Water Quality Monitoring Practices Assessment Report

A Report Prepared for the GEF-IWEco National Sub-Project in St. Kitts and Nevis for the project entitled, "Upgrading Water Quality Monitoring Protocols in St. Kitts and Nevis".

Final report submitted by Ambient Environmental Consulting Inc.

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Scope of Work

A document detailing a comprehensive assessment of water quality (potable, recreational and wastewater) monitoring practices (sampling and analysis protocols, identification of sampling points with maps and GPS coordinates, equipment, human resources, data storage and analysis and overall enabling environment), gaps and recommendations for improved monitoring practices inclusive of human and physical assets for both St. Kitts and Nevis.

1. Overview

This report was prepared following field and laboratory assessments conducted by Dr. Quincy Edwards in Nevis on August 25 and in St. Kitts on September 28, 2021, as well as face to face or virtual interviews, or communication media exchanges by members of the consulting team with the individuals listed in Appendix I. The report is divided into separate assessments of current water quality monitoring practices in Nevis and in St. Kitts, respectively, followed by observations and recommendations that apply to both locations.

2. Assessment of Water Quality Monitoring in Nevis

2.1 Water resources and institutional roles

On the island of Nevis, drinking water is pumped from groundwater resources using several wells located around the island, as well as from a small number of surface springs. A national report on water resources in St. Kitts and Nevis published in 2001 (Department of Environment, Ministry of Health and Environment, 2001) provided details on water resources in Nevis. A later report on the water resources in selected Caribbean states, including St. Kitts and Nevis released in 2004 by the US Army Corp of Engineers provided valuable quantitative data on yields and consumption of surface water and groundwater resources in both St. Kitts and Nevis (US ACE, 2004). More recent information on water resources and the water distribution system in Nevis was included in a paper by Williams (2010) on "The State of the Water Resources of St. Kitts and Nevis". In Nevis, surface waters and groundwater are pumped to storage tanks, where there is chlorine disinfection prior to distribution to homes and businesses. There are no recent data on aquifer recharge rates on Nevis to determine the sustainability of the water resources. However, the clay substrate and low rainfall in Nevis limit recharge on the island (Department of Environment, Ministry of Health and Environment, 2001).

On the island of Nevis, the Water Department has the responsibility for collecting and testing water samples. The Water Department also has responsibility for maintaining the water pumping, disinfection and distribution systems. The Nevis Water Department is supported by a yearly stipend provided by the Nevis Island administration. Analysis of samples on a fee-for-service basis for independent clients is an additional source of revenue.

2.2 Scope of water quality monitoring

The primary focus of water quality testing in Nevis is monitoring of potable water, which is conducted by collecting samples of treated water at locations throughout the drinking water distribution system, as well as monitoring of untreated water at the wellheads and surface water springs. The sampling locations on the island are listed in Table 2.1 and a map showing the locations of these sampling stations is provided in Appendix II. The standpipes in the water distribution system and sources of surface water are sampled monthly (Tuesdays) and water storage tanks and wells are also sampled monthly (Wednesdays). Personnel use a vehicle shared with other government departments to travel to the sampling sites. The water in the storage tanks is chlorinated at discharge into the distribution system three times per week (Monday, Wednesday and Friday) by the metered addition of "chlorination pellets" (i.e., calcium hypochlorite).

Additionally, the Water Department in Nevis conducts regular testing on a fee-for-service basis for samples supplied by two commercial bottle companies (i.e., Nelson Spring Bottled Water, Nevis Spring Bottled Water), and *ad hoc* samples collected from the cisterns of private homes. Staff at the Water Department advised that it would be optimal to add two additional surface water sites at Jessup's Spring and Maddens Spring to the water quality monitoring timetable. In addition, staff advised that the aquifer that provides potable water to the prison and the prison farm on the island is currently not being tested for water quality. Coastal recreational waters are not currently being monitored for water quality by the Water Department, but in a previous report, concerns were expressed over the quality of recreational waters in Charleston, Mosquito Bay, Gallows Bay and Pinney's Beach (Department of the Environment, Ministry of Health and Environment, 2001).

The Nevis Water Department does not sample or test domestic wastewater. The only wastewater treatment facility on Nevis is located at the Four Seasons Hotel and Resort. The hotel does its own in-house monitoring of the treated wastewater for pH, biological oxygen demand (BOD) and chlorine (indicating that the effluent is disinfected with chlorine). There is no monitoring of this facility by the Water Department. All other domestic sewage generated on the island is collected and treated in septic systems or is deposited in latrines.

2.3 Staff and laboratory space

The four staff that collect and process water samples include a Senior Laboratory Technician, a Laboratory Technician, an Assistant Laboratory Technician/Driver and an Assistant Laboratory Technician. The Senior Laboratory Technician received on-the-job training in the past from the St. Kitts and Nevis Bureau of Standards, as well as water operators training in Jamaica, a short course on Introduction to Lab Testing in St. Lucia and a short course in Water Testing offered in Trinidad. The Laboratory Technician received on-the-job training at the Bureau of Standards laboratory. The other staff were trained on the job by the Senior Laboratory Technician and Laboratory Technician. The Manager of the Water Department provides oversight and evaluates the data generated by laboratory personnel.

All water quality testing is conducted in a small laboratory in Nevis. No fume hood or sterile cabinets are present in the laboratory, and there are no eye wash stations or emergency shower. There is no lockable safety storage cabinet for reagents. Analyzed samples and reagents are disposed of in the lab by flushing down the drain.

Table 2.1: Sampling sites for water quality monitoring in Nevis. N/A = Not available.

Sampling Site	Sample Type	Lat/Long and GPS Coordinates		
Fothergill's Well Bead	Well water	17°8'39.5"N 62°33'41.7"W	17.1443	-62.56158
Padlock #1	Well water	17°8'30.8"N 62°32'47.7"W	17.14191	-62.54655
Padlock #2	Well water	17°8'30.8"N 62°32'51.3"W	17.14188	-62.5476
Padlock #3	Well water	17°8'28.9"N 62°32'52.3"W	17.14399	-62.54786
Zion Well	Well water	17°8'38.5"N 62°32'45.5"W	17.14404	-62.54605
Butler's Well #1	Well water	17°10'19.2"N 62°33'6.7"W	17.17198	-62.55187
Butler's Well #2	Well water	17°10'19.9"N 62°33'1.1"W	17.1722	-62.55030
Maddens #1	Well water	17°10'22.9"N 62°33'8.8"W	17.17301	-62.5525
Maddens #2	Well water	17°10'22.9"N 62°33'8.6"W	17.17301	-62.5524
Maddens #3	Well water	17°10'30.5"N 62°33'6.2"W	17.1514	-62.55165
Maddens Well Bead	Well water	17°10'25.5"N 62°33'36.2"W	17.17373	-62.56006
Hamilton Well Bead	Well water	17°8'8.4"N 62°36'46.9"W	17.13578	-62.61304
Nevis Peak	Surface water	17°8'37.4"N 62°34'18.6"W	17.14378	-62.57185
Camp Spring	Surface water	17°11'22.5"N 62°34'42.5"W	17.18960	-62.57844
Happy Hill	Standpipe	17°8'19.6"N 62°37'38.4"W	17.13881	-62.62738
Stoney Grove	Standpipe	17°8'1.1"N 62°37'7.9"W	17.13362	-62.61891
Hamilton Reservoir	Standpipe	17°8'17.9"N 62°36'46.8"W	17.13833	-62.61301
Church Grounds	Standpipe	17°7'52.1"N 62°35'57.6"W	17.13132	-62.5993
Brown Pasture	Standpipe	17°7'51.8"N 62°35'42.2"W	17.13107	-62.59503
Rice's Village	Standpipe	17°7'51.3"N 62°33'55.1"W	17.13093	-62.56527
Zion Village	Standpipe	17°8'42.5"N 62°33'11.1"W	17.14516	-62.55307

Adventist Church	Standpipe	17°9'53.7"N 62°32'55.9"W	N/A	N/A
Bricklin Village	Standpipe	17°11'4.5"N 62°33'33.2"W	17.18460	-62.55927
Almond Garden	Standpipe	17°11'52.6"N 62°34'30.1"W	17.19801	-62.57532
M & M Auto	Standpipe	17°11'52.2"N 62°34'35.4 "W	17.19790	-62.57652
Cotton Ground	Standpipe	17°10'29.9"N 62°37'8.6"W	17.17497	-62.61904
Jessup's Village	Standpipe	17°9'40.1"N 62°37'29.9"W	17.16117	-62.625

2.4 Water quality testing, data management and dissemination

There are no written protocols for collecting water samples in the field. Water samples are not coded and there is no chain-of-custody procedure for the collection and tracking of the samples. Sample bottles are re-used after cleaning with soap and water and disinfection with bleach solution and autoclaving.

In the Water Department, there is no written documentation of laboratory procedures for water quality testing. However, staff advised that the procedures generally follow the methods described in a manual acquired by the Senior Lab Technician at a training course he attended in 1996 at the Caribbean Environmental Health Institute (CEHI) in St. Lucia (USAID/WWP/CEHI, 1996). The laboratory staff usually run a lab blank sample during water quality testing, especially for bacterial measurements.

The water quality parameters and the methods used for analysis are summarized in Table 2.2. Lab equipment can be serviced or calibrated at the St. Kitts and Nevis Bureau of Standards. However, most of the lab equipment has not been calibrated since acquisition. There is no documentation of equipment calibration registered in the laboratory logbook.

Water quality data are hand-written on data sheets and then copied into Excel files. These files are shared with Water Department Manager via email on a weekly or monthly basis. The Water Department Manager is responsible for sharing the data with personnel in other government departments.

