MAY 2021

Regional Standard Operating Procedures (SOPs) & Key Adaptation Protocols (KAPs) for Climate Resilient Water Infrastructure

ENHANCING CLIMATE RESILIENCE IN CARIFORUM COUNTRIES

GCCA+

Foreword

Climate change exacerbates water security and water-related issues, which directly threatens the achievement of a number of Sustainable Development Goals. Impact. The increased sea surface temperatures, associated with global warming, are projected to lead to more intense hurricanes and extreme precipitation events resulting in flash floods. Severe hurricanes have devastating impacts on national water infrastructure, including wastewater and energy inseverable required to prevent pollution and distribute potable water for consumption. Similarly, the increasing frequency and intensity of flooding events also renders water systems inoperable due to excessive turbidity. Conversely, climate change is also increasing the frequency and duration of droughts with serious implications for water availability for human consumption, human health and food security. Sea level rise will accelerate saline intrusion and thus salinization of groundwater aquifers, which will pose serious problems for countries like Barbados, the Bahamas, St. Kitts and Nevis, Antigua and Barbuda, and Guyana that depend primarily on groundwater sources, which further exacerbates water security concerns. Furthermore, climate-related disasters also undermine the physical water infrastructure.

Despite the climate-related hazards that are threatening the water sector, however, a myriad of other challenges also impacts water security and resilience across the Caribbean. These challenges include: Inadequate regional and national water governance structures such as land ownership issues in watersheds, issues of inadequate legislative and regulatory frameworks, , unclear and overlapping institutional responsibilities, inadequate management instruments, financial fragility, lack of information and water data and transparency of use, low levels of investment, human capital challenges, supply-driven management and fragmented and uncoordinated intra- and infra-sectoral coordination. Thus, building water resilience of the region is contingent on building resilience to the effects of climate change and the strengthening of water governance at the national and regional level.

In an effort to help build resilience of water sector across CARIFORUM countries, the Intra-ACP Global Climate Change Alliance Plus (GCCA+) project seeks to enhance climate resilience through a number of key activities aimed at strengthening an integrated system for the improved weather forecasting and information generating capacity, improving climate resilient water infrastructure, increasing awareness of climate variability, and improving climate risk management. This EU investment pays particular attention to the challenges undermine drought security in the CARIFORUM region by developing Standard Operating Procedures (SOPs) for climate proofing the expansion, renovation, management and operation of water distribution systems and infrastructure. The following SOPs, achieved through a partnership with regional water utilities and water resource managers, Global Water Partnership-Caribbean, Caribbean Water and Wastewater Association and the Caribbean Water and Sewerage Association, will contribute to the improvement of water security in the CARIFORUM member states through outlining best practices for climate proofing the expansion, renovation and retrofitting, management and operation of water distribution systems and infrastructure.

As a key component of the Enhancing Climate Resilience of CARIFORUM Countries programme this initiative supports a regional effort to increase the resilience of the CARIFORUM Member States to the adverse impacts of climate change and contributing to the achievement of the UN's Sustainable Development Goals, in particular its Goal 13 on climate action, to reduce poverty and promote sustainable development. The Centre wishes to thank the team the Delegation of The European Union to Barbados, The Organization of Eastern Caribbean States and CARICOM/CARIFORUM countries for their continued partnership and commitment to the people of the Caribbean.

Acknowledge . Commit . Act
Erkennen . Toewijden . Handelen
Comprensión. Compromiso. Acción
RECONNAÎTRE . S'ENGAGER . AGIR

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DRINKING WATER SUPPLY

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LIST OF ACRONYMS

Acronym	In Full
ASCE	American Society of Civil Engineers
BKWTP	Bangkhen Water Treatment Plant
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
EPA	Environmental Protection Agency
IWA	International Water Association
MGD	Million Gallons per Day
MWA	Metropolitan Waterworks Authority
NRW	Nonrevenue Water
NTU	Nephelotric Turbidity Unit
SOPs	Standard Operating Procedures
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

EXECUTIVE SUMMARY

The water and sanitation targets of Millennium Development Goal 7 have forced action internationally towards a collective effort of achieving sustainable access to drinking-water and sanitation. Actions are therefore required by water utilities develop adaptive capacity to managed water supplies that are resilience to climate change. Climate change is likely to increase **water demand** while shrinking **water supplies**. Both surface and groundwater will experience changes in water quality and quantity cause by increase extreme rainfall events, droughts, and tropical cyclones. Water supply is threatened when the quantity of water available for supply is reduced by activities that decrease the infiltration of water into the ground (e.g., urbanization), overuse due to increasing demand, inefficient water use, and inappropriate allocation. Point and non-point source pollution also affects water supply by impacting water quality.

Manmade infrastructures used by the utilities to extract water supplies will need to be adapted to account for these changes. Drinking-water infrastructure can be flooded and put out of commission for extended periods (days, weeks, or months). Droughts can result in falling groundwater tables and reduced surface water flows can lead to wells drying up. Potential indirect effects of climate change on the water supply includes the impacts of energy interruptions, increasing the unreliability of piped water. The SOP identifies several options that can be implemented to improve resilience in both drinking water supply. The approach is a combination of watershed management, infrastructural change, water distribution and treatment options.

Drinking water source protection should be developed as an integral part of watershed management strategy. Examples of measures than can be applied in watershed protection include i) watershed land acquisition; ii) conservation easements; iii) public education; iv) ecosystem restoration; and v) erosion and sediment control.

Impacts on infrastructure ranges from increased turbidity to physical damage. Pumping and storage facilities may need to be hardened, relocated, rebuilt with better construction materials, or expanded to achieve an acceptable level resiliency. Climate change implications for wells and treatment plants strategies such as i) relocation or decommissioning wells; ii) reduce pumping; iii) increasing freshwater recharge of the aquifer (e.g. injection wells); iv) salinity barriers; v) seeking new freshwater sources and vi) modifying water treatment process, provides options in climate proofing these systems. Water treatment and distribution are components of the drinking water supply and improvement to the existing treatment processes may be necessary to ensure that quality of water supply continues to meet standards as climate change impacts source or receiving water quality.

The following are climate adaptation strategies for treatment facilities or operations, i) establishing location outside of a potential disaster zone; ii) improvement to existing treatment processes or implementation of additional treatment technologies; iii) minimize the exposure of essential utility equipment; iv) Flood barriers to protect critical infrastructure; and v) establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions. Water distribution system such a pipeline is the primary means of delivering water to customers. The varieties of water pipes include large diameter main pipes, which supply entire towns, smaller branch lines that supply a street or group of buildings, or small diameter pipes located within individual buildings. Leakages or nonrevenue water is a major source of loss throughout the Caribbean and has gain attention with efforts made to reduce this and to improve supply. Climate related damages to pipelines include physical damage to pipes and corrosion. Materials selected for pipelines have a large influence on their ability to withstand climate stressors and if they are exposed or buried. Buried materials are less sensitive to climate-induced damages. The effects of climate change are often first in the water sector through droughts, floods, or storms. When these disasters hit, they can wipe out entire water supplies or leave them contaminated. Making the water supply and distribution system resilient requires a range of option.

1 STANDARD OPERATING PROCEDURE: DRINKING WATER SUPPLY

The SOP is provided in the following pages. Sections 1.4 and 1.5 relate to Climate impacts and to Utilities Response respectively.

1.1 Purpose

The purpose of the SOP is to provide climate resilient solutions to issues arising from the impacts of climate hazards on drinking water supply infrastructure in the Caribbean.

1.2 Introduction

Climate hazards such as floods, droughts, hurricanes and sea-level rise are impacting water-related infrastructure including drinking water supply ones in the Caribbean. To mitigate these effects, water utilities need to prepare their infrastructure before, during and after these climate events. This SOP provides guidance to water utilities to adapt their infrastructure so that it becomes more resilient to climate change.

1.3 Scope

This SOP covers the areas of climate resilience of drinking water supply infrastructure. The impacts of climate change on raw water supply, such as turbidity increase, are addressed as well as various drinking water treatment and distribution systems. Efficiency and alternative energy sources are also explored.

1.4 Climate impacts

- Excessive Rainfall and Floods
  - Damage to facilities
  - Contamination of wells
  - Increase runoff
  - Increase siltation of reservoir with decreased capacity
  - Increased turbidity in raw water supplies
  - Contamination of water distribution and storage facilities
  - Loss of power and telemetry
- Drought
  - Decreased surface supply, water intake issues
  - Pressure loss and water quality degradation in distribution system caused by water rationing

  - Increased wellfield drawdown, decreased recharge, supply and saline water intrusion
  - Increased concentration of pollutants, varying water quality (algae blooms due to increased eutrophication), potential increase in treatment process costs
  - Increased water demand and storage requirements

- Hurricanes
  - Loss of power and telemetry
  - Inadequate chemical treatment, fuel and supplies
  - Damage to treatment facilities
  - Damage to distribution and storage facilities
  - Contamination of water distribution and storage facilities
  - Excessive water demand
  - Lack of health and safety operating conditions

- Heat
  - Increased water demand
  - Increased evaporation
  - Water quality changes including algae blooms due to increased eutrophication

- Sea Level Rise
  - Damage to facilities including corrosion from increased saline water
  - Increased salinity (treatment technologies)
  - Well contamination (saline water)

1.5 Utilities Response (SOP)

1.5.1 Potential impacts on Raw Water Supply

Climate change is likely to increase **water demand** while shrinking **water supplies**. Both surface and groundwater will experience changes in water quality and quantity cause by increase extreme rainfall events, droughts, and tropical cyclones. Manmade infrastructures used by the utilities to extract water supplies will need to be adapted to account for these changes. As part of the planning process to increase water supply, water utilities should first investigate ways to reduce non-revenue water and to maximize water efficiency.

1.5.1.1 Surface Water increased turbidity

Turbidity is a measure of the degree of cloudiness or muddiness of water.

It is caused by suspended matter in water like silt, clay, organic matter or microorganisms. Even when caused by factors that do not pose a health risk, turbidity is objectionable because of its adverse aesthetic and psychological effects on the consumers. While some of the suspended materials will be large and heavy enough to settle rapidly to the bottom of a container, very small particles will settle only very slowly or not at all. These small solid particles cause the liquid to appear turbid.

