditor then chose four critical control points randomly for a visit. They were monitoring point at the treated water tank at Gaba II, the Mutungo Reservoir, the Namirembe Booster Station and Valve Box nr. 1345 at Mutundwe. This audit is not a thorough review of the whole process of the water safety plan as carried out in Kampala Water but a random test. The documents used for information on the Water Safety Plan for Kampala are two reports; "Water Safety Plans for Utilities in Developing countries – A case study from Kampala" (Godfrey et al., 2003) and report on internal audit "WSP audit report of Kampala water treatment plants and distribution quality monitoring and management programme" carried out in February 2008 by Sarah M. Tibatemwa, Principal Analyst at NWSC (Tibatemwa, 2008).

6.2.2 NWSC and Kampala Water

Kampala Water is a part of the Uganda nationally owned company NWSC. NWSC is currently responsible for water supply in twenty-two towns in Uganda providing 60.5 million cubic meters to 180,697 water connections in a network that is 3,206 km. It has been a rapidly growing corporation from serving three towns in 1972, seven towns in the eighties, twelve towns in the nineties and twenty two towns in 2007 (NWSC, 2008). That year NWSC served 1,8 million people with water which is 71% of the population in the areas. Targeted population is now 2,5 million. Only 6% of the population in the towns are currently served with sewerage. The population of Uganda is estimated at 32 million.

In Kampala 71% of the population of 1.4 million, or approximately 1 million, is served with water from the distribution system of Kampala Water through house connection or public stand-posts. Average water production is around 177 thousand m^3/day and the capacity is 197 thousand m^3/day. This increase in capacity is due to the new Gaba III Water Treatment Plant that was commissioned in May 2007. Before Gaba III the capacity of the water treatment plants was too low at peak demand and the clarification process did not keep up with demand which resulted in high colour number. This problem is now solved but there is need to establish confidence in the safety of the Kampala Water.

6.2.3 Water Safety Plan in Kampala Water

Water Safety Plan (WSP) was introduced in NWSC in 2002. Later that year a joint project between NWSC, the Water Engineering Development Centre (WEDC) of Loughborough University and the Department of Civil Engineering at Makerere University in Kampala developed a WSP for Kampala Water. This was funded by the UK Department for International Development (DFID) and was partly implemented two years later, in 2004 (Tibatemwa, 2008). The WSP is a preventive approach build on risk assessment from water intake to delivery point to consumers and regular control on critical control points to prevent pollution of the water. This method is described in the third edition of WHO Guidelines for Drinking-water Quality (WHO, 2004).

As a part of the WSP for Kampala Water a risk map was developed. This was done with the field data from the system assessment and existing surveillance data. The risk ranking for each inspection point was based on a risk matrix incorporating hazard, vulnerability and susceptibility and each with a number of sub categories. Risk ranking is based on population density, elevation of the area, pipe material, size, length and age, pipe breakage, discontinuity of supply and leakage. The scoring is in three categories where >30 is high risk, 15-30 is medium risk and 0-15 is low risk.

According to the risk map there are eighty-two critical control points in the system; treatment plants, service reservoirs, booster stations and valve boxes. Of the eighty-two critical control points 12% are classified as high risk, 80% as medium risk and 8% as low risk. There is a plan for a regular visit to every control point for monitoring and a procedure for sanitary inspection at each site. The sanitary inspection is used to trace faults and risk of contamination. When there is a deviation and action needs to be taken the quality team that carry out the visit write a memo to the engineering department but no follow up is on action taken. In August this year a new quantitative risk matrix was conducted and that resulted in lowering of the risk score for some of the control points and

also added some new points to the system. This new matrix was not made available to the auditor or the operational manual.

The quality department for Kampala Water has six employees. Their responsibility is to monitor the quality of water being delivered to the customers. At the booster stations and service reservoir there are attendants, at least two at each, which are stationed on the premises and are responsible for keeping them well maintained. Attendants have basic training in plumbing and engineering.

Table 6-1 Risk ranking for the sites chosen for visit (source: Godfrey et al., 2003).

Name	Population hazard	Low lying area	Pipe				Performance			Risk score
			Length	Dia-meter	Mat-erial[1]	Age	Break-age	Discont-inuity	Leak-age	
Scope of risk scores	1-4	0 and 1	1-4	1-2	6-13	1-2	1-5	1-8	1-15	
Risk scores criteria	1= Very low 2= Low 3= Med 4= High	0= No 1 = Yes	1=5-100 m 2=150-750 m 3=1000-2000 m 4=3000-4000 m	1 = 300-800 mm 2= 50-250 mm	6=PVC 10=PE 11=AC 11=DI 12= ST 13=GI	1=1959-2002 2=1929-1958	No of inspection with reported mains burst	Recorded disconti nuity	No of inspections with sign of leakage	0-15 = low risk 15-30=med.risk >30 = high risk
Gaba II WTP-treated water tank	1	1	3	1	11	0	0	0	0	17
Mutongo Service Reservoir	2	0	1	2	12	0	0	4	11	32
Namirembe Booster station	3	0	2	2	12	1	1	6	11	38
Valve Box (V1345) Mutundwe	1	0	2	2	12	1	5	4	14	41

1) PVC, PE = flexible Polyethylene, AC= Asbestos Cement, DI= Ductile Iron, SI= Steel, GI= Galvanised Iron.