According to the Water Department Manager, if there is evidence of a major water contamination issue, water samples will be immediately re-tested in Nevis. If the water contamination problem is confirmed, water samples will then be sent to the St. Kitts and Nevis Bureau of Standards for testing, and/or by the Caribbean Public Health Agency laboratory in Trinidad or a fee-for-service laboratory in Miami. Water extractions at specific wells or at surface water sites can be temporarily halted or permanently decommissioned, depending on the results of these tests.

Table 2.2: Water quality parameters tested by the Water Department in Nevis and the methods/instrumentation used for the analysis.

Parameter	**Location**	**Method/Instrument**
Temperature	Field	Infrared temperature monitor
pH	Field	HACH water quality test strips and HACH Pocket Pro+
Total hardness	Field	HACH water quality test strips
Turbidity	Field	HACH 2100Q turbidity meter
Conductivity	Lab & field	Hach Sension 7 (lab) and HACH 2100Q conductivity meter (field)
Salinity	Lab & field	HACH Sension 7 (lab) & HACH Pocket Pro+ (field)
Total dissolved solids	Lab & field	HACH Sension 7 (lab) & HACH Pocket Pro+ (field)
Chloride	Field	HACH water quality test strips
Total chlorine & free chlorine	Field	HACH water quality test strips
Total coliforms	Lab	Membrane filtration and plate count method
Faecal coliforms	Lab	Membrane filtration and plate count method

Note: The HACH Sension 7 is a benchtop meter for analysis of TDS, salinity and conductivity. The HACH pocket Pro+ Multi-2 is a multi-parameter field meter for analysis of pH, TDS, salinity and conductivity.

3. Assessment of Water Quality Monitoring in St. Kitts

3.1 Water resources and institutional roles

In St. Kitts, potable water is sourced from both groundwater and surface water. Although out of date, a consultant's report published in 1999 provided an overview of the water supply and management situation in St. Kitts (PAHO, 1999). A report released in 2004 by the US Army Corps of Engineers also provided a comprehensive evaluation of surface water and groundwater resources in St. Kitts at that time (US ACE, 2004). According to a study conducted over 20 years ago, 11.75 million Imperial gallons per day was the estimated total amount of water that could be tapped from the aquifers in St. Kitts (Department of the Environment, Ministry of Health and Environment, 2001). In 2004, the total annual groundwater yields in St. Kitts were estimated as 20 million m^3 (US ACE, 2004). The annual water production in St. Kitts in 2009 was estimated to be 751 million Imperial gallons for surface water and 1,310 Imperial gallons for groundwater (Williams, 2010). At that time, the "safe yield" of groundwater was estimated to be 11 million Imperial gallons per day, similar to the earlier estimate from Department of the Environment, Ministry of Health and Environment (2001), and since the amount withdrawn in 2009 was 6 million Imperial gallons per day, it was suggested that growth in water demand could be managed in a "sustainable manner" (Williams, 2010). However, water shortages are now being experienced in some regions of St. Kitts, and most acutely in the Frigate Bay area. There are declining water levels in the well-field tapping the aquifer in the Basseterre Valley (IWCAM, 2011).

In St. Kitts, the Water Services Department has the responsibility for operating the water treatment plant and for chlorine disinfection of water in storage facilities, as well as for the installation, maintenance and operation of the water distribution system. There is treatment of raw drinking water at the La Guerite Treatment Plant in St. Kitts which provides water to the Basseterre area. Treatment at this facility includes sedimentation, sand filtration and disinfection with chlorine gas added from pressurized cylinders. All other raw drinking water is treated by chlorine disinfection only. The Department of Environmental Health currently collects potable water samples from locations throughout the water distribution system and conducts the tests in the field and laboratory for basic water quality parameters. The laboratory testing is done by staff of the Department in designated space within the laboratory of the St. Kitts and Nevis Bureau of Standards.

The Water Services Department in St. Kitts currently lacks the equipment, staff and resources to carry out a water monitoring programme. However, the Manager of the Water Department has expressed an interest in acquiring the capability for in-house water quality monitoring. The Department of Environment in St. Kitts has conducted periodic sampling of marine waters, including waters near recreational beaches. These samples have been analyzed for a range of water quality parameters by the St. Kitts and Nevis Bureau of Standards.

The Department of Environmental Health receives a yearly stipend to fund its monitoring operations from the government of St. Kitts and Nevis through the Department of Finance. The Bureau of Standards receives fee-for-service funding for analysis of water samples provided by government departments, as well as private entities, such as the Marriot Hotel and the St. Kitts Biomedical Research Foundation, and from commercial bottled water companies.

3.2 Scope of water quality monitoring

The primary focus of water quality testing in St. Kitts is monitoring of potable water, which is usually conducted on the last Tuesday and Wednesday of each month. Samples include untreated and treated drinking water and samples of treated water collected from sites located throughout the drinking water distribution system. Table 3.1 lists the locations for sampling of water from the treatment plant, and from standpipes and tap water. A map of the sampling points in St. Kitts is provided in Appendix III.

According to staff with the Department of Environmental Health, it would be optimal to add the following locations for monitoring potable water at standpipes: New Road housing area (Basseterre), Shadwell area (Monkey Hill) and locations in the Southeast Peninsula, as well as some additional sites in the countryside. Other additional sites include Mattingly Heights and Ogees. There is currently no monitoring program for untreated water at the wellheads and at surface water collection sites.

Monitoring of wastewater is currently not included within the mandate of either the Water Department or the Department of Environmental Health. Most domestic sewage in St. Kitts is collected in septic systems or deposited in latrines. There are package wastewater treatment facilities at the Marriott Hotel (Royal Utilities), the Park Hyatt Hotel, the Four Seasons Hotel, the Ross University School of Veterinary Medicine, and the Joseph N. France General Hospital. The Royal Utilities plant also collects and treats domestic sewage originating from the Half Moon Bay developments. Notably, a dedicated wastewater treatment plant is included in the design of the proposed new Basseterre High School.

Table 3.1: Sampling sites for water quality monitoring in St. Kitts. N/A = Not available.

Code	Sampling Sites	Sample Type	Lat/Long and GPS Coordinates		
WF1	T.P Inflow	Treatment plant	17°18'03.9"N 62°44'11.3"W	17.30109	-62.736476
FS1	T.P Inflow	Treatment plant	17°18'04.1"N 62°44'11.4"W	17.301133	-62.736491
LG1	T.P Outflow	Treatment plant	17°18'02.4"N 62°44'07.8"W	17.300658	-62.735506
LG2	Cardin Ave.	Standpipe	N/A	N/A	N/A
LG3	Sandown Rd.	Standpipe	17°17'42.9"N 62°43'09.9"W	17.295247	-62.719407
LG4	Port Zante	Standpipe	17°17'32.2"N 62°43'26.2"W	17.292275	-62.723933
JNF	Hospital	Standpipe	17°17'50.7"N 62°44'12.4"W	17.297425	-62.736766
BA1	Customs	Standpipe	N/A	N/A	N/A
BA2	Frigate Bay	Standpipe	17°16'54.2"N 62°41'22.8"W	17.281733	-62.689674
BA5	Morne Peak	Standpipe	17°18'56.7"N 62°42'24.7"W	17.315752	-62.706848
CA1	Parray Village	Standpipe	17°17'25.0"N 62°41'56.7"W	17.290285	-62.699094
CA2	St. Peter's Village	Standpipe	N/A	N/A	N/A
CH1	Christophe Hbr.	Standpipe	17°19'03.9"N 62°43'29.1"W	17.317735	-62.724737
KE1	Keys	Standpipe	N/A	N/A	N/A
CA4	Cayon	Standpipe	17°20'20.7"N 62°42'39.6"W	17.339086	-62.711008
LO1	Lodge Village	Standpipe	17°21'05.3"N 62°44'02.3"W	17.351475	-62.733967
PH1	Molineux	Standpipe	17°21'57.2"N 62°45'01.0"W	17.365898	-62.750290
MA1	Mansion	Standpipe	17°22'09.3"N 62°45'18.3"W	17.369235	-62.755081
TA1	Tabernacle	Standpipe	17°22'57.8"N 62°45'25.4"W	17.382710	-62.757045
SV1	Saddler's Village	Standpipe	17°23'21.8"N 62°46'07.7"W	17.389390	-62.768815
PR1	Dieppe Bay	Standpipe	17°24'16.8"N 62°47'33.9"W	17.404661	-62.792737
SP1	St. Paul's Village	Standpipe	17°24'53.4"N 62°48'50.6"W	17.414837	-62.814048

OR1	Newton Ground	Standpipe	17°24'24.6"N 62°50'10.1"W	17.406823	-62.836125
SG2	Sandy Point	Standpipe	17°23'23.7"N 62°51'03.7"W	17.389910	-62.851033
WF3	Old Road	Standpipe	17°21'31.5"N 62°50'54.4"W	17.358757	-62.848442
WF2	Halfway Tree	Standpipe	N/A	N/A	N/A
BH1*	Brimstone Hill restaurant/canteen	Tap water	-	-	-
BH2*	Brimstone Hill orientation room	Tap water	-	-	-

*These codes were assigned in this report for the purposes of showing the sampling location on the map in Appendix III.

Coastal water sampling is conducted only occasionally in St. Kitts. In 2021, a coastal sampling campaign was conducted only once in July at Camps, Lime Kiln and Basseterre Harbour by the Department of Environmental Health in collaboration with the St. Kitts and Nevis Bureau of Standards. The following parameters were tested in these marine samples: BOD, dissolved oxygen, pH, nitrate and phosphate, faecal coliforms, and intestinal *Enterococci*. Some other coastal locations that have been monitored in past sampling campaigns include recreational beaches along the coast of Frigate Bay and the Southeast Peninsula. An additional concern for the quality of coastal waters in St. Kitts is the spillage of oil and other petroleum products (e.g., fuel) from fishing ports, marinas and harbours.