DIVERSIFIED DRINKING WATER SOURCES

Diversified Drinking Water Sources helps to reduce the risk that surface water supply will fall below water demand during high turbidity events. Examples of diversified source water portfolios include using a varying mix of surface water and groundwater, employing desalination when the need arises and establishing water supply cooperation with other utilities in times of water shortages or service disruption.

Examples – Additional water supply sources

- Surface water
- Groundwater
- Desalination
- Stormwater retention ponds (land intensive i.e. large land area required). Possible solution, multiple use of space. e.g. In Porto Alegre, Brazil retention pond located below netball courts or skateboard park as a measure of storm water management.
- Potable water reuse (EPA, n.d.)
- Recycled water - The supply of recycled water could depend on population size and therefore be unlimited and is not significantly influenced by weather. Physical improvements may be required at the treatment plant to increase the available water supply (see example in Annex).

CASE STUDY: TAMPA BAY DIVERSIFIES WATER SOURCES TO REDUCE CLIMATE RISK (USA)
(Agency, n.d.)

Tampa Bay Water provides drinking water for nearly two and a half million residents on the gulf coast of Florida. Historically, the utility relied largely on groundwater to satisfy the nearly 250 million gallons of water required per day (mgd). The utility's operators recognized the increasing vulnerability of its groundwater source to saltwater intrusion and completed construction of a desalination plant in 2008. The utility now delivers 'blended' water using groundwater, surface water, and desalinated water.

WATERSHED PROTECTION

Watershed Protection is the first area to investigate when attempting to control turbidity into surface water. Owning or having control of the land in the watershed area of your source water can make a tremendous difference in the source water's quality. Controlling land use for the purposes of reducing soil erosion and sedimentation control, is becoming more important as populations increase.

Examples – Watershed protection includes:

- Watershed land acquisition
- Conservation easements
- Public education
- Ecosystem restoration
- Erosion and sediment control
- Land use planning
- Regulations (buffer zones, etc.)

SEDIMENTATION BASINS

Sedimentation basins are the main treatment systems to reduce turbidity in raw water. Sedimentation is accomplished by decreasing the velocity of the water being treated to a point below which the particles will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow. In designing sedimentation tanks, the required retention time determines the dimensions of the tank. Potential limitation is availability of land for a sedimentation basin.

Example:

A rectangular shape is the simplest design to use. The basins' dimensions should be within the recommended length to width ratio of between 3:1 to 5:1 (ASCE, 2012). In general basins are usually no more than 3 to 4 meters in depth. Depending on the composition of the turbidity the sedimentation basin should be designed for water retention time of 3 hours to several days.

TURBIDITY MONITORING

Turbidity monitoring can be easily, accurately, and rapidly measured, and is commonly used for operational monitoring of control measures included in water safety plans or SOPs. The WHO Guidelines for Drinking-water Quality can be used as a basis for choosing between alternative source waters and for assessing the performance of several control measures, including coagulation and clarification, filtration, disinfection, and management of distribution systems. (World Health Organization, n.d.). Turbidity should ideally be kept below 1 Nephelometric Turbidity Units (NTU) because of the recorded impacts on disinfection. This is achievable in large well-run municipal supplies, which should be able to achieve less than 0.5 NTU before disinfection at all times and an average of 0.2 NTU or less, irrespective of source water type and quality. If the existing treatment system is unable to achieve the required turbidity values then additional treatment systems will be required. Additional treatment systems which can reduce turbidity include chemical feed (coagulation), flocculation (mixing of coagulant), dissolved air flotation, clarification, solids contact units, sedimentation and filtration.

Examples – Turbidity monitoring locations:

- Source water
  - Rapid changes
  - Changes over time
- Water treatment (processes impacted by turbidity)
  - Sedimentation
  - Filtration
  - Disinfection
- Distribution systems and storage
  - Rapid changes

Contained in the Annex is equipment for continuous monitoring of turbidity, the unit is solar powered and could be used as an early warning system to prevent damage of treatment equipment and to allow operational staff time to prepare for elevated turbidity levels.

IMPROVEMENTS TO EXISTING TREATMENT PROCESSES

Existing water treatment systems may be inadequate to process water of significantly reduced quality. Improvement to the existing treatment processes may be necessary to ensure that quality of water supply continues to meet standards as climate change impacts source or receiving water quality.

Examples – Improvements to these treatment processes can increase turbidity removal:

- Coagulation
- Flocculation
- Sedimentation
- Clarification
- Solids contact units
- Dissolved air flotation
- Filtration

CASE STUDY: BANGKEHN WATER TREATMENT PLANT (THAILAND)

The changing rainfall patterns and rising sea levels have affected the drinking water supply in Thailand. The growing industrial sector in the central parts of Thailand has led to an increase in drinking water demands. The responsibility to provide safe drinking water in the capital city of the country resides with the Metropolitan Waterworks Authority (MWA). MWA has been dependent on the Chao Phraya River and Mae Klong River to meet the demands of water supply. Wet season brings along flood in the Chao Phraya River Basin. This leads to a sudden increase in the turbidity of the river water, which is also aided by the water flowing from the flooded city into the river.

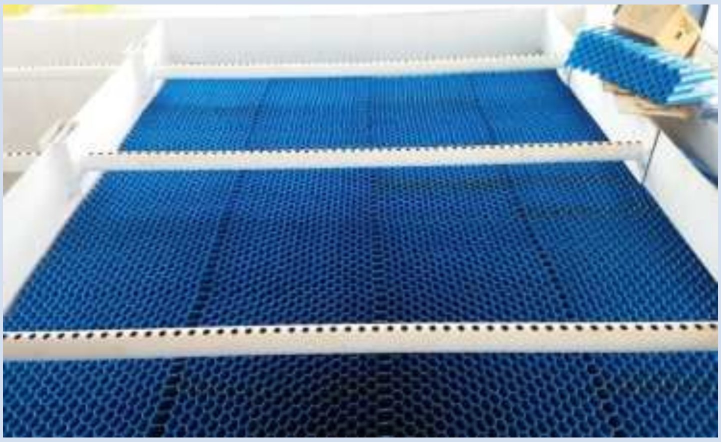

Figure 1. Tube settlers

Bangkhen Water Treatment Plant (BKWTP) is the most essential part of the water supply system of MWA, providing drinking water supply to Bangkok, Nonthaburi and Samut Prakan. This treatment plant has 6 major operations – raw water selection, clarification, filtration, water storage, transmission and distribution, and sludge lagoon. The plant in its current specifications has certain thresholds, which if exceeded leads to subpar quality of treated water: thresholds for turbidity levels greater than 200 NTU beyond which production of water is reduced. To increase the efficiency and to keep the plant operational for future in case of any sudden increase in turbidity is observed, tube settlers can be installed. Tube settlers can increase the surface loading rates and in turn can increase the efficiency of the plant. (Sharma, n.d.) Specifications for tube settlers are included in the Annex.

INTAKE STRUCTURE

Surface water supply changes due to increased turbidity can result in the need to redesign the location of the intake structure. In addition, designs can be modified or changed for intake type.

Examples – Intake structure types (World Health Organization, n.d.) – Annex 1 for diagrams

- Protected side intake
- River bottom intake
- Floating intake
- Sump intake

SEDIMENTATION AND LOSS OF CAPACITY

Climate variability may mean an increased frequency of very heavy precipitation events. Increases in heavy precipitation will result in increased sediment loads, since high flows have a much greater erosive capacity than lower flows. This will result in increased sediment yields even if annual precipitation volume remains the same.

Examples – Sediment management strategies (National Reservoir Sedimentation and Sustainability Team):

- Reduce sediment delivery
- Pass sediment through or around a reservoir
- Sediment removal

1.5.1.2 Wells

EQUIPMENT FLOODING

Equipment flooding of well systems can impact water quality and operation for many years if not properly addressed at the earliest possible time. Floodwaters can directly influence the well when debris carried by the flood impacts the structure; damaging or destroying caps, vents, piping, and the well casing and pump components. Additionally, by destabilizing the ground around a well, flooding can weaken the structural integrity of a well, jeopardizing the sanitary seal. (Michael Schnieders)

Examples – Well flood protection:

- Ensure proper seal of casing, and electrical conduit
- Elevate or relocated electrical panels and well vents
- Have provisions for backup power such as secondary electrical feed, temporary or permanent emergency generator

DECREASED CAPACITY

Decreased capacity of water supply wells is a possibility in certain locations as the result of over extraction and reduced recharge of groundwater both of which are a direct result of climate change. The reduced capacity or well yield can be increased using several rehabilitation methods.

Example: Increase well capacity options

- Chemicals to dissolve encrusted or biological materials (Well Development & Rehabilitation, n.d.)
- Brushing or physical cleaning
- Well deepening (re-drilling)

Decreased water quality

Sea-level rise, storm surge in combination with increased groundwater pumping can increase saltwater intrusion into groundwater aquifers. Saltwater intrusion into groundwater aquifers can increase treatment costs for drinking water facilities or render groundwater wells unusable.

Water resources along the coasts face risks from saltwater intrusion. Rising sea levels, drought and changes in water demand and availability can increase the salinity of both groundwater and surface water sources of drinking water.

Figure source: EPA, n.d.

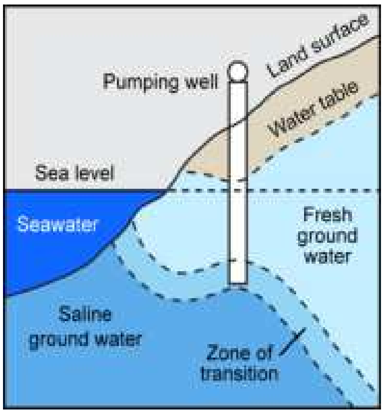

Figure 2. Salt water Intrusion

Examples: Strategies to reduce climate impacts

- Deepen existing wells which have experienced excessive drawdown, this option would only be feasibly for wells located inland which not subject to salt water intrusion
- Relocate well
- Reduce pumping
- Increase freshwater recharge of the aquifer (e.g. injection wells)
- Salinity barriers
- Seek new freshwater sources
- Modify water treatment process

CASE STUDY: CITY OF HALLANDALE BEACH, FLORIDA (USA)

City of Hallandale Beach (population 40,000) has been investigating its options pertaining to its future water supply. Realizing that saltwater intrusion continues to move toward the City's current well field, various strategies have been investigated. The strategies investigated do deal with the potential saltwater intrusion into the wellfield and include:

- Wellfield relocation
- Wellfield revitalization
- Purchase water from neighbouring utilities
- Membrane filtration treatment

Reference: (City of Hallandale Beach, 2013)

1.5.2 Water Treatment Systems

Traditionally the design of water treatment facilities has been predicated on the underlying assumption that ample source water is available to meet all water use requirements within the design life of the facility and that the quality and quantity of water available from a given source are relatively predictable based on historical data. However, increasing evidence of climate variability is raising questions about the validity of traditional design assumptions, particularly since the service life of many facilities can exceed 50 years, typically well beyond the design life. (IWA, n.d.)