From Table 6-1 on risk ranking for the site visited it can be seen that the main risk ratings on all sites visited are because of pipe material and likelihood of leakage.

The risk scores for pipe material are from 6 for PVC to 13 for galvanised iron (GI). Ductile iron pipes get the risk score 11 as of Gaba II and steel pipes get the risk score 12 as in all the other sites. Breakage is based on number of inspections with reported mains bursts and gets the risk score from 1 to 5. Highest score for breakage is at the valve box in Mutundwe. Discontinuity is based on recorded discontinuity and scored from 1 to 8 with the highest score at Namirembe booster station, a risk score of 6. Leakage scoring is based on number of inspections with sign of leakage and scored 1 to 15. Leakage scoring is high in all sites except at Gaba II, highest 14 at the valve box at the Mutundwe.

6.2.4 Challenges

Some of the challenges that were pointed out to the auditor are as follows:

- ✓ There is a lack of financial support from management to carry out necessary improvements and corrective actions to secure safety of the water.

- ✓ Vandalism of the infrastructure by local people is a risk to water safety.

- ✓ The ratio of unaccounted for water is high in Kampala Water. Non-revenue Water accounts for 38.5% of water use in Kampala in 2006/2007 while in other areas of NWSC it was 18.2% for the same period (NWSC, 2009). Some of the reasons are ageing of the networks that result in high leakage, theft of water from monitoring points and illegal water connections.

- ✓ Lack of support to the operation field team. It was planned that the field team should carry out simple monitoring and sanitary inspection at control points and bring the results regularly to the quality team. They are not willing to carry this out without some recognition of their contribution. So all regular control on critical control points is now the responsibility of the Water Quality Department.

- ✓ Difficult to mobilize other technical sections to get active involvement in WSP activities.

- ✓ Poor solid waste management among the low income communities.

- ✓ Presence of pit latrines in low lying areas coupled with poor sanitation may affect water quality, especially when latrine is near to water pipe.

6.2.5 Main findings

Findings in system assessment

- ✓ An important part of a water safety plan is to set up critical limits that are to be acted on if exceeded. Also to set up procedures to prevent recontamination such as a cleaning plan and maintenance plan. This has to be documented to be able to verify that this has been followed. There is a cleaning plan and procedure for cleaning of reservoirs is in place. It is carried out as a part of ISO 9001 but the documentation is not a part of the WSP.

- ✓ New WSP team has taken over the task of the team that was responsible for the implementing process. This new team is to take over managing the WSP and to be responsible for continuous success and improvement of the management system. It includes the following six representatives; Principal Analyst for NWSC, Quality Assurance Manager for Kampala Water, Senior Laboratory Technician for distribution, Senior Laboratory Technician for production, GIS specialist and System Development Manager. This team is still not active. It has only had one meeting at the date of the audit and that was last spring.

- ✓ There is no emergency response plan in place.

- ✓ Registration of malfunction and leakage is partly in place.

- ✓ There is registration of complaints but that is not used systematically to spot risk to water quality.

- ✓ An important factor of continuous improvement of managing risk is feedback on incidents where critical limits are exceeded and documentation on corrective action that are taken to manage that risk and to prevent it from developing into hazard. This provides the management with some verification on the functionality of the WSP. There was no systematic documentation on incidents available for inspection when asked for and there is no summary of incidents or deviation for each year.

- ✓ The distribution network system has expanded since implementation of the WSP in 2004 but there does not seem to be any plan for continuous improvement built into the WSP.

- ✓ No valid permit to show that the WSP has formally been launched as there is no specific authority to launch WSPs.

- ✓ An important support to successful WSP is to have training of the concept of WSP and water quality for a broad range of staff responsible for the water supply. It is an effective way to firmly establish the preventive approach into the working culture of the corporation. There is a training plan in place in Kampala Water but it has only partly been implemented. The plan is to have a training course once a year for the operation staff and technical supervisors in each zone to carry out regular monitoring and bring the result to the quality department. This has not worked out and the operational staff have not been keen to carry out this work as this is in their view only an addition to their workload and should be the responsibility of the quality department.

Findings in site visits

Visit to the four critical control points revealed some of the challenges that the quality staff are facing. The four critical control points that were chosen for a visit are as follows; Monitoring point at the treated water tank at Gaba II, the Mutungo Service Reservoir, the Namirembe Booster Station and Valve Box nr. 1345 at Mutundwe.

Gaba II

First visit was to the Gaba II Water Treatment Plant. It is at the shore of Lake Victoria where the water intake is for Kampala Water and water treatment plants, Gaba I, II and III are situated. The monitoring site at the treated water tank visited is the last site before the water leaves the treatment plant. The risk scores are 17.