The St. Kitts and Nevis Bureau of Standards has the capacity and the equipment to test a wide range of water quality parameters in samples of drinking water, marine waters and wastewater on a fee-for-service basis. This laboratory has conducted the analysis of marine waters collected in past sampling campaigns organized by the Department of Environmental Health in St. Kitts.

3.3 Staff and laboratory space

The four staff that collect and process water samples in St. Kitts include a Senior Environmental Health Officer, an Environmental Health Officer, and two Vector Control Officers. In the past, the Senior Environmental Health Officer received training from the St. Kitts and Nevis Bureau of Standards, as well as a course on Certified Laboratory Training delivered by the Caribbean Public Health Agency in St. Lucia. One of the Vector Control Officers received training in water sampling and the other Vector Control Officer received public health training. The Environmental Health Officer also received public health training. The junior staff are primarily trained on the job by the Senior Environmental Health Officer. The Chief Health Officer in St. Kitts provides oversight and evaluates the data generated by laboratory personnel.

The Department of Environmental Health has a small, designated space within the laboratory of the Bureau of Standards where water quality analyses are conducted. The Bureau of Standards has sterile cabinets, eye wash stations and a safety shower, as well as lockable reagent storage cabinets. Analyzed samples and reagents are disposed of in the lab by flushing down the drain.

3.4 Water quality testing, data management and dissemination

There is no written documentation of field collection methods or laboratory procedures for water quality testing by the Department of Environmental Health. The Report on the Development of a Water Sampling Program for St. Kitts and Nevis (PAHO, 1999) provides a general guide for the design of a water quality testing programme in St. Kitts, but this report does not document any detailed standard operating procedures (SOPs). Water samples collected in St. Kitts are coded (Table 3.1), but there is no chain-of-custody procedure for tracking the samples. Sample bottles are re-used after cleaning with soap and water and disinfection with bleach solution, followed by autoclaving. The laboratory staff usually run a lab blank sample during water quality testing, especially for microbiological analysis and measurements of free chlorine. The water quality parameters and the methods used for analysis are summarized in Table 3.2. Lab equipment is periodically calibrated according to the instructions provided by the equipment manufacturers. However, there is no logbook for documentation of equipment calibration.

Table 3.2: Water quality parameters tested by the Department of Environmental Health in St. Kitts and the methods/instrumentation used for the analysis.

Parameter	**Location**	**Method/Instrument**
Temperature	Field	Mercury thermometer
pH	Lab	Orion Model 250A (inoperable)
Turbidity	Lab	LaMotte 2020e Turbidity meter
Conductivity	Lab	HACH Sension 7
Salinity	Lab	HACH Sension 7
Total dissolved solids	Lab	HACH Sension 7
Free chlorine	Field	HACH Pocket Colorimeter II MR and MH
Total coliforms	Lab	Membrane filtration and plate count method
Faecal coliforms	Lab	Membrane filtration and plate count method

Note: The HACH Sension 7 is a benchtop meter for analysis of TDS, salinity and conductivity. The pH meter owned by the Bureau of Standards is currently not working.

Water sampling data are entered by hand onto datasheets and these data are later transcribed onto an Excel spreadsheet. The spreadsheets are emailed to the Chief Health Officer on a monthly basis. The Chief Health Officer is responsible for sharing the data with other government departments in St. Kitts.

If there is evidence of a major contamination issue in drinking water samples, the samples will be immediately re-tested by the Department of Environmental Health. If the water contamination problem is confirmed, water samples will then be tested by the St. Kitts and Nevis Bureau of Standards, and/or by the laboratory of the Caribbean Public Health Agency in Trinidad or a fee-for-service laboratory in Miami.

4. Evaluation and Recommendations

4.1 Water quantity and quality

Periodic water shortages during the dry season in some areas of the island of St. Kitts indicate that withdrawals of water from aquifers are currently at or exceed the rates of groundwater recharge. In Nevis, increasing salinity observed in some coastal aquifers may indicate saltwater intrusion caused by water withdrawals that exceed recharge. An assessment of water resources in selected Caribbean states, including St. Kitts and Nevis conducted in 2004 by the U.S. Army Corps of Engineers concluded that surface water and groundwater resources on both islands were stressed and saltwater intrusion was a threat to groundwater quality (US ACE, 2004). The impacts of climate change, including prolonged periods of drought, extreme weather events that lead to rapid runoff without adequate time for recharge, and sea level rise causing saltwater intrusion into aquifers may exacerbate water quantity and quality problems over the medium to long term (CWWA, 2018). Hydrological studies to estimate rates of groundwater recharge vs. current and future water withdrawals are urgently needed to ensure the sustainability of the supply of potable water. These investigations may be part of a pending drought modelling study for St. Kitts and Nevis funded through the UNEP Adaptation Fund and implemented through the Department of Environment.

An evaluation by the consultants of a small subset of recent water quality data collected in Nevis at source and at standpipes indicates that the potable water is generally of good quality, except for the high salinity readings in water from a few of the wells. In St. Kitts, there is currently no regular monitoring of wells and surface waters by either the Water Department or the Department of Environmental Health, so no data were available for the consultants to evaluate the quality of the sources of drinking water. However, water quality data provided to the consultants for samples collected in July of 2021 at the intake of the drinking water treatment facility before treatment (i.e., raw drinking water) indicated that there are elevated levels of faecal coliforms (>300 CFU/100 mL) in the untreated water. In a study of the Basseterre aquifer conducted by the Colorado School of Mines (2006), faecal coliforms were found in samples from all wells tested, with “The Factory” well having the highest counts of 15.8 CFU/100 ml, while the other three wells had counts of between 0.2 and 2 CFU/100 ml. The consultants also received anecdotal information that some sources of groundwater in St. Kitts have elevated levels of nitrates. Overall, there is evidence of poor quality of the water from some sources in St. Kitts, but without a comprehensive program for monitoring these sources of potable water, it is currently not possible to assess the extent or the severity of the problem. It would be a priority to monitor these “source waters” for water quality parameters on at least a quarterly basis.

In many jurisdictions in North America and Europe, “Source Water Protection” strategies have been implemented to maintain the quality of potable water. This multi-barrier approach is based on the concept that there are four barriers for ensuring access to high quality potable water: i) protecting the sources of the water, ii) the drinking water treatment system, iii) the water quality testing procedures, and iv) the water distribution system. It is recommended that a Source Water Protection strategy be adopted in St. Kitts and Nevis. To a large extent, this approach has already been adopted in Nevis, where source water samples are collected from wellheads and surface waters for testing. It is recommended that a similar monitoring program to test the quality of waters at source be implemented in St. Kitts. A further refinement of this strategy is Source Protection

Planning, which involves the delineation of well head protection zones and surface water intake protection zones and the development of policies and regulations to reduce threats to these zones. The establishment of the Royal Basseterre Valley National Park in the well field that accesses the Basseterre Valley aquifer is consistent with Source Protection Planning. Well head protection planning was recommended by Ocean Earth Technologies Consortium (2009) to protect groundwater resources within the Basseterre Valley aquifer in St. Kitts.

4.2 Monitoring of drinking water

Currently, the water quality monitoring programs in both St. Kitts and Nevis are focused on ensuring access to high quality drinking water for the populations inhabiting both islands. This should continue to be the highest priority because of the obvious need to protect the health of the island citizens, and in some cases, of island visitors and tourists. However, there are several aspects of the current practices for monitoring potable water for which improvements are warranted. In the critical evaluation below, when upper limits for drinking water quality are discussed, the Guidelines for Canadian Drinking Water Quality (GCDWQ) published by Health Canada (2020) and/or the regulations published by the World Health Organization (WHO, 2017) are presented as relevant water quality benchmarks.

4.2.1 Water sampling protocols

There is a strong need to develop written SOPs for field collection of water samples in both St. Kitts and Nevis. Procedures such as the time taken to run water from the standpipes prior to collecting samples and the handling of sample bottles prior to and following sample collection should be standardized. Bottles for microbiological analysis of samples collected from the water distribution systems should contain sodium thiosulphate (i.e., 0.1 mL of 10% solution added before sterilization) to neutralize the free chlorine. Sample bottles should be coded for ease of sample tracking after collection. The time of collection and the time of delivery of samples to the laboratory should be recorded.

4.2.2 Water quality parameters

There are currently no written SOPs for the analysis of water quality parameters in the field or in the laboratory to direct the personnel charged with monitoring water quality in both St. Kitts and Nevis. It is clearly a priority to develop manuals that document in detail the methods that are required to conduct these analyses, as well as quality control measures needed to ensure the accuracy of the measurements.

The three most critical water quality parameters for protecting the health of the populations of St. Kitts and Nevis are: i) Levels of indicator bacteria, ii) Levels of residual chlorine, and iii) Turbidity. In addition, to evaluate the potential for contamination of freshwater aquifers by salt water, monitoring of salinity is also recommended. Each of these parameters critical for the protection of human health are discussed individually (below). In addition, there is a discussion of other water quality parameters that are not considered a hazard to human health but have water quality guidelines that are set for aesthetic reasons. Finally, there is a discussion of other contaminants in drinking water that should be considered for periodic monitoring because of the potential for effects on human health.