The first step in determining the impacts of climate change on an existing water treatment facility is to conduct a vulnerability analysis. As part of the process historical records are reviewed to understand the past frequency and intensity of different natural disasters and how the utility was and could continue to be impacted. Assessments can be conducting using CCORAL Tool to understand climate influences on the water utility. Once these climate influences are understood, CCORAL Tool contains many other built-in tools to determine the vulnerability of the water treatment system. Potential climate related impacts to water treatment facilities and operations include floods, storm surge, wind, hurricanes and sea level rise. Treatment equipment or processes that may be impacted by climate stressors include:

- Treatment, Storage and Administration Buildings
- Coagulation, Flocculation and Clarification
- Softening
- Ion Exchange
- Membrane Filtration
- Filtration
- Disinfection
- Pumping
- Residuals treatment and disposal
- Chemical Storage and Feed Systems
- Electrical and Emergency Power
- Instrumentation and Controls

Examples: Climate adaptation strategies for treatment facilities or operations

- Establish a location outside of a potential disaster zone where equipment, electronics, or vital records can be relocated in order to move vital resources out of harm's way.
- Existing water treatment systems may be inadequate to process water of significantly reduced quality. Substantial improvement to existing treatment processes or implementation of additional treatment technologies may be necessary to ensure that quality of treated water supply continues to meet water quality standards.
- Minimize the exposure of essential utility equipment such as pump stations, treatment systems, generators and fuel tanks, transformers, and information technology infrastructure to failure.

Relocating vulnerable, critical elements to higher elevations or lower-risk areas above base flood elevations can reduce risk from coastal or freshwater flooding and erosion.

- Flood barriers to protect critical infrastructure including seawalls. A related strategy is flood proofing, which involves elevating critical equipment or placing it within waterproof containers or foundation systems.
- Establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions. Make sure delivery contracts are flexible to adjust shipments to account for any temporary storage on site.
- Buildings can be protected from landslides by maintaining ground cover (plants, grass) on slopes and building channels to redirect flow around structures.
- Tanks should be enclosed with a roof to protect from debris and to maintain water quality.

Case Study: Designing Water Systems for Climate Change in Cumayasa, Dominican Republic (Kuartz, 2018)

A case study was conducted in partnership with an elementary school located in Cumayasa, Dominican Republic. From 2011 to 2012, a drinking water treatment system,a water distribution system, and sanitation facilities were implemented at the existing elementary school in Cumayasa. Due to increased enrollment in the school, a new school was under construction to accommodate 1,200 students. In 2015, a project to design and implement a climate-ready potable water system at the newly constructed school was formed with a partner institution. Cumayasa is a developing coastal community located in the Yuma region of the Dominican Republic vulnerable to the impacts of climate change, sea level rise, and hurricanes.

The alternatives analysis phase of the water project identified and compared potential solutions to determine the most appropriate design. Climate change adaptation was incorporated into this phase by: (1) rating climate risk; (2) mapping pathways between climate hazards (i.e., flood and drought), impacts, and design adaptations; and (3) prioritizing appropriate solutions to select which adaptations should be incorporated in the final design. In addition to water scarcity, a deterioration of water quality associated with drought was also expected. Decreased groundwater recharge, combined with and reduced dilution of pollutants and wastes due to reduced groundwater can cause an increased pollutant concentration. Drought conditions can reduce the capacity for water services to supply sufficient quantity of water and cause a reliance on water trucking and bottled water. Water quality in piped water systems is vulnerable to reduced annual precipitation and drought. When piped distribution systems are empty and unpressurised due to intermittent operation, contaminants can enter damaged pipes.

The following design adaptations were determined to have high priority in Cumayasa; therefore, they were incorporated into the system design:

1. Use of an activated carbon filter to remove chemical contaminants
2. Incorporate chlorine disinfection
3. To address turbidity problems, the filtration system incorporated a 5-micron (µm) membrane filter to remove turbidity
4. Ensure proper maintenance and protection of the underground storagecistern
5. Elevate electric-powered pump to protect from flood events
6. Diversify water sources (e.g., include a rainwater harvesting system, install an independent borehole)

The high priority design adaptations identified were incorporated into the system design. Design adaptations determined to have medium or low priority were to be addressed following implementation of the primary water treatment system.

In general, the components of the proposed drinking water treatment system were to be located inside of a secure pump house. The principal microorganisms of concern in water treatment are (1) Giardia lamblia, Cryptosporidium parvum, and other protozoa, (2) bacteria, and (3) viruses. The design of the water treatment system used included a 5 µm membrane filter which physically removes larger contaminants (5 µm or greater in diameter), such as sediments. The second and third filters in the series were 1 µm membrane filters. The 1 µm membrane filters physically remove smaller contaminants such as Giardia lamblia cysts which are 11 to 15 µm in diameter and C. parvum oocysts which are 3 to 5 µm in diameter. Therefore, both are larger than the pore size ratings of the 1 µm membranes and should be completely removed. The final filter in the series is an activated carbon block filter. The activated carbon block filter removes chemical contaminants. Following the filter series, a liquid chlorine dosing point for disinfection of remaining microbial contaminants was included. The treated water is then pumped into a 500-gallon elevated storage tank. Disinfection occurs in the tank. Following the required contact time for disinfection, treated water can be collected from a tap inside the pump house. Operational procedures and training were provided to the community to ensure proper disinfection and regular water quality testing prior to consumption.

1.5.3 Water Distribution System

Climate change is likely to lead to increasing risks on the water distribution infrastructure used distribute water to customers. There are significant threats from damage to infrastructure, poor operation and maintenance, and disruption of essential power systems. Warmer temperatures and prolonged drought can change the soil conditions of pipelines, sea level rise and storm surge can introduce corrosion from salt water into pipelines and pump stations. Also, during extreme flood events and tropical cyclone the disruption of power and increased damage from trees and roots can lead to significant disruptions. In order to properly address impacts from both climate change and emergencies the water utilities should maintain accurate maps and drawings of the existing infrastructure.

1.5.3.1 Pipelines

Materials and methods used in the construction of water supply systems are affected by climate impacts. Understanding how different materials withstand the stresses of wind, storm and landslide damage from extreme climate change-related events can be helpful in designing new climate-resilient systems. Climate related damages to pipelines include:

- Corrosion of metal pipes weaken structures over time
- Physical damage to pipes from flooding, storm surge and landslides
- Contamination of drinking water from pipes damaged by flooding or landslides
- Physical damage to exposed pipes from falling trees and structures
- Physical damage to buried pipes entangled with tree roots that become uprooted with trees
- Corrosion of metallic pipes exposed to seawater from inundation
- Lowering of groundwater levels and consolidation of the soil. The resulting (differential) settlements associated with soil property transitions, may damage underground pipe infrastructure.
- The lack of water demand caused by interrupted water supplies may cause low pressure in the pipeline which can lead to water infiltration and contamination.

One of the biggest issues faced by water distribution pipelines is leakage caused by the above-mentioned climate related impacts. Leakage of water in the distribution system leads to high non-revenue water (NRW) losses which waste resources and leads to higher tariffs. NRW can also impact the quality of water in the pipelines due to the potential of contamination from extraneous sources.

Materials selected for pipelines have a large influence on their ability to withstand climate stressors and if they are exposed or buried. Buried materials are less sensitive to climate-induced damages.

Table 1. Materials Sensitivity from Typhoon Yolanda Damage Assessments

Material	Flooding	Land-slides	Wind	Storm Surge	Sea Level Rise
Metal pipes (buried)	Low	Medium	Low	Low	Low
Plastic pipes (buried)	Low	Medium	Low	Low	Low
Metal pipes (exposed)	High	High	Medium	High	High
Plastic pipes (exposed)	High	High	Medium	High	High

Source: (USAID, 2017)

EXAMPLES
(USAID 2017)

Concrete Encased Pipeline

Hardened Pipeline River Crossing

Pipeline Raised Above Flood Level

Realigned Pipeline Along Stable Slope

1.5.3.2 Pumping and Storage

Appropriate selection of construction materials is vital for climate-resilient water infrastructure such as pump buildings and storage tanks. Building materials differ in sensitivity to climate change impacts from increased salt water exposure, excessive rainfall, wind, flooding, and increased water demand. Pumping and storage facilities will need to be hardened, relocated, rebuilt with better construction materials or expanded in order to achieve an acceptable level resiliency.

Examples: Resiliency options (Steven R. Hilderhoff)

- Stabilize landslide-prone areas by planting trees
- Construct walls around pump stations and tanks to prevent ingress of flood waters
- Retrofit or reinforce structures to be able to withstand stronger hurricanes
- Construct new and climate-resilient facility
- Elevate critical equipment and/or structures above flood level
- Install water-tight doors or temporary flood barriers
- Have provisions to increase pump station and storage capacity due to increasing demand
- Have provisions for temporary or permanent emergency power

Removable Flood Protection

Elevate Critical Structures

1.5.4 Efficiency and Alternative Energy (water and sanitation infrastructure)

A significant amount of municipal energy use occurs at water and wastewater treatment and distribution facilities. With pumps, motors, and other equipment sometimes operating 24 hours a day, seven days a week, water and wastewater facilities can be among the largest consumers of energy in a community—and thus among the largest contributors to the community's total GHG emissions. In the United States the energy used by water and wastewater utilities accounts for 35 percent of typical US municipal energy budgets. Electricity use accounts for 25–40 percent of the operating budgets for wastewater utilities and approximately 80 percent of drinking water processing and distribution costs. (US EPA, 2013)

Water utilities can also reduce energy use at water and wastewater facilities through measures such as water conservation, water loss prevention, and sewer system repairs to prevent groundwater infiltration. Measures to reduce water consumption, water loss, and wastewater lead to reductions in energy use, and result in savings associated with recovering and treating lower quantities of wastewater and treating and delivering lower quantities of water.