It was noted that the manhole covers on the tank are poorly designed and could not be properly closed. There is therefore an open access for vermin and sabotage to the tank as can be seen in Figure 6-1. This is a significant risk for water quality.

Figure 6-1 Manholes at treated water tank at Gaba II.
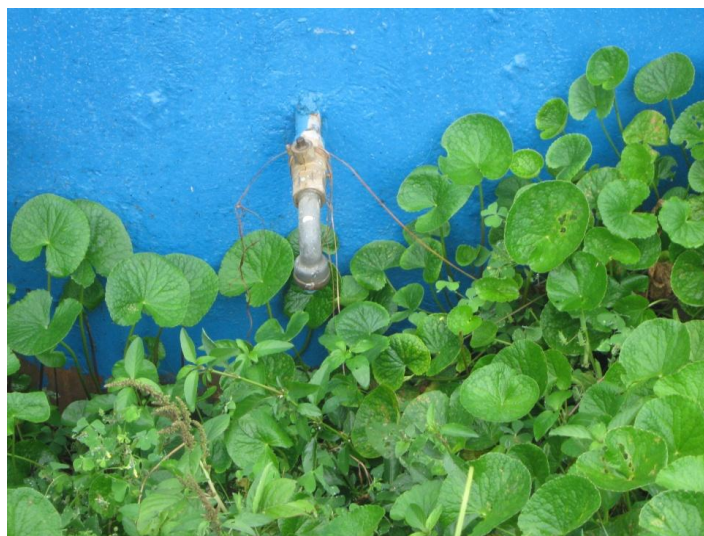
Figure 6-2 Monitoring tap site at Gaba II.

The main comments regarding the monitoring site at Gaba II water treatment tanks are as follows:

✓ There is a significant risk to water quality due to open manhole on top of the tank. The manholes are not vermin proof. This is a significant risk to water quality and this is not accounted for in the risk matrix. To repair this should be given a very high priority.

✓ The monitoring site was at the time of visit nearly covered with vegetation as shown in Figure 6-2 and this can affect results from quality monitoring. It was stated that it has to be cut very frequently. It is a better practise to have a monitoring site in a build in locker that is well kept. It should be kept in good order with regular cleaning and maintenance.

✓ Near to the tank is a gate that was open at the time of visit for staff and the families living near to the premises. At the time of the visit it was open and ongoing traffic of pedestrians. It is better practise to have restricted access to a site that is as important for water quality as the site after treatment before entering the supply net.

✓ Apart from this comments the premises looked well kept and clean.

Mutongo Service Reservoir

This site is visited by the quality team three times a month. This is a service reservoir in the low pressure zone in East Kampala, see Figure 6-3. The risk score was 32 and is now down to 26 according to Mr. Arwata. The decrease is mainly because an inlet of galvanized pipe has been replaced and this has decreased leakage. The tank had also been repaired and that stopped leakage.

Figure 6-3 Mutongo Service Reservoir.

The main comments regarding Mutungo Service Reservoir are as followed:

- ✓ The site was very well kept,
- ✓ Manholes where well locked and vermin-proof.
- ✓ No sign of leakage
- ✓ Large area is fenced in and the fencing seemed to be in good order.

Namirembe Booster station

This station is visited once a month by the quality team. The risk score is 38. Leakage is still contributing to high risk score or nearly 30% of the scores are from that category. Another high risk is from pipe material that is steel pipes. Discontinuity is also high with 6 scores out of 8. This is due to frequent power cut and lack of reserve power. There is also improper water balancing of the whole network.

Figure 6-5 Gate to Namirembe Booster station.

Figure 6-4 Attendant at Namirembe Booster station.

The main comments regarding Namirembe Booster station are as follows:

- ✓ The pumping stations seemed reasonably well kept. Housing for the attendant is on the premises. There should be strict rules on orderliness at critical control points e.g. sanitation, washing and rubbish disposal.
- ✓ The station is not fenced in. There is a gate and a part of a fencing that has not been finished and an open access to all passing by into the station. There is an urgent need to finish the fencing to be able to secure safety of the water in that area.

Valve Box (V1345) Mutundwe

This site is visited by the quality team once a month. The risk score is 41 (see Table 6-1). The site is on a busy junction with sale stalls for various commodities (Figure 6-6). The top of the valve box is used as table for cooking and when we arrived the cooking device was quickly removed (Figure 6-7). The lock on the valve box was missing (Figure 6-8). It had been stolen and the valve box is used for rubbish. The valve box was with lot of rubbish (Figure 6-9) even though it had been cleaned the week before.

Figure 6-6 Valve site.

Figure 6-7 Valve box V1345.

Figure 6-8 Lock has been stolen.

Figure 6-9 View into the valve box.

There is a high score for leakage for this site in the risk matrix, 14 out of 15 possible. Population hazard is only one out of four. This is too low a score for this site as this is a very busy junction with lot of activities and an open access to the valve box.

The main comments regarding Mutundwe Valve Box (V1345) are as followed:

✓ The valve box is in a hazardous area and many possibilities of contamination of water.

✓ The lock is regularly stolen and the valve box used as a free water source and as a rubbish bin.