4.2.2.1 Indicator bacteria

Indicator bacteria are monitored in potable water to evaluate the potential for contamination by waterborne pathogens, including bacteria, viruses, and parasites. Total and faecal coliforms were the bacterial indicators recommended by the US EPA in 1976, but in 1986, the US EPA modified the guideline to specify the use of E. *coli* and enterococci as the indicators of choice. Therefore, in most jurisdictions in North America, total coliforms and E. *coli* are the microbial indicators that are monitored, and intestinal enterococci are also monitored in some jurisdictions. According to the GCDWQ, no more than 10% of drinking water samples collected from a water distribution system on a given sampling day should contain detectable amounts of total coliforms and the maximum acceptable concentration (MAC) of E. *coli* in drinking water samples is nil. The WHO limits for drinking water are <5 colonies per 100 mL for total coliforms, nil for faecal coliforms and nil for E. *coli.*

Currently, the method used for analysis of indicator bacteria in drinking water in both St. Kitts and in Nevis is the membrane filtration (MF) method followed by manual counting of colonies for total and faecal coliforms. This is a labour intensive and time-consuming method that requires sterile conditions. In addition, many samples generate data in which no coliform bacteria are detected in the water. Therefore, it is recommended that the laboratories in both St. Kitts and Nevis switch to the IDEXX Colilert® system for monitoring total coliforms and E. *coli*. A description of this colourimetric method and a cost comparison with the MF method is provided in Appendix IV. The Colilert® system is accepted as an alternative to the MF method by many jurisdictions, including the US Environmental Protection Agency (US EPA), Health Canada, the World Health Organization (WHO) and United Nations agencies, and this method is described in recent editions of *Standard Methods for Analysis of Water and Wastewater*. In a recent comparative study of the Colilert® system with the MF method conducted in Trinidad, Ramoutar (2020) concluded that this system is "suitable for water quality monitoring of recreational waters in the Caribbean due to its similarity to MF and its simpler and faster methodology".

For most samples collected from water distribution systems, the Colilert® presence/absence test can be used to detect whether total coliforms and E. *coli* are present. For samples collected from source waters, untreated drinking water or treated drinking water where there is a history of microbial contamination, the Colilert® Quanti-tray method can be used to enumerate the numbers of total coliforms and E. *coli* in the samples. The advantages of this system are ease of analysis, minimal requirements for sterile conditions (and so minimal chances of false positives) and short incubation times (i.e., 18-24 hours). The disadvantage is that all consumables and reagents must be purchased from IDEXX. Note that IDEXX has also developed the Enterolert® system for analysis that is approved for detection of intestinal *Enterococci* in water in the USA and the EU. This Enterolert® assay uses the same approach and equipment as the Colilert® system and is much simpler and more rapid than the equivalent MF method (Ramoutar, 2020).

4.2.2.2 Residual chlorine

Primary disinfection refers to the addition of chlorine (or any other strong oxidizing agents) to untreated drinking water to kill pathogens in the drinking water supply. Secondary disinfection refers to the presence of "residual" chlorine in the water distribution system to prevent bacterial regrowth. It is essential to monitor the levels of residual chlorine in the water distribution system as a measure of the efficacy of secondary disinfection. The pH of water affects the chlorination process, with the optimal pH being between 6.5 and 8.0. Although this is within the pH range of waters in St. Kitts and Nevis, it is advisable to monitor the pH in the water distribution system.

The chlorine residual can be measured as either the "total chlorine residual" or as "free chlorine residual". The total chlorine residual is a measure of the total amount of chlorine in the sample, regardless of its form. The free chlorine residual is a measure of the amount of chlorine that is not reacted with other compounds in the water and so is readily available to kill pathogens. The combined chlorine residual is the difference between the total and the free chlorine residual.

The lower limits for free and total chlorine residual in a drinking water distribution system, according to the GCDWQ are 0.2 mg/L and 1.0 mg/L. respectively. However, these limits vary widely across jurisdictions. For instance, the lower limit for free chlorine residual in the province of Ontario in Canada is 0.05 mg/L. Free chlorine residuals below this value are cause for concern. Very high free chlorine residuals >4.0 mg/L are also cause for concern because the taste and odour of chlorine in the water may be offensive to consumers. It is optimal to measure chlorine residuals in the field to avoid loss of chlorine by outgassing into the headspace of the sample bottle, or out of the sample bottle if the lid is not airtight. Test strips or a handheld colourimeter are suitable for this purpose, although the colourimeter provides more analytical precision if properly calibrated.

4.2.2.3 Turbidity

Turbidity is a measure of the amount of suspended particulate material present in the water. High turbidity may indicate that there are taste and odour problems and suspended particulates may harbour waterborne pathogens. Turbidity is typically measured in nephelometric turbidity units (ntu), which are based on measurements of the turbidity of a silica standard suspended in water. Although the WHO has set limits for turbidity in drinking water of <5 ntu, the primary value of taking turbidity measurements is to monitor temporal patterns. If there is an increase in turbidity in source waters or in drinking water, this may indicate deteriorating water quality. Collecting data on turbidity in the field is optimal, as the suspended particulates in stored samples may precipitate out of suspension over time, or dissolved materials could flocculate and increase turbidity values in the sample. A hand-held turbidity meter is a suitable field device for this purpose.

4.2.2.4 Salinity

As mentioned previously, aquifers in St. Kitts and Nevis may become more saline over time because of saltwater intrusion. Recent monitoring data collected in Nevis indicated that there are salinity readings >900 mg/L in water from a few wells located close to the coast. Salinity concentrations of less than 600 mg/L indicate good quality drinking water, while levels of 600 to 900 mg/L indicate fair quality. Salinity concentrations of 900 to 1,200 mg/L indicate poor water quality, and values greater than 1,200 mg/L are regarded as unacceptable and a hazard to human health. Salinity in water can be measured in the field or in the laboratory using a suitable salinometer device.

4.2.2.5 Aesthetic parameters

There are several other parameters for which there are water quality guidelines based on aesthetic (e.g., palatability) criteria and not because of human health concerns. The parameter of total dissolved solids (TDS) is a measure of the total amount of inorganic and organic materials dissolved in water. TDS is recorded in milligrams per litre (mg/L). The WHO regards drinking water with TDS levels of <600 mg/L as palatable, but drinking water becomes increasingly unpalatable at TDS levels >1,000 mg/L. TDS can be measured in the laboratory or in the field.

Another measure of the amount of dissolved material in water is electrical conductivity (EC). The standard EC unit is micro-Siemens per centimeter (µS/cm), which represents the conductance of an electrical current in water over a 1 cm path length. Pure deionized water has a conductivity of 0.05 µS/cm, while seawater has a conductivity of about 50,000 µS/cm (i.e., 50 mS/cm). Palatable drinking water should have an EC value between 200 to 800 µS/cm. In well water samples collected from the Basseterre aquifer in 2006, EC values were between 705 and 1,413 µS/cm, and historical data indicated that the EC values had been increasing over time (Colorado School of Mines, 2006). EC can be measured in the laboratory or in the field using a suitable device.

Water hardness is a measure of the concentrations of total cations in water, which is primarily from the amounts of dissolved calcium and magnesium ions. Total hardness is estimated by expressing the sum of major cations in terms of an equivalent quantity of calcium carbonate. The degree of hardness of drinking water may be classified in terms of its calcium carbonate concentration as follows: soft, 0 to <60 mg/L; medium hard, 60 to <120 mg/L; hard, 120 to < 180 mg/L; and very hard, 180 mg/L and above. Hardness for a "typical well" in St. Kitts was listed as 120 mg/L by Williams, (2010), which would place it at the lower limit of the "hard" water designation. Although hardness may have significant effects on palatability, public acceptance of hardness may vary according to the local conditions. Water supplies with a hardness >200 mg/L $CaCO_3$ are considered poor but have been tolerated by consumers, while water with hardness >500 mg/L $CaCO_3$ is considered unacceptable for most domestic purposes. High water hardness may lead to "scaling" of the inside of the pipes used to distribute water.

In Nevis, the concentrations of total chlorides (mg/L) are monitored regularly in source waters and in drinking water. Water quality guidelines for chlorides in drinking water are based on palatability. As can be seen from Figure 4.1, the levels of chlorides are correlated with the salinity of source waters in Nevis. Therefore, this parameter can be regarded as an additional check on the salinity of sources of drinking water.

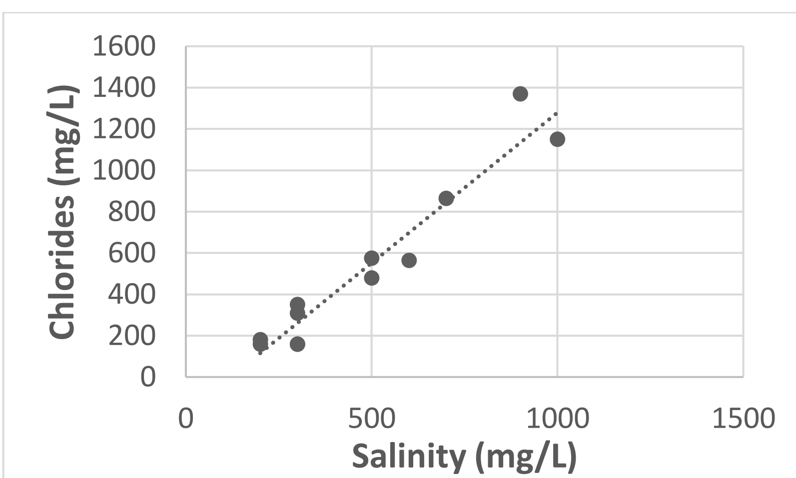

Figure 4.1: Salinity values (mg/L) plotted against concentrations of total chlorides (mg/L) recorded by the Water Department in Nevis for samples of well water collected in February 2021.