1.5.4.1 Audits

Saving energy through energy efficiency improvements can cost less than generating, transmitting, and distributing energy from power plants, and provides multiple economic and environmental benefits. A step-by-step approach to designing and implementing energy efficiency improvements for water utilities is included in the Annex.

1.5.4.2 Solar Power

Solar power is increasing in usage as an alternative power supply for water and wastewater facilities in many parts of the world. The combination of reduced cost, social consciences and public acceptance has increased the usage by utility providers. Electrical usage of utility facilities represents a large portion of budgets and the cost are increasing every year. In the United States some power companies, National and some local governments offer financial incentives for the installation of solar power systems. In addition to financial incentives, some solar companies offer energy services contracts, whereas the solar companies finance the installation of solar systems in exchange for a percentage of the financial savings of power usage.

As described in Section 1.6.2, the power usage of water and wastewater facilities is large. Solar power systems based on existing technology can only supply a portion of the electrical demand at water and wastewater facilities, in addition due to the lack of power storage and issues of solar effectiveness during inclement or cloudy weather solar power can only be used to supplement existing electrical supply. Nevertheless, as the cost of solar power systems drop and existing electrical costs increase the use of solar power will only increase in the future.

Figure 3. 184 KW Solar System at Palm Beach County Water Reclamation Plant

Source: Maurice Tobon.

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2 APPENDICES

2.1 Intake structure types

(World Health Organization, n.d.)

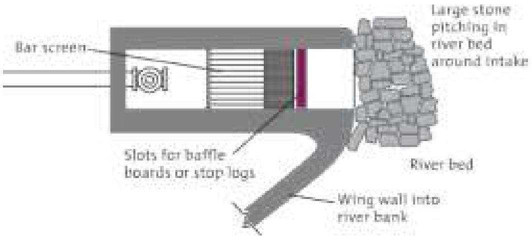


Figure 4. Protected Side Intake

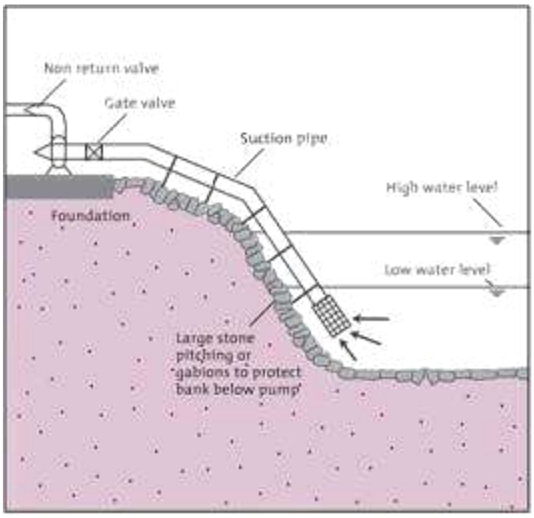


Figure 6. River-bottom Intake

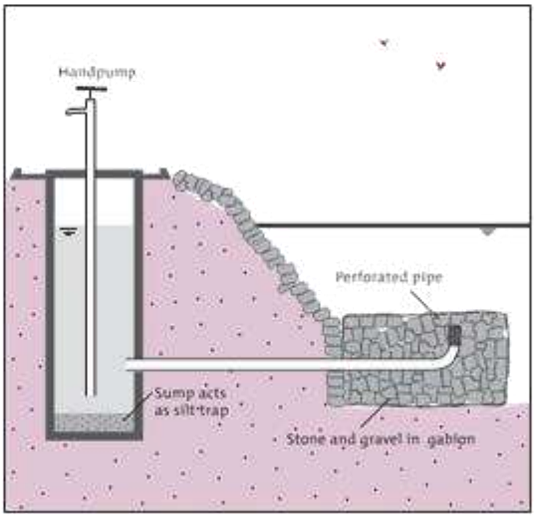


Figure 5. Sump intake

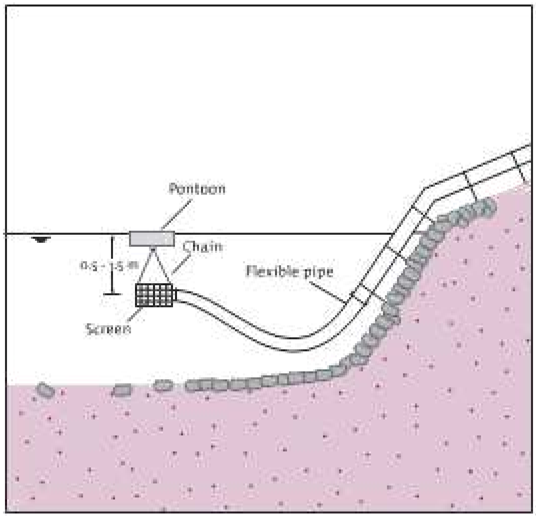


Figure 7. Floating intake

2.2 Water reclamation process

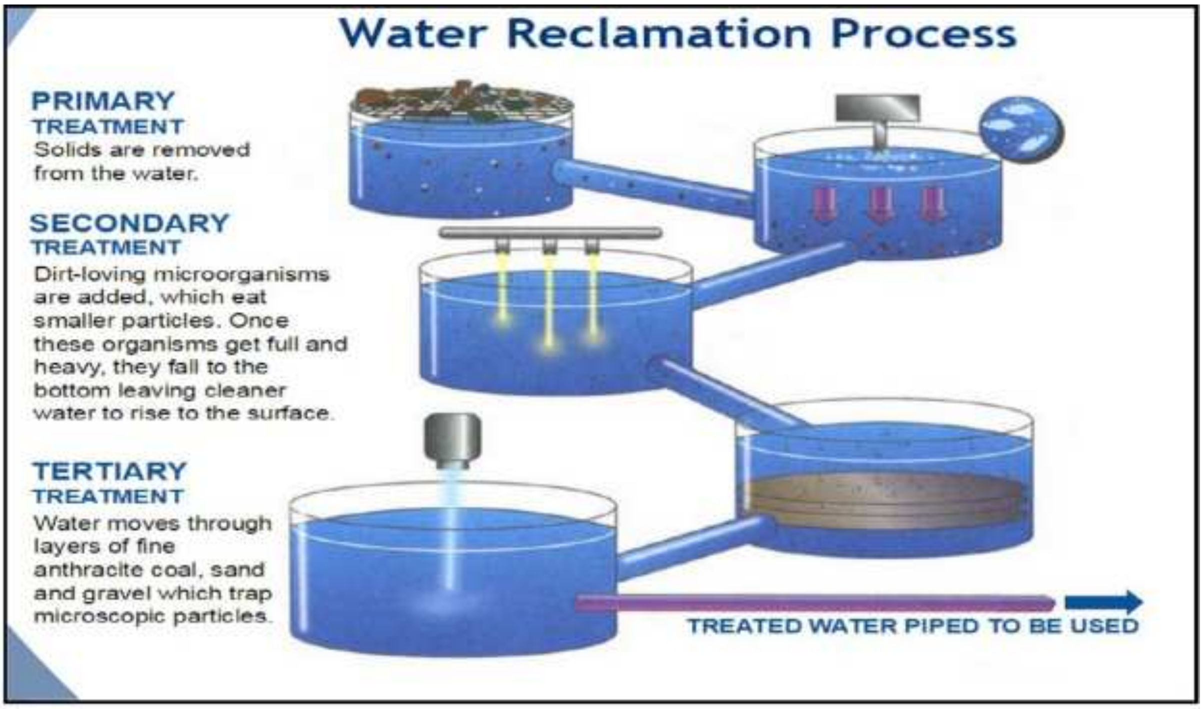


Figure 8. Recycle Water Process

Source: Water Solutions Inc., 2015

2.3 Tube settlers

Figure 9. Tube Settlers

HEWi[Tube] Lamella series

Water and waste water application				
model	LS50	LS84	LS60	LS38
Typical Application	Potable water Rainwater treatment Process water Humus tanks	Primary sedimentation Activated sludge Combined sewer overflow	Effluent Polishing Potable water Humus tanks	Effluent Polishing Aquaculture Rainwater treatment
made	Polypropylene	Polypropylene	Polypropylene	Polypropylene/PVC
Angle	45°-90° STD 55°/60°	45°-90° STD 55°/60°	60°	60°
Channel	Equidistant chevron	Equidistant chevron	Trapezoidal flutes	Trapezoidal flutes
Specific surface*	~13 m2/m3 (55°) ~11 m2/m3 (60°)	~7 m2/m3 (55°) ~6.3 m2/m3 (60°)	11.5 m2/m3 (average)	15 m2/m3 (average)
Hydraulic radius	17mm	25mm	12mm	17mm
Certification	KTW / NSF	KTW / NSF		
Color(s)	Black Blue (KTW/NSF)	Black Blue (KTW/NSF)	Black	Black
Std dimension				
Length (mm)	300 - 1500	300 - 1500	800 - 2400	800 - 2400
Width (mm)	300 - 1500	300 - 1500	300 - 600	300 - 600
Height (mm)	500 - 2000	500 - 2000	900	600

*) vertical projected surface = effective settling surface

Design Guideline for HEWi[Tube] Lamella settlers

Most engineers are using Hazen's law as design approach for the settling efficiency.

Hazen's law links the settling velocity [V_t] of the target particle with the flow rate [Q] and the installed vertical projected surface [A_f].

The Hazen velocity ($V_H = Q/A_f$) is the most important design parameter.

Particles with a settling velocity that is equal or faster than the Hazen velocity will be removed.