✓ There is an urgent need for raising the public awareness of the importance of safeguarding the quality of the water.

6.2.6 Recommendation for improvement of WSP to secure safety of drinking water

It must be noted that this audit is only a random test of the process of WSP in Kampala Water not a thorough review of the whole process. There can be many loopholes in the process that the auditor did not recognize. It would have been better to see more of the documentation to verify if work is done as planned.

The following are the main recommendation of the auditor:

✓ The main focus should be on finishing the process of implementing the WSP and firmly establish the culture of preventive approach into the whole corporation. This should not only be the task of the quality team though they are to be the torchbearer of this new approach. It is very important to establish this approach into all aspects of water supply

and that everyone has responsibility in safeguarding water quality– "this is the way we do it here in this corporation". It would be advantageous to have a formal acknowledgement of the WSP from a governmental body.

✓ This process involves improving documentation. It is important to continuous improvement to document that what is planned is carried out and if there are deviation or critical limits are exceeded what is done to correct that to safeguard water quality.

✓ WSP is an ongoing process and it should have an in-built continuous improvement. This is best done with regular internal audit where the steering team e.g. goes through documentation and checks on deviations and reaction to the incidents, review the risk map and add in new critical control points.

✓ Regular meeting of the WSP team with agenda and minutes from the meeting to follow up on internal and external audit and necessary improvements should be held. The WSP team should include people from all level in the water works to ensure that the team as a whole has the widest possible experience and practical knowledge of the system.

✓ Conduct a plan to improve assets that are in the most need e.g. ensure that all tanks are vermin-proof and finish fencing on critical sites for water quality.

✓ Conduct a training plan for most of the staff of Kampala Water in waterborne diseases, what challenges are to safe water and how to safeguard drinking water with systematic preventive approach. Special training plan for attendant should be carried out as they are key people in safeguarding water on the spot. Regular monitoring, sanitary inspection and checking critical limits should be a recognized part of the tasks of the attendants.

✓ As it can be a hazard to have attendants with families living at critical control points there should be regular training for all that live there and strict rules on orderliness e.g. sanitation, washing and rubbish disposal.

✓ Conduct a public awareness campaign in a way that suits the local circumstances.

It is important to note that the process of preventive approach is an ongoing process not a process that can be dealt with and then forgotten. The main long term task and the one that has to be constantly worked on are to change the awareness of the staff from end-point testing to preventive approach. Of course the end-point testing is important to verify that the water that is delivered is up to national standards and is not jeopardizing the health of the consumers. But it should be kept in mind that the focus is on preventing contamination.

Kampala Water is the first city in the developing world to implement a water safety plan and is one of the case studies referred to in the 3rd Edition of the WHO Drinking Water Quality Guidelines. This demonstrates to other developing countries that the implementation of WSPs is possible and is applicable to all regardless of the economical status. The auditor is impressed by the way the corporation is working on safeguarding drinking water despite the many challenges and in many ways it is dealing with the same problems that can be seen in the developed world. This is said in light of the long experience of the auditor with WSP in her homeland, Iceland, where the implementation of WSPs started in 1997 in the capital city Reykjavik and now around 70% of the population of Iceland have their water from a water supply with WSP.

Kampala Water can be very proud of its effort and should inform the citizens of Kampala e.g. in the very ambitious annual report of NWSC and in a public awareness campaign. It is important for the consumers to know that Kampala Water is taking a systematic preventive approach to safeguard drinking water.

6.3 Comparison of WSP in Uganda and Iceland

The Uganda research investigates lessons learned in utilizing WSP in a developing country. The water utility in the capital of Uganda was the first country in Africa to implement a WSP (Davison et al., 2005). The process started in 2002 and was completed with a functioning WSP in 2004. There is therefore some years of experience and interesting to investigate similarities between lessons learned in Iceland and Uganda.

There are many parallels between Uganda and Iceland in lessons learned from WSP. This can be seen when comparing results from the research at 16 water utilities in Iceland described in chapter 3 with the experience described in the interviews with Sarah M. Tibatemwa in chapter 6.1 and from the external audit of Kampala Water in chapter 6.2. Better service and improved water safety was considered beneficial in both countries and interviewees were convinced of financial gain although it had not been calculated. In both countries knowing the water system is seen as a great benefit. Going through the process of implementing a WSP raises awareness of the staff and makes them more conscious of pathways of contamination. Improved data on performance was seen as important in both countries when asking for funding for improvements with the argument of water quality issue. The investment was also more consistent in tackling the issue of water safety. In both countries interviewees mentioned that it was good to have WSP in time of crises and in Uganda an example of such an incident was given. It was seen as important to have good contact with the health authorities. Training both in the beginning and then continuously is seen as essential in both countries, so is managerial support, especially of top management.