4.2.2.5 *Other parameters*
In a report to PAHO (1999), the project consultant recommended a list of water quality parameters that were considered appropriate for monitoring of drinking water quality in St. Kitts and Nevis:

"Critical" parameters:

- faecal coliform bacteria
- total coliform bacteria (for chlorinated supplies only)
- free chlorine residual (for chlorinated supplies only)
- turbidity
- pH

"Basic" parameters:

- chloride
- conductivity
- fluoride
- manganese
- nitrate
- phosphate

The "critical" parameters identified by the consultant that prepared the report are generally consistent with the recommendations provided above in the present report. However, the following are recommended changes: i) substitution of E. *coli* as a bacterial indicator rather than faecal coliforms, ii) analysis of total coliforms in both raw and treated drinking water and not just in chlorinated supplies, and iii) addition of salinity as a critical parameter. With respect to the "basic" parameters recommended previously by the consultant, monitoring of conductivity and chloride levels could provide useful data to evaluate changes in water quality over time. However, the other basic parameters recommended in the earlier report require some critical evaluation.

Monitoring of nitrates in drinking water should be a priority in St. Kitts and Nevis because of the potential for contamination of water resources from leaking septic systems and/or agricultural runoff. Exposure to nitrates in drinking water is associated with methaemoglobinemia in infants (i.e., "blue baby" syndrome) and possible effects on thyroid function in adults. The GCDWQ established a guideline of 45 mg/L of nitrate-nitrogen (NO_3-N) in drinking water, which is the same as the WHO guideline. However, the US EPA set a limit that is lower than the WHO guideline, of 10 mg/L NO_3-N. In St. Kitts, Williams (2010) reported nitrate concentrations of 6.6 mg/L in a "typical well". Nitrate concentrations in samples of well water collected in 2006 from the Basseterre aquifer varied from 13.4 to 41.4 mg/L (Colorado School of Mines, 2006), which were all above the US EPA limit and close to the WHO guideline of 45 mg/L in one case. Therefore, at least quarterly monitoring of nitrate in drinking water from catchments in St. Kitts is recommended. The consultants were unable to find any data on nitrate levels in surface water, groundwater or treated drinking water in Nevis, so this is a critical data gap.

Current methods for the analysis of nitrate include ion chromatography with method detection limits (MDLs) in the range of 0.002 mg/L NO_3-N. The cadmium reduction method with colourimetry for the analysis of combined nitrate and nitrite has MDLs as low as 0.01 mg/L. Ion selective electrodes are also available for the analysis of nitrate, with MDLs in the range of 0.1

mg/L. Low-cost test kits that use colourimetry are also available that have MDLs typically in the range of 1 to 50 mg/L. For routine monitoring of nitrate in St. Kitts and Nevis, the test kits and/or ion selective electrodes would be appropriate techniques, although both methods are subject to interference from other anions (e.g., sulphate, sulfide) that may be present in the water. These rapid methods are not suitable for analysis of brackish or marine waters because of interferences from chloride and other anions.

The GCDWQ established an aesthetic objective for manganese of 0.02 mg/L, and this is well below the thresholds for neurological effects in humans from intake of manganese in drinking water. The sources of manganese include some industries (anthropogenic sources) and geological deposits (geogenic sources). Williams (2010) reported manganese levels of 0.025 mg/L for a "typical well" in St. Kitts, so this level may be of concern as an aesthetic parameter but is not a health risk. The possible sources of fluoride contamination in water are also both anthropogenic and geogenic. In some jurisdictions, fluoride is added to drinking water at levels of approximately 0.5 mg/L to promote dental health. The World Health Organization recommends an upper limit for fluoride in drinking water of 1.5 mg/L, which is also the guideline for fluoride in drinking water for several other jurisdictions, including Canada, Australia and the European Union. Since it is unlikely that there are anthropogenic sources of fluoride in St. Kitts and Nevis, geological mineral deposits are the only likely source of contamination. The levels of fluoride in samples of surface waters and groundwater collected in the Basseterre Valley region of St. Kitts were all within the range of 0.2 to 0.8 mg/L (Ocean Technologies Consortium, 2009), so no adverse health effects are likely from consumption of drinking water, and in fact, these levels may promote dental health.

Sources of phosphates in water include apatite sedimentary rock, contamination from sewage and runoff of agricultural fertilizers. While guidelines for phosphates in water have been set for the protection of aquatic life because of the capacity of this nutrient to promote eutrophication, phosphates are not considered a hazard to human health at levels typically found in groundwater and in surface waters. Williams (2010) reported orthophosphate levels at the limit of detection (i.e., 0.01 mg/L) for a "typical well" in St. Kitts. Therefore, regular monitoring of phosphate and other forms of phosphorus in sources of drinking water in St. Kitts and Nevis is not a priority.

In a report released in 2004 on water resources in selected Caribbean states, including St. Kitts and Nevis, geogenic arsenic contamination was mentioned as a potential water quality issue in Nevis (US ACE, 2004). This potential water quality problem in Nevis should be investigated further and if contamination is proven to be significant, then future monitoring programs should include analysis of arsenic. The WHO provisional guideline for arsenic in drinking water is 10 µg/L, although some countries where there is widespread arsenic contamination from geogenic sources (e.g., Bangladesh) have guidelines as high as 50 µg/L. In St. Kitts, levels of arsenic detected in surface waters and in groundwater in the Basseterre Valley were generally below the WHO guideline for drinking water of 10 µg/L, but arsenic concentrations above the WHO guideline were detected in groundwater at "Well I-48" (i.e., 19 µg/L) and at "Taylor" (i.e., 11 µg/L), as reported by Ocean Earth Technologies Consortium (2009). Therefore, regular monitoring of arsenic is recommended for both source waters and drinking water in St. Kitts. If necessary, there are several low-cost technologies for removing arsenic from water, including using sorbents produced from agricultural waste products and coconut husks (Thakur and Samil, 2013).

In samples of well water collected from the Basseterre aquifer in 2006, the concentrations of cadmium were 0.006 to 0.007 mg/L and the authors of the report were of the opinion that "cadmium levels found could pose a serious health effect" (Colorado School of Mines, 2006). However, Williams (2010) reported that cadmium levels were at the limit of detection of 0.001 mg/L in a "typical well" in St. Kitts. The recommended limits for cadmium in drinking water vary across jurisdictions. For instance, the WHO guideline is 0.003 mg/L, but the GCDWQ guideline is 0.007 mg/L. Overall, periodic monitoring of cadmium in drinking water is warranted for St. Kitts. The consultants could not find any data on cadmium concentrations in drinking water in Nevis.

The US ACE (2004) report cited anecdotal information that the Wingfields catchment area in St. Kitts may be contaminated with pesticides from agricultural activity. Ocean Earth Technologies (2009) provided analytical data for a range of pesticides in surface waters and groundwater in the Basseterre Valley and the concentrations were all below detection limits. To the knowledge of the consultants, there is currently no capacity for the analysis of current use pesticides in St. Kitts and Nevis, so water samples would have to be shipped elsewhere for analysis. To further investigate potential pesticide contamination in sources of drinking water in St. Kitts, an assessment should be made of the pesticides applied on the island that have the greatest potential for leaching into groundwater or transport into surface waters. Golf courses should also be considered a potential source of pesticide contamination. For instance, a fungicide commonly used for treatment of turf on golf courses (i.e., chlorothalonil) and its toxic metabolite were detected in Barbados in surface waters (Edwards et al., 2017) and in groundwater (Edwards et al., 2019).

Finally, a report by IWCAM (2011) identified potential threats to the aquifer in the Bassettere Valley in St. Kitts from fuel oil spillage at the power plant operated by the Electricity Department and by jet fuel leakage at the international airport. Currently, there is no laboratory capacity in St. Kitts to detect petroleum hydrocarbons in drinking water in the event of contamination from one of these scenarios.

4.3 Monitoring of recreational waters

In many countries, recreational waters are also monitored for microbial contamination. In drinking water, analyses for levels of total coliforms and E. *coli* are the primary method of assessing microbial contamination. In recreational waters, intestinal *Enterococci* are recommended as the primary indicators of faecal contamination. This is based on epidemiological studies showing that concentrations of enterococci measured in recreational marine waters polluted by domestic wastewater were strongly correlated to the number of swimmers becoming sick with gastrointestinal illness and other infections. Given this evidence, the USA and the EU recommended that intestinal *Enterococci* be adopted as the primary indicator of the risk of illness among swimmers in recreational waters. The WHO has also adopted guidelines for *Enterococci* as the standards for evaluating microbial contamination of recreational waters (WHO, 2021).

The guidelines for marine recreational waters vary by jurisdiction, but the US EPA marine recreational water quality criterion for *Enterococci* is <104 colony forming units (CFU) per 100 mL measured in a single sample and <35 CFU/100 mL as a geometric mean of values measured over time. In the EU, standards for *Enterococci* in recreational waters range from limits of 100 to 400 CFU/100 mL, depending on whether the site is marine or freshwater, and whether the beach is rated as excellent or just sufficient for swimming. The most recent guidelines from the WHO

(2021) set the criteria for *Enterococci* shown in Table 4.1. The WHO also recognized the potential for transmission of illness from contact with contaminated beach sand and so made a provisional recommendation for *Enterococci* of <60 CFU per gram of sand (WHO, 2021). In St. Kitts, an assessment of risks to human health should be conducted using existing data on the levels of *Enterococci* in marine recreational waters to determine whether continued regular monitoring of beach areas is warranted. A preliminary survey on *Enterococci* in waters near recreational beaches in Nevis is recommended.

Table 4.1: Guidelines for intestinal *Enterococci* (CFU/100 mL) developed by the WHO for coastal and recreational waters.