Typical Design Hazen Velocity		
Feed water	Hazen	Product HEWi[Tube]
Potable water	0,5 – 0,9 m/h	LS50 / LS60
Primary settling	0,9 – 1,2 m/h	LS85
MBBR effluent	0,4 – 0,5 m/h	LS50
Trickling filter effluent	0,5 – 0,8 m/h	LS50
Polishing	0,5 – 0,8 m/h	LS50 / LS60
Aqua culture	0,4 – 0,8 m/h	LS50 / LS38

Our partners

C. E. Shepherd Company, L. P.

hewitech INNOVATION IN PLASTIC

Aqua Equip Technologies LLC, PO Box 1790, Tarpon Springs, FL 34688

Figure 10. Tube settlers

Source: Aqua Equip Technologies LLC

2.4 Solar powered floating turbidity monitoring

Figure 11. Solar powered floating turbidity monitoring

CB-450

DATA BUOY

specifications

Hull Outer Diameter	34.0" (86.4cm)
Hull Height	20.0" (50.8cm)
Data Well Inner Diameter	10.3" (26.2cm)
Data Well Height	19.5" (49.5cm)
Pass-Through Hole Diameter	4.0" (10.2cm)
Tower Height	20.0" (50.80cm)
Solar Panels	3x 15-watts
Weight	130 lb (59kg)
Net Buoyancy	450 lb (204kg)
Hull Material	Cross-linked polyethylene foam with polyurea coating & stainless steel deck
Hardware Material	316 stainless steel
Mooring Attachments	3x 3/4" eyenuts

parts list

Part #	Description
CB-450	Data buoy with polymer-coated foam hull & (3) 15-watt solar panels, 450 lb. buoyancy
CB-A05-1	CB-Series buoy battery harness with integrated solar regulator & (1) 28 A-Hr battery
CB-A05-2	CB-Series buoy battery harness with integrated solar regulator & (2) 28 A-Hr batteries
CB-PTL	CB-Series buoy pass through data well lid for custom integrations, includes set of plugs & cable gland fittings
X2-CB	X2-CB buoy-mounted data logger
M550-F-Y	Solar marine light with flange mount & 1-3 nautical mile range, 15 flashes per minute, yellow

NEXSENS technology

tel: 937.426.2703
8am to 7pm EST, Monday-Friday

fax: 937.426.1125

NexSens Technology, Inc.
2091 Exchange Court
Fairborn, OH 45324
info@nexsens.com

nexsens.com

Figure 12. Solar powered floating turbidity monitoring

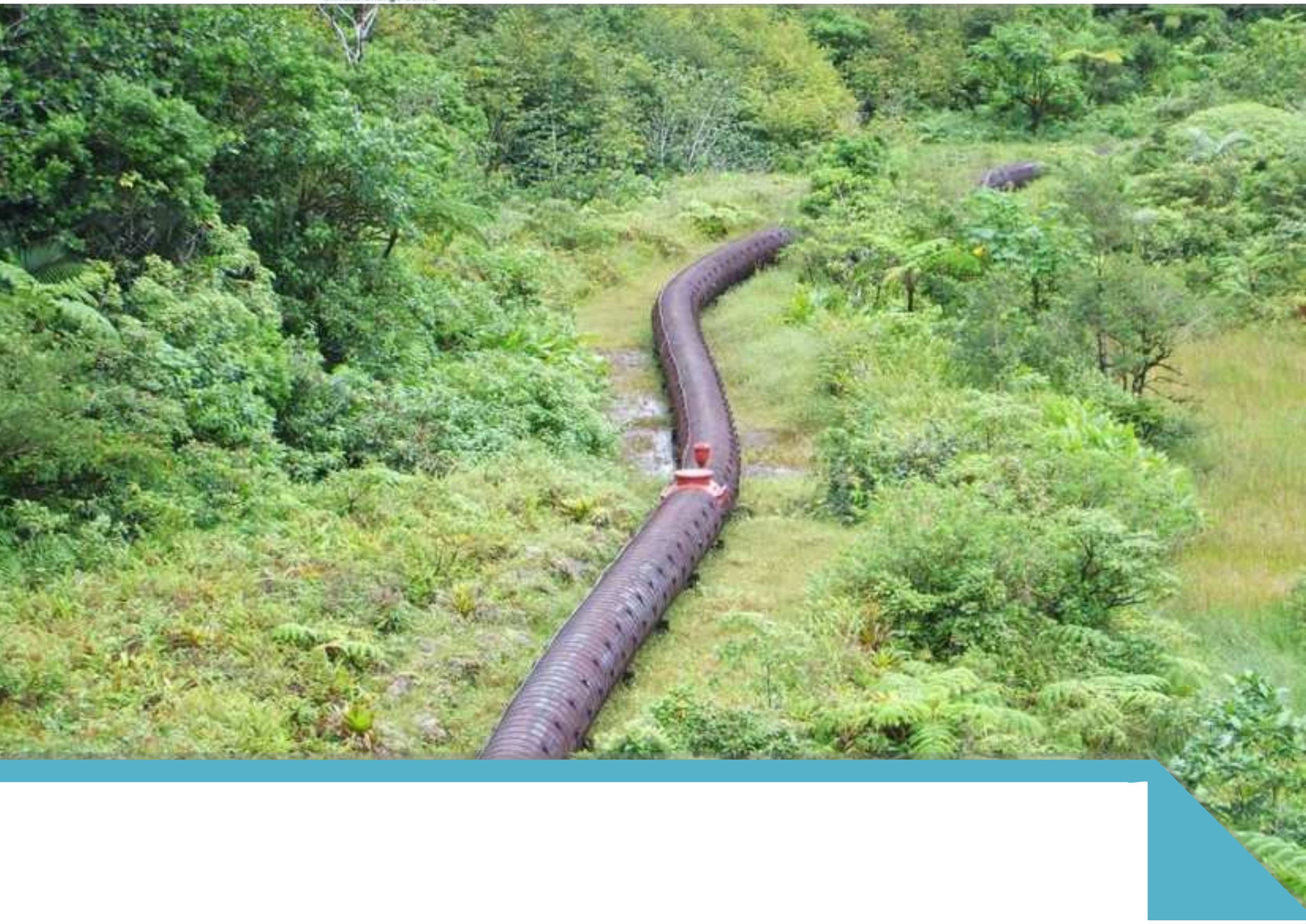
Source: NEXSENS technology

Caribbean Community Climate Change Centre

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

GCCA+

THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE



Regional SOPs for Climate Resilient Water Infrastructure

SOP 2:

DESALINATION

EU-GCCA/SER/006

May 2021

Ref R2390

Developing Standard Operating Procedures (SOPs) for
Climate Resilient Water Infrastructure in the CARIFORUM countries

SOFRECO

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LIST OF ACRONYMS

Acronym	In Full
CCCCC /5C	Caribbean Community Climate Change Centre
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
FEMA	Federal Emergency Management Agency
SOPs	Standard Operating Procedures

EXECUTIVE SUMMARY

Desalination is used in the Caribbean is used to augment potable water supply in some cases and in other island this is the only source of potable water. Islands totally dependent on desalination include Anguilla, Bahamas, British Virgin Island, Cayman Island and Turks and Caicos. Due to their location along or near the coast, desalination treatment plants are vulnerable to climate stressors such as sea-level rise, tropical storms, and storm surges. The increase occurrence of these events could require that all part of the water treatment system such as the intake, pump station, treatment building and all other critical facilities be hardened, relocated, or redesigned to accommodate the climate impacts.

To address climate resilience for desalination the focus was on water intake and pumping, treatment systems, as well as building and equipment. Building hardening or strengthening can be achieved through building and equipment storm mitigation measures that target structural improvement for the building envelope. Important components of the desalination plant are the intakes and associated pumping systems. Their type and location have a measurable impact on the quality and cost of plant operations and thus proper design and construction is a vital component of the desalination system ability to withstand climate stressors. Construct walls around pump stations and tanks to prevent ingress of flood waters.

A vulnerability analysis is the first step in determining the impacts of climate change on an existing desalination treatment facility. Assessments can be conducted using CCORAL Tool to understand climate influences on the water utility. Once these climate influences are understood, the CCORAL Tool contains many other built-in tools to determine the vulnerability of the water treatment system.

Climate adaptation strategies for treatment facilities or operations is a necessary step in improving resilience and should include measures to; i) Establish a location outside of a potential flood zone where possible; ii) establishing flood barriers to protect critical infrastructure such as seawalls, dike, flood door, temporary barrier; iii) have provisions to increase capacity of treatment processes as a result higher water demand iv) establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions, and v) standby generators, dual power feed, diesel drive pumps, and /or renewable energy which is an emerging application and can provide a sustainable way to produce fresh water. Renewable energy is a means of developing synergies between power generation and water services which could also prove to be a valuable source for resilience when local power grid is down due to for example hurricanes.

Desalination plants contribute to adaptation to climate change in circumstances in which water scarcity problems may be exacerbated in the future.

1 STANDARD OPERATING PROCEDURE: DESALINATION

The SOP is provided in the following pages. Sections 1.4 and 1.5 relate to Climate impacts and to Utilities Response respectively.

1.1 Purpose

The purpose of this SOP is to provide climate resilient solutions to issues arising from the impacts of climate hazards on desalination infrastructure in the Caribbean.

1.2 Introduction

Climate hazards such as floods, droughts, hurricanes and sea-level rise are impacting water-related infrastructure including desalination ones in the Caribbean. To mitigate these effects, water utilities need to prepare their infrastructure before, during and after these climate events. This SOP provides guidance to water utilities to adapt their infrastructure so that it becomes more resilient to climate change.

1.3 Scope

This SOP covers the areas of climate resilience of desalination infrastructure. The impacts of climate change on water intake and pumping are addressed as well as on desalination treatment system and, treatment building and equipment.

1.4 Climate impacts

- Excessive Rainfall and Floods
  - Damage to facilities
  - Loss of power and telemetry
- Drought
  - Increased water demand
- Hurricanes
  - Loss of power and telemetry
  - Inadequate chemical treatment, fuel and supplies
  - Damage to treatment facilities
  - Excessive water demand
- Sea Level Rise
  - Damage to facilities including corrosion from increased saline water

1.5 Utilities Response (SOP)

Desalination treatment plants due to their location along or near the coast are vulnerable to climate stressors such as sea-level rise, tropical cyclones and storm surges. The increase in these impacts could require that all part of the water treatment system such as the intake, pump station, treatment building and all other critical facilities be hardened, relocated or redesigned in order to accommodate the climate impacts.