When looking at the obstacles and challenges there is also a lot of similarities. Both countries were the first to implement WSP in their region and had to develop it from scratch. Iceland started in 1997 and relied on the methodology of HACCP (hazard analysis of critical control points) that was developed for the food industry which is in many ways different from water supply while Uganda relied on the framework from WHO but had some challenges and had no experience elsewhere to tap into. Both have experienced lack of support and external audit from authorities and community. There has not been a regular internal audit in either country. The Icelandic survey revealed gap in documentation at nearly every utility and the situation seems to be the same in Uganda. No documentation on summary deviation incidents and subsequent corrective action were available on request, neither in Kampala nor at the 16 water utilities in Iceland. WSP teams were not active when the implementing process was over. In both countries there has been little public relation work and the public was not aware of the WSP, but both countries emphasized the importance of good public relation.

The factors mentioned above are not related to economical status of the countries and success with WSP in these areas relies more on attitude of staff, utility culture and the presence of champions at the utility to keep the process going. Other factors, such as economical means to improve the system or legal framework for water source protection are in better order in Iceland. Illegal connection to water pipes is not a problem in Iceland

while that, as well as vandalism, is problematic in Uganda. In the Uganda WSP has included a comprehensive risk mapping when doing the risk assessment and Iceland would do well in considering adapting similar methods.

Lessons are clear from this comparison between Iceland and Uganda. Corrective action have to be supported and prioritized and there is a need for improving internal and external audit as they are the driving force of WSP with follow up from authorities. There is a need to have training and guidelines for the regulator in both countries to be able to monitor performance of a WSP. It is imperative to emphasize in all guidelines the need for good and continuous training and include training in documentation. It is also important to incorporate support action to involve all stakeholders and public relations activity was lacking in both countries though seen as important for success.

The conclusion for the comparison between Iceland and Uganda is that the WSP methodology is equally adaptable in the developed and the developing world at larger utilities. Lack of reliable laboratories and legal jurisdiction over protection of water sources is more likely to be a challenge in the developing world and the poor sanitation and hygiene threatening water safety is a bigger challenge. Sustainable tariffs for water supply are problematic in the developing countries especially in the poorer peri-urban areas where people using stand-post pay more for water than in the more wealthy areas with piped water to houses. Problem arises in smaller utilities and rural areas. In both countries effort needs to be made to support the smaller utilities with external sources, educational program and guidelines. In the developing world a pictorial manual on WSP for small systems in rural areas that are adapted to the region are required if it is to be possible use WSP to increase access to improved sources.

7 Conclusions

Iceland was one of the first countries to legislate the use of WSP at water utilities. The water utilities started to use the methodology in 1997 and by 2009 81% of the population was served by water utilities with WSP. This process was initiated in 1995 when the legislator defined drinking water as food with the request of preventive management to secure safety of food. The methodology gained a rapid acceptance within the water utilities and staff welcomed this opportunity to improve the water supply system and found that it made their jobs less stressful. This research investigated the consequences of the WSP legislation on safety of drinking water and analyzed what lessons should be highlighted in continued quest for safer drinking water which benefits public health worldwide.

The research on accumulated WSP experience and lessons learned from WSP addressed if, and then what, benefits were from implementing and running WSP and what has to be in place for successful subsequent operation. Sixteen water utilities, that serve around two thirds of the population of Iceland, were investigated. The main benefits stated were the change in attitude by the staff and utility culture towards water quality and risk of contamination. Another strong influence that was considered as a great benefit was that it stimulated better knowledge of the system, more systematic workmanship in all procedures and increased proficiency of work. The main obstacles and shortcomings that came to light were lack of documentation and of regular internal and external audit. There was also little communication to the public although many mentioned that was important for success. Many important elements of success were revealed where intensive training of staff and participation of staff in the whole process was deemed the most important. It was also important to have simple and well structured guidelines and good cooperation with the health authorities. When WSP performance was correlated to underlying factors it revealed significantly higher scores at larger utilities, especially in support actions. This indicates that WSP can be effective in small systems but there is a need for real commitment and attention from authorities to support them. Training improved performance and so did both external and internal audit. There was also a correlation between the WSP scoring and good understanding of the WSP methodology.

Based on the results from the research on the WSPs a summary of recommendations were made both for existing WSP users as well as for utilities that intend to implement a WSP system. They include several steps in each of the following categories; management of human resources, improvements in operating the WSP, securing support and interest from all stakeholders. This must be supported by ongoing training and education of the water sector and the health sector on good practice in water supply and prevention of contamination. Special effort is needed to support the smaller utilities with guidelines and educational program.

The research on measureable benefits from WSP showed that water quality improved following implementation of WSP. A preliminary investigation with the two largest utilities showed improved compliance from 94% to 99% and 88% to 99%, respectively

some years before and after WSP. In depth research at five utilities of up to thirteen years before and up to ten years after implementation process supported that conclusion at four of the five utilities. Incidents of detecting *E. coli* in water samples decreased from 1.28% before WSP to 0.32% after WSP implementation and reduction in non-compliance to drinking water regulation in samples was from 10.9% to 2.3% in the distribution network. The result showed also that share of water samples with HPC over 10 cfu per ml reduced significantly and variation in sampling results decreased considerably following WSP implementation.