Range of Values (CFU/100 mL)	Basis of Derivation
<40	Low risk of adverse effects
41 to 200	Above the threshold of illness transmission
201 to 500	Substantial elevation of risk of illness
>500	Significant risk of high levels of illness

The WHO guidelines are based on mitigating risks to human health, and so no other water quality parameters are recommended by this agency for routine monitoring in marine recreational waters, except for the analysis of substances arising from harmful algal blooms (HABs), such as cyanotoxins. However, other water quality criteria developed for the protection of aquatic life could be monitored, including the lower limits for dissolved oxygen, and upper limits for total suspended solids, biological oxygen demand and nutrients (e.g., phosphorus, nitrogen). Analysis of *Enterococci* in water is currently offered on a fee-for-service basis by the St. Kitts and Nevis Bureau of Standards. The development of in-house capacity to collect and analyze marine samples for *Enterococci* in both St. Kitts and Nevis would require training of laboratory personnel. Note that the Enterolert® assay system marketed by IDEXX is a possible test method.

4.4 Microbial source tracking

In order to identify sources of microbial contamination in drinking water and in recreational waters in St. Kitts and Nevis, targeted studies may be warranted using more sophisticated analytical methods. Although regulatory agencies recommend using E. *coli* to detect faecal contamination in drinking water and recommend monitoring of intestinal enterococci in recreational waters, these indicator bacteria are not definitive markers of pollution from domestic sewage. Both classes of bacteria have been detected in pristine environments, can multiply in sediments and are present in the intestinal tract of all warm-blooded animals, and not just humans.

Since traditional microbial indicators cannot discriminate between faecal contamination from humans and warm-blooded domestic and wild animals, several studies have explored using other source-specific indicators of pollution from domestic sewage. Chemical detection methods offer several advantages over monitoring for microbial indicators. Compounds present in foods and beverages that are excreted by humans into sewage such as caffeine and artificial sweeteners have been shown to be reliable indicators of contamination from domestic wastewater (Serville-Tertullien et al., accepted; Edwards et al., 2019; Tran et al., 2015). Quantitative polymerase chain reaction (qPCR) techniques applied to microbial source tracking make it possible to identify whether faecal bacteria in water originate from humans or from domestic animals (Tran et al., 2015). Assays using genetic markers for strains of the *Bacteroidales* class of faecal bacteria are particularly useful for these studies (Serville-Tertullien et al., accepted; Wade et al., 2015).

4.5 Monitoring of domestic wastewater

As discussed previously, there are several "package" plants for treating domestic wastewater that are currently operating in St. Kitts, and one plant that is operating at a hotel in Nevis. Discussions with the Manager of the Royal Utilities plant operating at the Marriott Hotel indicate that there is in-house monitoring of treated wastewater for levels of total suspended solids (TSS) and biological oxygen demand (cBOD5) and it is assumed that the other hotels have similar monitoring protocols. The regulations for treated wastewater vary widely across jurisdictions. Table 4.2 provides a summary of the regulations for treated municipal wastewater in Canada, the USA, and the EU.

Wastewater monitoring need not be a priority in Nevis because there is only one package wastewater treatment plant operating at the Four Seasons Resort on the island and effluent quality is monitored in-house. In St. Kitts, the proposed construction of a package wastewater treatment plant at a new high school in Basseterre may necessitate routine monitoring of treated wastewater, and this could be expanded to include monitoring of effluents from the package plants operating at the hospital and the veterinary college. There are also package treatment plants serving homes in the Frigate Bay, Halfmoon Bay and Southeast Peninsula regions of St. Kitts that could be periodically monitored for wastewater quality. A program to monitor wastewater effluent quality in St. Kitts should include, at a minimum, analysis of TSS and either cBOD5 or COD; the latter being a less time-consuming parameter to measure. The EU regulations for TSS, cBOD5 or COD (Table 4.2) could be applied to evaluate wastewater quality. However, the report by IWCAM (2011) noted that there were no regulatory policies in place in St. Kitts at the time of the release of the document to establish effluent regulations and to enforce compliance.

Table 4.2: Comparison of the wastewater effluent regulations in Canada, the USA, and the EU. N/A = Not applicable; cBOD5 = Carbonaceous biological oxygen demand measured over a 5-day period; COD = Chemical oxygen demand; TSS = total suspended solids; NH_3-N = Ammonia nitrogen in the toxic, unionized form. The source of the data in the table is CWN (2018).

Parameter	**Canada**	**USA**	**EU**	
Population trigger	N/A	N/A	10,000 to 100,000	>100,000
cBOD5	25 mg/L	25 mg/L	25 mg/L	25 mg/L
COD	-	-	125 mg/L	125 mg/L
TSS	25 mg/L	>85% removal	35 mg/L	35 mg/L
NH_3-N (unionized)	1.25 mg/L	-	-	-
Chlorine*	0.02 mg/L	-	-	-
pH	-	6 to 9	-	-
Total nitrogen	-	-	15 mg/L	10 mg/L
Total phosphorus	-	-	2 mg/L	1 mg/L

*Where chlorine is used for disinfection of treated wastewater prior to discharge.

Analyses of the parameters listed in Table 4.2 are currently offered on a fee-for-service basis by the St. Kitts and Nevis Bureau of Standards. The development of in-house capacity to collect and analyze wastewater effluent in St. Kitts by the Water Services Department or the Department of Environmental Health would require training of personnel and investment in the appropriate laboratory equipment. Health and safety considerations would be a necessary part of the training for personnel that are collecting samples from wastewater treatment facilities and handling those samples in the laboratory.

4.6 Community-based monitoring

In some jurisdictions, a community-based approach for monitoring water quality has been adopted, whereby citizens are recruited to collect water samples that are then forwarded to an analytical laboratory for testing, or alternatively, there is some capacity for testing of basic water quality parameters by the citizens themselves. This approach is particularly useful in remote regions, where sending staff long distances to collect water samples is costly and time-consuming. However, these community-based programs require considerable logistical and organizational support for delivery and pickup of sample bottles, training and coordination of citizen volunteers and reporting of the water quality data back to the public (CRWA, 2013). Because of a lack of resources, a large community-based monitoring program is not feasible at this time in St. Kitts and in Nevis. However, it may be possible to organize limited sampling programs for monitoring recreational waters using citizen volunteers and/or staff from local hotels.

It may also be possible to enlist students enrolled in high school programs or in the community college at St. Kitts to conduct targeted projects that contribute to a better understanding of temporal and spatial trends in water quality. For instance, students could collect samples to assess changes in the quality of surface waters before, during and after storm events, or they could collect samples at recreational beach areas to evaluate whether deteriorating quality of coastal waters is correlated with rain events.

4.7 Laboratory infrastructure and instrumentation

As part of the consultation process, lists of equipment and upgrades to facilities were provided by staff at the Department of Environmental Health in St. Kitts and the Water Department in Nevis. These lists are provided in Appendix V of this report. In addition, the laboratory equipment needs in St. Kitts and Nevis, as well as the priorities for professional development and training of staff were previously identified in the Laboratory Assessment Report recently prepared for IWEco (2021). Recommendations for acquiring equipment and upgrades to laboratory facilities will be forthcoming in the second report of the current project. However, there are some basic principles that will guide these recommendations:

- The consultants will not provide recommendations on which government agencies in St. Kitts and in Nevis should receive and utilize new equipment and facilities. This is beyond the scope of the project and these decisions should be made at the local level, taking into account any fiscal, human resource and organizational constraints.
- As much as possible, parameters for drinking water quality should be measured in the field and the data recorded on-site.

- Priorities for the measurement of drinking water quality should focus on those parameters critical for protecting the health of the populations of St. Kitts and Nevis (i.e., bacterial indicators, turbidity, residual chlorine, salinity, nitrates).
- The methods for analysis of indicator bacteria should be switched to the IDEXX Colilert® system for the analysis of total coliforms and E. *coli.*
- Laboratory facilities should be properly equipped to protect the health and safety of the staff.
- An assessment of the needs and the feasibility of routine monitoring of treated domestic wastewater and coastal waters at recreational beaches needs to be conducted before recommendations for equipment acquisitions can be made.
- The financial resources currently available for equipment acquisitions, facility upgrades and training of staff in both St. Kitts and Nevis are limited.

4.8 Data management and dissemination

The procedures for recording, managing, and disseminating water quality data generated in both St. Kitts and Nevis are in need of updating. Currently, data are handwritten on data sheets and these numbers are then transcribed into Excel spreadsheets. This approach is time consuming, subject to errors from the copying of data and does not facilitate observations of temporal or spatial trends. As discussed previously in this report, evaluations of trends in water quality over time or across different regions of the islands is an essential part of a monitoring programme.

Although dedicated data management systems are available from commercial suppliers, the costs for purchase or subscriptions to these systems is prohibitive. A more cost-effective approach is to make use of Microsoft products that are available for a relatively low cost and are compatible with a range of devices. As part of the Office 365 package, Microsoft Forms can be used to set up an on-line data entry system that can be accessed using a smart phone, tablet, laptop or desktop computer. Data entered in the field or in the laboratory into the on-line forms are automatically integrated into Excel spreadsheets. The Microsoft product, Power Automate® can be used to set up workflows for the data that are entered, including automated sharing of data with stakeholders. Data that exceed regulatory guidelines can be automatically flagged for additional scrutiny (e.g., quality control). This product can also be used to visualize temporal and spatial patterns in the data and to generate reports. A single license is required for this Microsoft product, which can be controlled by the data manager.

Currently, water quality data generated in St. Kitts is reviewed by the Chief Health Officer and the data generated in Nevis is reviewed by the Manager of the Water Department. These individuals are responsible for sharing the data with appropriate government departments. In a report to PAHO submitted over 20 years ago, the project consultant recommended the establishment of a data sharing protocol, a strategy for remedial action and a system for informing the public if hazards to water quality are detected in drinking water (PAHO, 1999). Further, the consultant recommended that a "Water Quality Surveillance Committee" comprised of high-level representatives from stakeholder agencies be set up to periodically review the water quality monitoring programmes in St. Kitts and Nevis.