1.5.1 Water Intake and Pumping

1.5.1.1 Intake structure and pumping

Desalination plant intakes are configured and designed to collect saline water of adequate quantity and quality reliably to facilitate cost effective production of desalinated water with minimum impact to the environment. The main function of intake pump stations is to reliably deliver source water collected by the intake to the downstream pretreatment facilities. Intakes and associated pumping systems are thus important components of the plant, and their type and location have a measurable impact on the quality and cost of plant operations. The proper design and construction of the intake and pump station systems is a vital component of the desalination system ability to withstand climate stressors. As the result of climate change, tropical cyclones may increase in frequency and intensity which may require the need to upgrade, harden or relocate these facilities. In addition, these facilities could see an increase in the exposure of salt water to the materials of construction leading to their corrosion. Appropriate selection of construction materials is vital for climate-resilient water infrastructure such as intakes and pump buildings including relevant equipment. Redesign of intake structures could be required to protect from debris and shifting beach erosion patterns.

Examples: Intake designs

There are several different types of intake designs in desalination plants which can be divided into two main groups: surface and subsurface.

The most common intake systems for the larger desalination facilities are surface intakes, which include deep water intakes, onshore intakes, and offshore intakes. These are open directly to the ocean and, therefore, use a combination of location, barrier, and deterrents to decrease incidents of impingement and entrainment. (Thomas M. Missimer, 2018)

Subsurface intakes are below the seafloor, so they do not don’t cause any impingement or entrainment and have the added benefit of natural filtration through sand. Such systems include well and galleries type intakes. These intake types are more common in smaller desalination facilities.

Images sources: (Thomas M. Missimer, 2018)

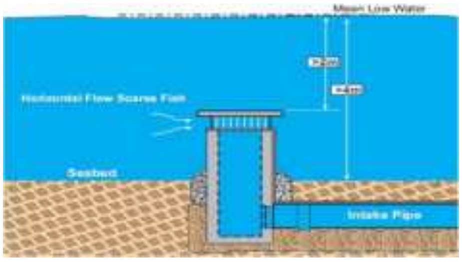

Figure 1. Surface water intake

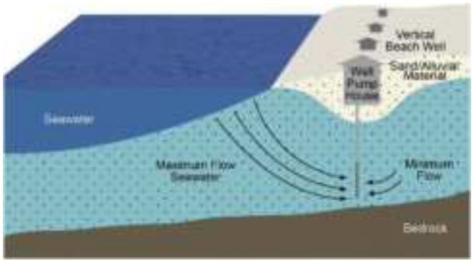

Figure 2. Subsurface well intake

Examples: Pump station designs

There are many types of pump station designs that could be used to convey sea or brackish water from the intake structure to the treatment facility. The need for a pump station is also dependent on capacity of the desalination facility, smaller system may not need a separate pump station as all equipment and system are located at one location. Therefore, for larger desalination treatment plants pump station resiliency options could include (Steven R. Hilderhoff):

- Construct walls around pump stations and tanks to prevent ingress of flood waters
- Retrofit or reinforce structures to be able to withstand stronger hurricanes
- Construct new and climate-resilient facility
- Elevate critical equipment and/or structures above flood level
- Install water-tight doors or temporary flood barriers
- Have provisions to increase pump station and storage capacity due to increasing demand
- Have provisions for temporary or permanent emergency power

1.5.2 Desalination Treatment System

The first step in determining the impacts of climate change on an existing desalination treatment facility is to conduct a vulnerability analysis. As part of the process historical records are reviewed to understand the past frequency and intensity of different natural disasters and how the utility was and could continue to be impacted. Assessments can be conducting using CCORAL Tool to understand climate influences on the water utility. The CCORAL Tool (CCCCC) is a system which helps decision makers to see all kinds of activities through a 'climate' or 'climate change' lens, and to identify actions that minimise the climate risks.

Link: https://www.caribbeanclimate.bz/caribbean-climate-chage-tools/tools/.

CCORAL contains a resource database of nearly 80 tools. These tools are organised according to key criteria derived from the initial tool evaluation. Potential climate related impacts to the facilities and operations include floods, storm surge, wind, hurricanes and sea level rise can be identified from the CCORAL tools. Treatment equipment or processes that may be impacted by climate stressors include:

- Coagulation and Flocculation
- Sedimentation
- Prefiltration
- Reverse Osmosis
- Post Treatment Chemical
- Disinfection
- Pumping
- Chemical Storage and Feed Systems
- Electrical and Emergency Power
- Instrumentation and Controls

Examples: Climate adaptation strategies for treatment facilities or operations

- Establish a location outside of a potential flood zone where equipment, electronics, or vital records can be relocated in order to move vital resources out of harm's way.
- Minimize the exposure of essential utility equipment such as pumps, treatment systems, generators and fuel tanks, transformers, and information technology infrastructure to flooding.
- Flood barriers to protect critical infrastructure such as seawalls, dike, flood door, temporary barrier.
- Have provisions to increase capacity of treatment processes as a result higher water demand

- Install hurricane rated doors and window, remove skylights and other unnecessary roof penetrations
- Standby generators, dual power feed, and/or diesel drive pumps
- Establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions. Make sure delivery contracts are flexible to adjust shipments to account for any temporary storage on site.
- Relocate outside tanks and chemical storage indoors to protect from excessive sunlight and heat which could accelerate equipment failure and chemical decomposition.
- Buildings can be protected from landslides by maintaining ground cover (plants, grass) on slopes and building channels to redirect flow around structures.
- Tanks should be enclosed with a roof to protect from debris and to maintain water quality.

1.5.3 Treatment building and equipment

Wind with sufficient speed to cause damage to desalination facilities can occur anywhere in the Caribbean. Even a well-designed, constructed, and maintained critical facility may be damaged in a wind event much stronger than one the building was designed for. Most damage occurs because various building elements have limited wind resistance due to inadequate design, poor installation, or material deterioration.

Desalination facilities are usually housed in a steel panel or concrete block building, nevertheless the building envelope, exposed treatment systems, and non-structural building systems are usually the systems that fail due to extreme winds which can cause the entire desalination facility to halt operations. The section below contains numerous examples of best practices and real-world examples of wind mitigation strategies as it pertaining to new and existing facilities.

1.5.3.1 Structural improvements

Structural damage (e.g., roof deck blow-off, blow-off or collapse of the roof structure, collapse of exterior bearing walls, or collapse of the entire building or major portions thereof) is the principal type of damage that can occur during strong hurricanes. It can take days, months, or more than a year to repair the damage or replace a facility. In addition to the costs associated with repairing or replacing the damage, other social and financial costs can be even more significant. The repercussions related to interrupted production of water from the desalination facility can include impacts to medical facilities, schools, public safety and health.

Examples:

The following building and equipment storm mitigation measures examples are from various unpublished Hurricane hardening studies which were developed as part of co-author Maurice Tobon’s responsibilities as Engineering Director for Palm Beach County Water Utilities. The pictures below show both resilient and non-resilient (recommend for mitigation) building and equipment examples.

Figure 4. Open metal structure- recommend enclosing structure to reduce failure potential

Figure 3. Tee roof beam brackets added to resist wind uplift forces.

Figure 6. Roof joist to wall connection- recommend adding bracket to secure wall and roof

Figure 5. Unreinforced decorative wall block- recommend removal and replace with solid wall

1.5.3.2 Building envelope (windows and doors) protection

Building envelope components have historically sustained the greatest and most frequent damage in high winds (US Department of Homeland Security, 2007). This section addresses openings, doors, rolling doors and windows. Failure of doors and windows can allow the penetrating of wind driven rain which can damage components of the desalination building and equipment which can lead to the inability to produce potable water.

Examples:

The pictures here after show both resilient and non-resilient (recommend for mitigation) windows, doors, and louvers.

Figure 8. Wind wall installed to prevent wind driven rain from entering thru louvers

Figure 7. Unprotected window-recommend hurricane shutters or impacted rated windows

Figure 10. Hurricane rated rollup door

Figure 9. Windows with accordion hurricane shutters

Figure 11. Hurricane rated louvers

1.5.3.3 Secure outside treatment equipment

The securing of equipment (tanks, piping, treatment systems, vents, air conditioners, etc.) located at the outside of the desalination main building is an important aspect of minimizing impacts to water production. The outside equipment should be protected from damaging wind forces and impact from wind borne object. An example tie down system for tanks is included in the Annex.

Examples: The examples show various good practices to secure outside equipment; conversely examples of non-protected equipment are also included.

Figure 13. Equipment lacking tie-down

Figure 12. Tie down of roof equipment

Figure 15. Unsecured storage tank container

Figure 14. Chemical tanks with proper anchor

Figure 17. Lack of anchor bolts on generator

Figure 16. Chemical tanks with proper hold down straps

1.6 References

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2 APPENDICES

2.1 Example tank tie-down detail

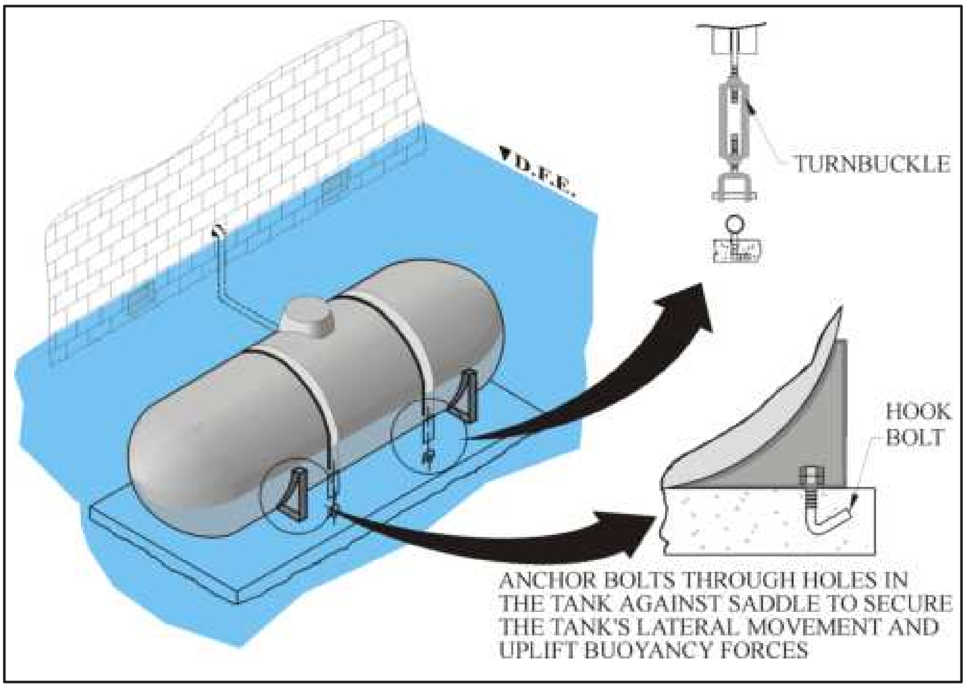

Figure 18. Example tank tie-down detail (1)