The research on health benefits showed a significant decrease in incidence of diarrhoea where WSP was implemented. Of the seven PHCCs where WSP had been implemented and could be analyzed before and after, five had a statistically significant decrease in diarrheal incidence following WSP implementation. This research indicates that drinking water is responsible for a part of diarrheal cases in the population with intermittent contamination most likely in the distribution network as the systematic preventive management with WSP in the operation of a water utility showed significant reduction in diarrhoea cases. From the research it can be estimated that about 14% of diarrhoea cases can be attributed to the water supply. The reduction is accomplished with preventive measures, such as regular hydrant flushing, protective procedure for maintenance, increased maintenance of the system and other improvements that are aimed at reducing the risk. This is similar result as in some other research. Hunter et al. (2005) estimated 15% of acute gastrointestinal illnesses could be associated with contamination of drinking water and Colford et al. (2006) concluded from five intervention trials that 12% can be attributed to drinking water.

The research in Uganda indicated many parallels between operating a WSP in larger utilities in a developed and a developing country. Hence, it indicates that the lessons learned from the research in Iceland are applicable to other parts of the world and is not limited to the more developed part. The parallels are for example the need for continuous training of staff and guidelines and support from the authorities with the emphasis on external audit and legal framework to support the process.

The research on the transport of pathogens in groundwater in coarse pumice at low temperature with a model comparison to an actual outbreak reveals a need for research on transport of pathogens and other contaminant in coarse strata at low temperatures as limited data is available in Iceland or abroad. In addition, the results demonstrate a need for systematic evaluation of the existing septic systems in rural areas in cold climate and setting minimal regulatory requirement and guidelines for more confident determination of safe setback distances for septic systems to protect water sources.

The research showed that there are a number of actions needed to secure safety of drinking water and continues success with WSP. These actions need to be taken in the water sector and by the regulator or the authorities that are responsible for public health. Vieira (2011) has proposed a framework for national strategy for implementing a WSP in Portugal and that methodology can also be replicated at a global level. This national framework is to work on institutional, practical and supporting mechanisms. Using this framework to outline the necessary steps for Iceland securing the functionality of WSP should be the following:

On the institutional level the following action are suggested. WSP is already mandatory in legislation in Iceland but some follow up on compliance and revision to the legislation are needed to strengthen the regulatory requirements: (1) implement legal restriction on catchments as permitted in legislation; (2) gather information on water utilities serving the inhabitants and make a list of which are to be tested according to IDWR for water quality. This list should include requirement regarding preventive management; (3) publish information on compliance to water quality requirements as stated in the regulation since 2001 and on compliance to WSP; (4) The Chief Epidemiologist at The Directorate of Health should improve registration of contaminant events and of waterborne outbreaks. This should include epidemiological investigation with report on the chain of events and follow up on incidents and close calls to be able to learn from these events with information available for the public; and (5) revision of the current drinking water regulation e.g. requirement on maintenance on infrastructure, protection of the resources, information to users, and how to secure safety of drinking water in small utilities.

On the practical level a number of actions are recommended, both at the regulatory level and at the water utility level. At the regulator level: (1) make guidelines on how to conduct an external audit of a WSP including frequency of audits, requirement on performance and how to react if not fulfilled. These guidelines should especially focus on water supply but not be included in general guidelines for the food industry as operation of a water supply is different from other food processing; (2) all WSP should be tested regularly by the auditor with an external audit and its functionality should be a prerequisite for having a working permit; and (3) improve cooperation between stakeholders regarding water safety, especially at a regional level. At the water utilities level: (1) use the recommendation given in Chapter 3.4 to produce guideline on best practice in implementing and operating a WSP; (2) ensure use of regular internal audit for example with use of the WHOs WSP Assurance tool; and (3) actively promote use of WSP in the sector with focus on the small utilities and the ones that still have not implemented WSP.

On the supporting level in research and education the following actions are recommended: (1) initiate research on status of the infrastructure and leakage from the network; (2) conduct a systematic evaluation of the existing septic systems in relation to water safety and safe setback distances; (3) initiate research on transport of pathogens in groundwater in volcanic strata to be able to decide with more accuracy the necessary size of the protection zone around a water intake, followed by guidelines on placement of septic systems; (4) initiate a joint effort in cooperation with the water sector to promote WSP in smaller water utilities with educational program and guidelines; and (5) conduct a training program for health inspectors on WSP initiated by the regulator.

In summary it is concluded that authorities need to take the initiative and create a national framework for safe drinking water with effective guidance and regular external audit of WSP and improved registering of information on water quality, compliance to legal requirements and contamination events. This information should be made easily accessible to the users as the safety of drinking water is an ongoing systematic preventive management effort that needs to be supported by all stakeholders together with a strong legal framework that allows protection and follow up on deviation incidents by authorities. The authorities, by seizing the initiative, would then acknowledge that safety of the water supply is foremost a public health issue which should take precedent over other interests.

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Appendix

Appendix 1 Survey questions for quantitative part of the research in Chapter 3.