5. Summary of Recommendations

From the previous discussions, the following recommendations for monitoring of water quality in St. Kitts and Nevis can be summarized:

- Training of the staff collecting drinking water samples and conducting laboratory analysis needs to be upgraded. Staff also need to calibrate analytical instruments on a regular basis and the dates of calibration need to be recorded in a logbook.
- Written standard operating procedures (SOPs) need to be developed for collection of water samples in the field, collection of water quality data in the field and the analysis of water quality parameters in the laboratory.
- Drinking water should continue to be primary focus for water quality monitoring in both St. Kitts and in Nevis. Critical water quality parameters include microbiological indicators, residual chlorine, turbidity and salinity.
- Residual chlorine and turbidity measurements need to be conducted in the field at the time of collection of drinking water samples to avoid changes in these parameters from the time of collection in the field to analysis in the laboratory. Appropriate field instrumentation should be purchased for this purpose.
- A point of discussion should be the feasibility of increasing the monitoring frequency and the number of monitoring sites (e.g., drinking water for prison in Nevis; standpipes for New Road housing area in Basseterre).
- Source waters (i.e., groundwater, surface water) should be monitored at least on a quarterly basis in St. Kitts to evaluate potential sources of contamination. The frequency of monitoring of surface waters should be a point of discussion, as surface waters are susceptible to short-term changes in water quality (e.g., during rain events).
- Nitrates should also be monitored as a critical parameter in drinking water, at least on a quarterly basis. Appropriate instrumentation or test kits should be purchased for this monitoring effort.
- Arsenic should be monitored periodically in source waters and drinking water in St. Kitts to determine if concentrations exceed WHO guidelines for drinking water.
- In Nevis, a scoping study should be conducted to evaluate the concentrations of nitrate, fluoride, cadmium and arsenic in drinking water to determine if these parameters need to be included in a monitoring program.
- Analytical methods for indicator bacteria in drinking water samples should be switched from the membrane filtration and plate count method for total and faecal coliforms to the IDEXX Colilert® method for analysis of total coliforms and E. *coli.* If monitoring of marine recreational waters is judged to be a priority, the Enterolert® method may also be adopted for analysis of intestinal *Enterococci.*
- A targeted study may be warranted to determine if pesticide contamination is occurring in water resources in St. Kitts.
- A microbial source tracking (MST) study may be warranted for St. Kitts to determine the sources of microbial contamination of drinking water.
- A risk assessment using available data in St. Kitts on the levels of intestinal *Enterococci* in marine waters should be conducted to determine whether routine monitoring of water near recreational beaches is warranted. Similar monitoring may be warranted in Nevis.

- If monitoring of domestic wastewater is judged to be a priority in St. Kitts, the minimum parameters for monitoring should be the levels of total suspended solids and either biological oxygen demand (cBOD5) or chemical oxygen demand (COD). The EU regulatory guidelines for these parameters can be applied to evaluate the quality of wastewater effluents. Acquisition of appropriate analytical instrumentation, method development and documentation, and staff training would be necessary to develop a routine monitoring program. However, there are currently no regulations for enforcing regulatory guidelines.
- Large community-based monitoring programs involving many volunteers are currently not feasible in both St. Kitts and Nevis, but students may be recruited to provide samples for targeted monitoring projects. Hotel staff and citizen volunteers may be recruited to collect water samples at recreational beaches.
- The procedures for recording and managing water quality data in both St. Kitts and Nevis require updating. A relatively low-cost solution is the use of Microsoft data management products, such as Microsoft Forms and Power Automate® to facilitate data collection, management, and dissemination.
- The framework for disseminating data to responsible authorities and the mechanisms for oversight of the water quality monitoring programmes in both St. Kitts and in Nevis need to be reviewed and updated. An emergency plan should be developed to respond to episodic events of poor drinking water quality.

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APPENDIXES

Appendix I: List of individuals in St. Kitts and in Nevis consulted during the preparation of this report.

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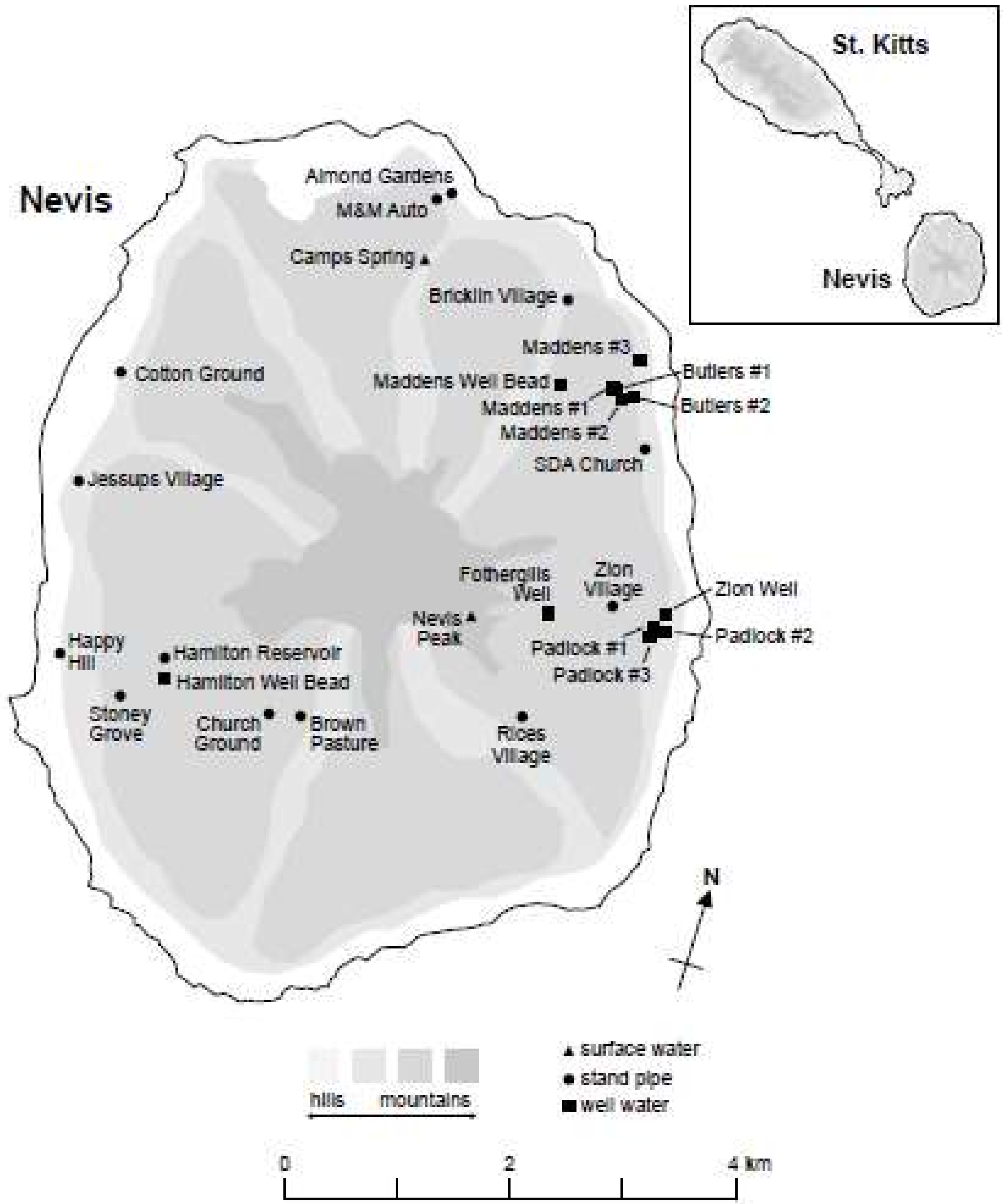
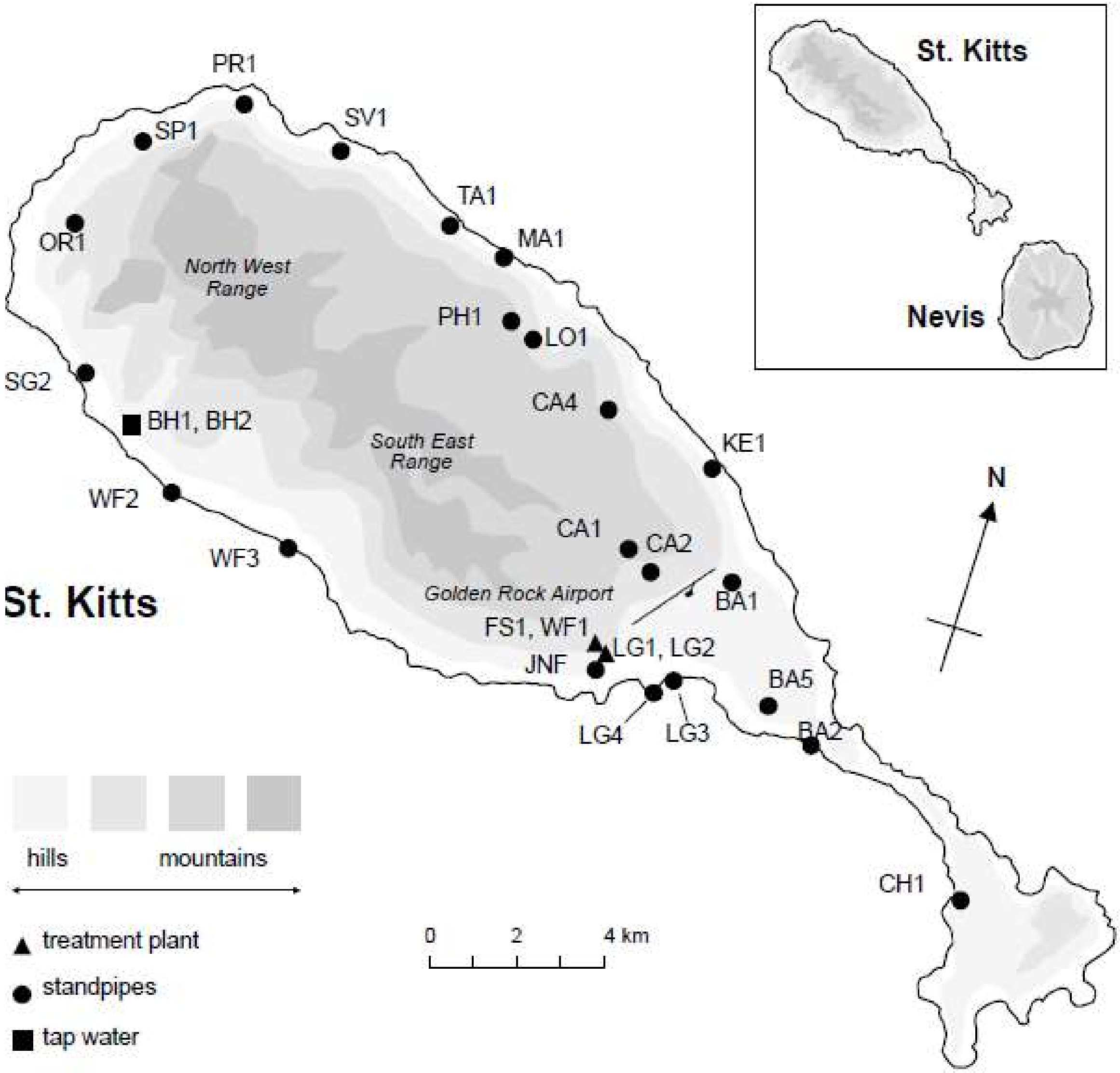
Appendix II: Map of Nevis showing sampling locations for water quality monitoring.