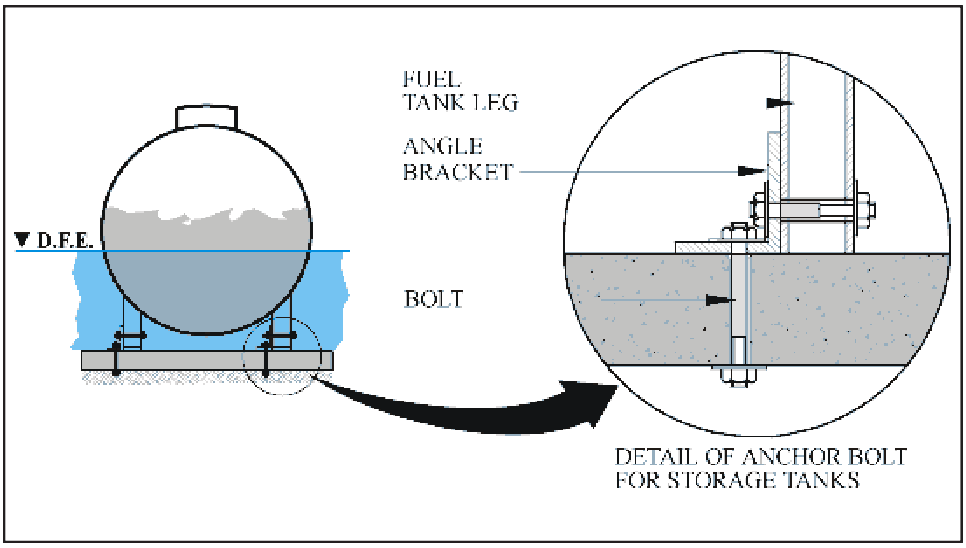

Figure 19. Example tank tie-down detail (2)

Source: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems, FEMA 1999

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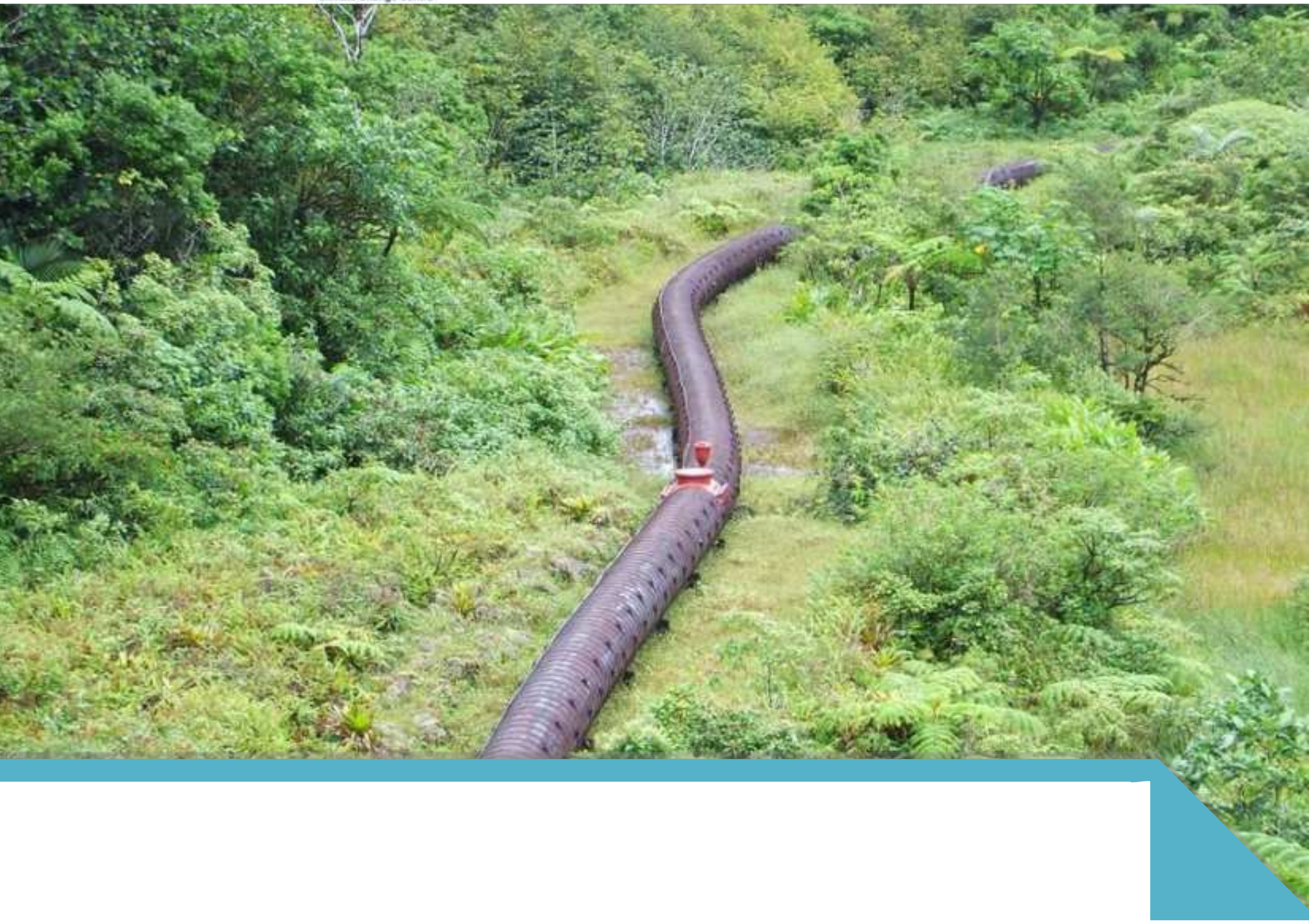
INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund



Regional SOPs for Climate Resilient Water Infrastructure

SOP 3:

WASTEWATER

EU-GCCA/SER/006

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LIST OF ACRONYMS

Acronym	In Full
CWA	Clean Water Act
EPA	Environmental protection Agency
SOPs	Standard Operating Procedures
WASD	Miami-Dade Water and Sewer Department
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

The wastewater sector plays a crucial role in protecting public health and the environment. With the climate change projections for the Caribbean region, the challenge will be to manage water quality, protect infrastructure and improve resilience after extreme events.

Increased storms and flooding can be harmful to wastewater treatment plants (WWTP) especially those in low lying coastal areas, strong waves during hurricanes can damage effluent pipes and sea level rise can endanger the location of many of these plants. Along with droughts, the conditions result in changes in influent and effluent quantity and quality. The threats to WWTPs are therefore both in terms of the physical structure as well as to the treatment systems within the plants. The approach to make climate proof WWTPs and at the same time improving their resilience during extreme events is therefore to focus on both infrastructure and treatment.

With respect to infrastructure, attention to wastewater collection systems, pipelines and pumping station are areas of concentration. Understanding how different materials withstand the stresses of wind, storm and landslide damage from extreme climate change-related events can be helpful in designing new climate-resilient systems. Efforts to improve infrastructure performance may include elevating critical equipment and structures, retrofitting and protection of structures, reinforcing, rusting proofing pipes, having a scheduled maintenance plan and make provision to expand infrastructure where needed.

Wastewater treatment system include screening, grit removal, aeration disinfection sludge dewatering to name a few. The combined effective operation of these components prior to, during and after any specific event is important in maintaining acceptable level effluent that is discharged to the environment. Climate adaptation strategies for treatment facilities or operations includes modifying wastewater system design to treat more concentrated influent, changing operations and maintenance routines, have provisions for temporary or permanent emergency backup power and establishing redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions.

The wastewater sector must adapt to changing water use patterns, a growing population, and a range of climate pressures in decades to come. Preparing for these changes will help the sector build resilience under today’s conditions and adapt to what lies ahead.

1 STANDARD OPERATING PROCEDURE: WASTEWATER

The SOPs are provided in the following pages. Sections 1.4 and 1.5 relate to Climate impacts and to Utilities responses respectively.

1.1 Purpose

The purpose of the SOPs is to provide climate resilient solutions to issues arising from the impacts of climate hazards on wastewater treatment infrastructure in the Caribbean.

1.2 Introduction

Climate hazards such as floods, droughts, hurricanes and sea-level rise are impacting water-related infrastructure including wastewater treatment ones in the Caribbean. To mitigate these effects, water utilities need to prepare their infrastructure before, during and after these climate events. These SOPs provide some guidance to water utilities to adapt their infrastructure so that it becomes more resilient to climate change.

1.3 Scope

These SOPs cover the areas of climate resilience of wastewater treatment infrastructure. The impacts of climate change on wastewater treatment system and wastewater pumping and collection systems are addressed.

1.4 Climate impacts

- Excessive Rainfall and Floods
  - Damage to facilities
  - Loss of power and telemetry
  - Operational disruptions (i.e. sludge dewatering)
  - Excessive rainfall entering sewer collection system (infiltration and inflow)
- Hurricanes
  - Loss of power and telemetry
  - Damage to treatment facilities
  - Damage to wastewater pumping and collection system
- Sea Level Rise
  - Damage to facilities including corrosion from increased saline water
  - Increase salinity of wastewater
- Drought
  - Changes to receiving water quality such as higher potential for eutrophication

1.5 Utilities Response (SOP)

Climate models show that across the Caribbean precipitation will increasingly occur in more concentrated extreme events. These intense precipitation events may challenge current infrastructure, wastewater infrastructure is particularly at risk to flooding when these extreme events occur due to the typically low elevation of facilities especially along the coast. In addition, more extreme events can lead to more overflows in combined systems and reduce the capacity of sewer systems already impacted by inflow and infiltration. Coastal storm surges may increase in frequency and extent where sea-level rise is combined with projected increases in storm frequency or intensity. This combination results in inundation of coastal areas, disruption of service and damage to infrastructure such as treatment plants, pump stations and sewer infrastructure. Overall, the lack of service provision with respect to wastewater systems contributes to increase levels of vulnerability to climate change impacts.