1. Baseline information

1.1 Which WSP model was used

Which model	WHO	
	Samorka model	
	HACCP	
	5 step model	
	Other	

Comment:

1.2 Are there other management system in place	**Yes**	**No**
ISO 9001		
ISO 14001		
Other		

Which:

1.3 When was the permit for the WSP issued:

Date.	
Duration:	

Comments:

Inspect permit

1.4 How often external audit:

yearly = 1, every two years =2, every third year =3, seldom = 4, never = 5	

Inspect report on external audit:

Comment:

1.5 How often internal audit:

yearly = 1, every two years =2, every third year =3, seldom = 4, never = 5	

Inspect report:

Comment:

1.6 Critical control points and control measures	Yes	No
Number of critical control points		
Cleaning plan		
Inspections of control points		
Monitoring of critical control points		

Comment:

1.7 Monitoring at critical control points

Which monitoring:	Yes	No	Partly %	On line monitoring
Flow				
Conductivity				
Turbidity				
pH				
Temperature				

Other monitoring:

Comment:

1.8 Procedure in place	Yes	No
Catchment		
Pump-house		
When deviation		
When complaints		
Communication with users in deviation incidents		

Other:

Accessibility of procedure (e.g. on the wall) :

Inspect:

Comments:

1.9 Training plan in place	Yes	No
Is there a training plan		
Is it in use		

Inspect the training plan:

Comment:

1.10 WSP team	Yes	No

Comment:

1.11 Water quality information	Yes	No
Is water quality information gathered		
Is it accessible by users		

2 Implementing WSP

2.1 Purpose of WSP	**Classify 1- 5**
Compliance with DW quality regulation	
Better service	
Secure quality	
Decrease complaints	
Other – What;	

Comment:

2.2 What was the incitement for implementing WSP	**Classify 1- 9**
Water quality poor	
Waterborne incidents or suspicion of such	
Pressure from water board/local government/government	
Pressure from companies in the area	

Pressure from users	
Interest of staff	
Influence from other water supplies	
Influence from outside	
Other – Whom	

Comment:

2.3 How was it implemented	Yes	No
Teamwork		
Consultants mostly		
Consultants with water supply staff		
Only by staff		
Cooperation with others – who:		

Comments:

2.4 Time from start until accepted by health authorities	
Number of months	

Comments:

2.5 Support of WSP	Classify 1 – 5 5 big support, 4 some support, 3 neutral, 2 wanted other methods, 1 against
Local government	
Municipalities /technical	
Health Authorities	
Companies	
Association of water utilities	
Other water utilities	
Others –	

Comments:

2.6 What part of the system is in use today	Yes	No	Parlty %

Documentation			
Control of critical control points			
Cleaning plan			
Deviation documentation			
Complaint documentation			
Training plan			
Emergency plan			

Comment:

Inspect:

3 Benefit of WSP

3.1 Attitude of staff and users	Classify frá 1 – 5 5 positive, 4 reasonably positive, 3 neutral, 2 some dissatisfaction, 1 dissatisfaction
Attitude of staff before implementing	
Attitude of staff after implementing	
Attitude of users before implementing	
Attitude of users after implementing	

Comments:

3.2 Improvement after WSP	Yes	No	Partly %	Does not apply
Fencing of water intake				
Protective measures of catchment				
Water intake				
Water Treatment				
Water mains				
Distribution Network				
Pump stations				
Control equipment				

Housing (e.g. building valve chambers)				
House connections				

Other improvements in assets – which

3.3 Improvements in procedure after WSP	**Yes**	**No**	**Partly %**
Orderliness on catchment			
Procedure with maintenance			
Procedure with tender			
Procedure with chemicals			
Procedure with cleaning tanks and pipelines			

Other - which

3.4 Documentation improved	**Yes**	**No**
Was there increase in documentation		

3.5 Cost of implementing

What is the estimated cost of implementing WSP	
Comments	

3.6 Cost of improvement

What is the estimated cost of improvements done	
Comments	

3.7 Yearly cost of regular control

Estimated cost of regular control	
Comment	

Appendix 2 Survey questions in qualitative part of the research in Chapter 3 (semi open questions).

1.	**Background information**
1.1	How long have you been working in the water utility
1.2	What is your status
1.3	What education and experience do you have that is useful in your work
1.4	Is water supply your only scope of work
1.5	Have any of the staff attended the comprehensive training course for workers in the field
1.6	Who is responsible for WSP
1.7	Who carries it out

2	**Implementing process**
2.1	Describe the WSP
2.2	What is the idea behind it
2.3	Who initiated the process (staff, board, public health people, customer or other)
2.4	Where there any obstacles and if so which
2.5	Was something lacking in the implementing process that would have helped the process
2.6	What is the best way to implement a WSP
2.7	Which part of WSP is working and which are not

3.	**Important for success**
3.1	What is important to succeed with WSP internally in the utility
3.2	What is important to succeed with WSP externally

4.	**Benefits from WSP**
4.1	What are the benefits of WSP (operational, externally etc.)
4.2	Can you name examples of financial gain