Appendix III: Map of St. Kitts showing sampling locations for water quality monitoring.



Appendix IV: Description of the IDEXX Colilert® system for monitoring total coliforms and *E. coli* in water, and an analysis of the costs of this system compared to the membrane filtration method.

The IDEXX Colilert® system utilizes enzymes that are specific to classes of microorganisms (i.e., coliform bacteria, *E. coli* bacteria). These enzymes are attached to dyes, which are released when the target microbe is present in the sample. IDEXX reagents are added to the sample for the simultaneous detection of total coliforms and *E. coli*. Presence/absence tests are based on the addition of the IDEXX reagents to a small (10 mL) water sample. The sample is incubated at 35 ± 0.5 °C for 18-24 h. Samples showing a yellow color under normal light are positive for total coliforms (Figure A1) and samples that fluoresce under UV light are positive for *E. coli*.

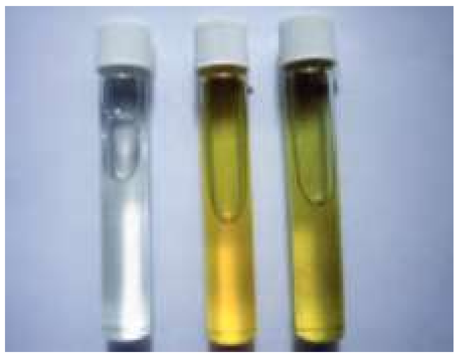


Figure A1: Colilert® tubes for presence/absence test. The sample on the left has no coliform bacteria and the other two samples contain coliform bacteria.

Enumeration of total coliforms and *E. coli* in the samples is based upon the use of a tray (i.e., Quanti-tray) which separates a water sample into 49 large and 48 small wells. The water sample spiked with IDEXX reagents is poured into the tray, which is then sealed and incubated at 35 ± 0.5 °C for 18-24 h. Test wells in the tray showing a yellow color under normal light are positive for total coliforms and test wells that fluoresce under UV light are positive for E. *coli* (Figure A2). The number of test wells that show the characteristic colour or fluorescence are then counted and used in conjunction with a standardized table to enumerate the bacteria in terms of the most probable number (MPN) in the water sample.

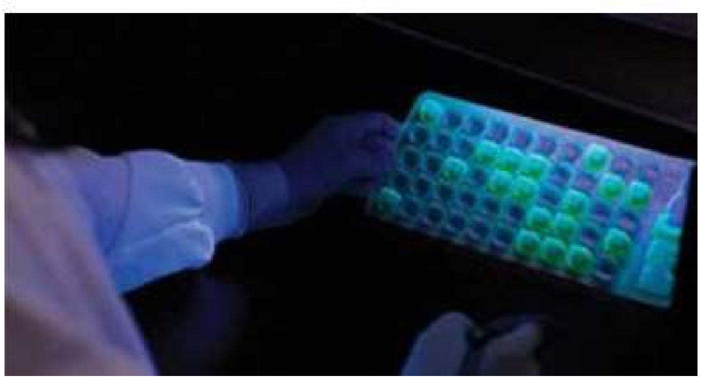


Figure A2: Enumeration of *E. coli* under UV-light in an IDEXX Quanti-tray.

Cost comparison:

i) Colilert method:

The quote below in USD was provided by the IDEXX sales office for Latin America and the Caribbean. The quote includes an introductory discount for the necessary equipment (one-time purchase) and for the consumables to analyze 200 water samples for total coliforms and E. *coli*. The Colilert-18 system requires only an 18-hour incubation time to produce results.

Category	Part #	Catalog #	Description	Qty	List	St Kitts & Nevis	Savings
Equipment	98-0002570-00	WQTSPLUS	Quanti-Tray Sealer Plus	1	$4,777.50	$4,200.00	$577.50
	98-21322-00	WCM10	UV Viewing cabinet - fits WL160	1	$314.34	$301.77	$12.57
	98-20724-01	WL160	6 watt UV lamp 110 v 365 nm	1	$220.81	$208.24	$12.57
Consumables	99-27074	WCMB18-200-2K	200-pack Colilert-18 and	1	$1978.22	$1,384.75	$593.47
			Quanti-tray/2000 200-pack	1			
	98-09221-00	WV120SBST-200	200-pack 120ml vessel w/ 100ml line, sodium thio & shrink band	1	$166.05	$116.24	$49.81
	98-09227-00	WQT2KC	Colilert Comparator in Quanti-tray/2000	1	$30.37	$21.26	$9.11

The consumables are all pre-sterilized and include a 200 pack of 120 mL sample tubes containing sodium thiosulphate to neutralize residual chlorine, a 200 pack of the Colilert-18 reagents, and a 200 pack of the Quanti-trays for enumerating the numbers of total coliforms and E. *coli* in the samples. These supplies have a shelf life of 15 months at room temperature, so a one-year supply of consumables can be secured with a single purchase order. Assuming the discounts from IDEXX for consumables would not continue after the initial order, the total list price for the consumables to analyze 200 samples for total coliforms and E. *coli* would be $2,174.64 USD, which corresponds to $10.87 USD per sample for the consumables. This does not include labour costs, which are estimated as 30 minutes per sample. These estimated costs are for the quantitative analysis of total coliforms and E. *coli (*i.e., most probable number) in the samples. The consumables for the presence/absence test for both total coliforms and E. *coli* just include the Colilert-18 reagents and the sample tubes, so the cost is estimated to be $3.50 USD per sample.

ii) Membrane Filtration method:

The St. Kitts and Nevis Bureau of Standards charges $57 ECD ($21 USD) per sample for analysis of total coliforms and $57 ECD ($21 USD) per sample for analysis of E. *coli* using the membrane filtration method, for a total of $42 USD per sample for analysis of both parameters. It is assumed that these charges reflect the costs of both labour and consumables, and a surcharge for overhead. Presence/absence tests are not possible using this methodology. Incubation times are 48-hours for total coliforms and 24-hours for detecting faecal coliforms and E. *coli*.

iii) Overview:

While these estimates of costs for the Colilert and membrane filtration methods are not directly comparable, these data indicate that the two methods are comparable on a cost per sample basis. The higher costs for consumables for the quantitative Colilert-18 method are balanced by the lower labour costs relative to the more labour-intensive membrane filtration method. The Colilert method also does not require sterile conditions and the incubation time is shorter. The presence/absence version of the Colilert test is a simpler and cheaper alternative to the quantitative test which can be applied for routine screening when microbiological contamination of samples is not expected.

Appendix V: Needs for equipment and facilities identified by staff with the Department of Environmental Health in St. Kitts and the Water Department in Nevis.

1. **Nevis Water Department**
    - New/refurbished cupboards and sink in the laboratory
    - Microscopes (2)
    - Back-up pump for water filtration (microbial testing)
    - A refrigerator/freezer dedicated for laboratory use
    - Bench-top spectrophotometer
    - Bench-top conductivity meter
    - Thermometers (for water bath and incubator)
    - Distilled/deionized water generator
    - Pick-up truck designated for water quality monitoring
    - Larger laboratory space/building

2. **St. Kitts Department of Environmental Health**
    - Portable (field) multi-parameter meter and probe (pH, turbidity, salinity, conductivity, DO, etc.)
    - Bench-top pH meter
    - Bench-top turbidity meter
    - Bench-top conductivity meter
    - Microscopes (2)
    - Back-up pump for water filtration (microbial testing)
    - Bench-top spectrophotometer
    - In-field infrared thermometers
    - Pick-up truck designated for water quality monitoring
    - Larger laboratory space/building