5.	**Obstacles and lacking in operating a WSP**
5.1	What is the main problem for this water utility
5.2	What are the obstacles in running the WSP
5.3	What is still lacking

6.	**Supporting actions**
6.1	Are there some procedures for complaints
6.2	Have you done any PR work related to WSP
6.3	Do you publish any guidelines on water savings
6.4	Does the water utility have a website
6.5	Is there information on water quality on the website
6.6	Is there information on WSP on the website
6.7	Was training included in the implementing process
6.8	Is there ongoing training
6.9	Describe internal audit
6.10	Describe external audit

7	**Other**
7.1	What is the worst that could happen (what is your nightmare)
7.2	Are staff worried about illness because of water

7.3	Have you noticed change in attitude towards the utility
7.4	What mitigating measures have been taken to improve the water supply system and water quality
7.5	Did you change the WSP system in the process
7.6	Are any change in WSP on the agenda

Appendix 3 Letter of invitation for External Audit of Kampala Water.

NATIONAL WATER & SEWERAGE CORPORATION

TELEGRAMS WATERS KAMPALA	HEAD OFFICE	P.O. Box 7053

Telephone: 256 - 41 - 315000
        256 - 31 - 260414/5
    Fax: 258299/345531/346447/346532
  Email: info@nwsc.co.ug
        KLA/CL/WSP
Our Ref:_____

PLOT 39 JINJA ROAD
KAMPALA

29th October, 2008

Ms. Maria Gunnarsdoltir
Samorka
108 Reykjavik
Iceland

Dear Ms. Gunnarsdoltir,

Invitation to carry out External Audit of Kampala Water

National Water and Sewerage Corporation, and specifically, Kampala Water developed Water Safety Plan (WSP) from the in-take to the distribution network in 2004. Since that time, WSPs have been partially implemented. The WSPs have never been audited by an External Auditor since its implementation due to lack of experienced personnel in the field. I am made to understand that you are willing to carry out an External Audit on the system during the 3rd week of November, 2008.

This letter is to formally invite you to carry out a WSP Audit of the Kampala Water System in November, 2008.

Yours faithfully,

Eng. Alex Gisagara
For: MANAGING DIRECTOR

c. c.   General Manager, Kampala Water
c. c.   Quality Control Manager, NWSC
bcc.   Manager, Gaba Water Works
bcc.   Quality Assurance Manager, Kampala Water

"NW&SC - Water is Good Water for Public Health"

Appendix 4 Letter with update on follow-up activity to External Audit of Kampala Water.

NATIONAL WATER AND SEWERAGE CORPORATION

Our Ref: KLA/CL/49

Date: August 17, 2011

Dear Maria,

I would like to thank you for the work you did with us. The audit exercise and the report is actually still referred to as a benchmark for our follow-up activities.

General brief:

The Directorate of Water Resources Management (DWRM) in the Ministry of Water and Environment (MWE) has, in the last 2 years (roughly), taken keen interest in working with water supply utilities in Uganda to develop and implement WSP as a means of system and product quality assurance. Senior staff of DWRM have been attending regional for a and a few sensitization/ training sessions been held with some private water operators and bottled water supplies. Also to note is the National Water Quality Strategy recommends use of WSP by all water suppliers companies and the 2008 version of the National Standards for drinking water quality also states that WSP has to be implemented by all water supply companies as a mandatory requirement.

The above notwithstanding, WSP still remains poorly institutionalized in Uganda, the issue mainly being low management commitment, poor resource allocation and possibly inadequate awareness of the concept and its benefits.

The main area of inadequacy for NWSC is catchment management and source protection. For all our sources, we have no mandate and control on the activities in the immediate catchments of our sources. We also have a big challenge in the area of quality at the consumer's premises, where cases of recontamination are out of our control. We only rely on community sensitization which is not adequately done.

Status of audit findings

On the status of the findings and recommendation of the audit, below is what is on the ground.

- The manhole cover on the final water (clear well) tank (Picture 1) that was found half covered has since been properly covered. The is hence no risk of entry of vermin into the treated water.
- The filtered water sampling point (Picture 2) at Gaba II is now well maintained, the vegetation is kept very low. The protection valve box was however not constructed as recommended.
- The small pedestrian access gate into the Gaba II-Gaba III remains open and so the risk of entry by unauthorized people still exists. Plant management thinks it is only duty staff that use it but total restriction of un authorized people may not be guaranteed.
- The Mutungo reservoir (Picture 3) is still well kept as it was found at the time of audit.

- Namirembe booster (Picture 4 and 5) still well maintained, the fence is properly fixed. The issue of staff residence and sensitization on hygiene and other precautions still remains but is relatively low rank risk. The staff's family is aware and keeps clear of the facilities but cannot be fully guaranteed.
- Mutundwe Valve box (V1345) conditions remain more or less as was found at the time of audit. Hygiene is still substandard, the lock keeps getting vandalized but replaced immediately to avoid illegal water use. The WQ monitoring team talks to the residents whenever they visit the site but the message may not reach all that should be targeted.

Regards and all the best in your career,

Christopher Kanyesigye
Manager, Quality Control