1.5.1 Wastewater Treatment System

The wastewater sector plays a crucial role in protecting public health and the environment. Projected changes in climate and hydrologic conditions have the potential to impact the wastewater treatment infrastructure and operations.

- Screening
- Grit Removal
- Aeration (bioreactor)
- Secondary Clarifiers
- Septage
- Disinfection
- Pumping and Blowers
- Sludge Dewatering and Drying
- Chemical Storage and Feed Systems
- Electrical and Emergency Power
- Instrumentation and Controls
- Higher peak flows into the waste water treatment plant (WWTP) and reduced biological load

Examples: Climate adaptation strategies for treatment facilities or operations

- Wastewater systems should be designed to accommodate the uncertainty associated with future climate
- Establish a location outside of a potential disaster zone where equipment, electronics, or vital records can be relocated in order to move vital resources out of harm's way.
- Substantial improvement to existing treatment processes capacity may be needed to account for increased wastewater flow from flooding or increased rainfall.
- Minimize the exposure of essential utility equipment such as pump stations, treatment systems, generators and fuel tanks, transformers, and information technology infrastructure to failure. Relocating vulnerable, critical elements to higher elevations or lower-risk areas above base flood elevations can reduce risk from coastal or freshwater flooding and erosion.
- Flood barriers to protect critical infrastructure including seawalls. A related strategy is flood proofing, which involves elevating critical equipment or placing it within waterproof containers or foundation systems.
- Establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions. Make sure delivery contracts are flexible to adjust shipments to account for any temporary storage on site.

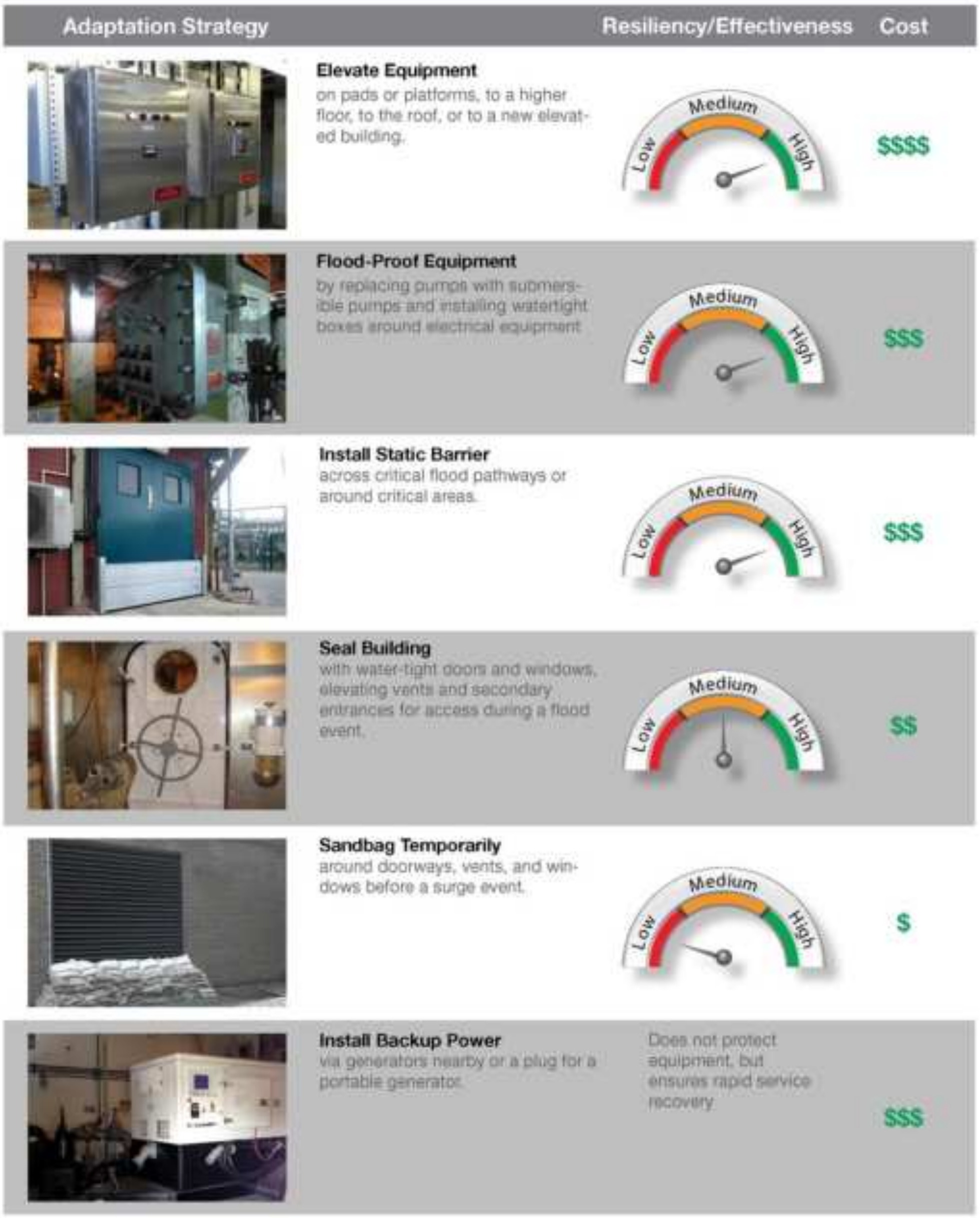

Figure 1. Wastewater Treatment Plant Adaptation Options and Relative Costs

Source: NYC Wastewater Resiliency Plan, NYCDEP 2013

CASE STUDY: MIAMI-DAEDE COUNTY

Much of Miami-Dade County's critical, aging infrastructure is vulnerable to climate change and associated sea level rise. Because of its exposed location on Virginia Key, the County's wastewater treatment plant is particularly susceptible. The incidence and magnitude of sewage spills and equipment failures are worsened by rising sea levels and more frequent, more intense storms. During the aftermath of Hurricane Irma in 2017, WASD's facilities released six million gallons of sewage into Biscayne Bay, posing a public health risk.

This was not the first time the plant discharged waste in violation of the U.S. Clean Water Act (CWA). In total, Miami-Dade's three wastewater treatment plants released over 50 million gallons of waste into nearby waters between 2007 and 2012. In 2013, the County reached a CWA settlement with the U.S. Environmental Protection Agency (EPA) to resolve sewage violations and improve failing infrastructure.

At the time, environmental watchdogs like Biscayne Bay Waterkeeper raised concerns the settlement failed to "account for sea level rise and climate impacts that will, if not appropriately accounted for, cause major failures in the sewage collection and treatment system during its useful life."

In the face of climate change, WASD weighed options to protect critical coastal infrastructure. It could do nothing. It could relocate the wastewater plant to a non-coastal location, at a high price. Or it could make incremental capital improvements to existing assets. WASD chose to strengthen infrastructure via ongoing capital improvements over multiple phases. Part of the budget funds adaptation projects to minimize risk, such as raising electrical panels or elevating critical chlorine facilities. (Katie Segal, 2020)

1.5.2 Wastewater Pumping and Collection Systems

1.5.2.1 Pipelines (forcemains)

Materials and methods used in the construction of wastewater forcemain systems are affected by climate impacts. Understanding how different materials withstand the stresses of wind, storm and landslide damage from extreme climate change-related events can be helpful in designing new climate-resilient systems. Climate related damages to pipelines include:

- Corrosion of metal pipes weaken structures over time
- Physical damage to pipes from flooding, storm surge and landslides
- Physical damage to exposed pipes from falling trees and structures
- Physical damage to buried pipes entangled with tree roots that become uprooted with trees
- Corrosion of metallic pipes exposed to seawater from inundation
- Lowering of groundwater levels and consolidation of the soil. The resulting (differential) settlements associated with soil property transitions, may damage underground pipe infrastructure.
- Maintain adequate physical separation between water mains and wastewater forcemains. If the forcemain leaks wastewater which can potentially enter a drinking water pipe if the water system pressure is low or zero. Low water pressure in a drinking water system can be the result of inadequate supply (water rationing), failure of pumps, water main breaks and hydraulic surges. Included in the Annex is an example of a specification to maintain adequate separation between water and wastewater pipes.

Materials selected for pipelines have a large influence on their ability to withstand climate stressors.

Table 1. Materials Sensitivity from Typhoon Yolanda Damage Assessments

Material	Flooding	Land-slides	Wind	Storm Surges	Sea Level Rise
Metal pipes (buried)	Low	Medium	Low	Low	Low
Plastic pipes (buried)	Low	Medium	Low	Low	Low
Metal pipes (exposed)	High	High	Medium	High	High
Plastic pipes (exposed)	High	High	Medium	High	High

Source: (USAID, 2017)

EXAMPLES
(USAID 2017)

Cable hanging of pipeline above river

Concrete encased pipeline for erosion protection

1.5.2.2 Wastewater collection system (|Gravity)

The shift to higher intensity events as the result of climate change will have impacts on wastewater systems which could be profound. Sea level rise, higher groundwater levels, more intense rain events and increased flooding will introduce extraneous water into wastewater collection systems. This additional water flowing into the collection system will reduce the capacity of the piping and pumping system and may result in widespread spillage of raw sewage into the environment and contaminate drinking water supplies. Inflow/infiltration are the terms used to describe the ways that groundwater and stormwater enter into dedicated wastewater systems, reducing inflow may also reduce the introduction of saline waters into the system as a result of sea level rise.

Examples: Resiliency options to reduce infiltration and inflow

- Gravity sewer lining
- Manhole coating
- Manhole inflow protector
- Sewer lateral replacement

1.5.2.3 Pumping Stations

Appropriate selection of construction materials is vital for climate-resilient water infrastructure such as pump buildings and storage tanks. Building materials differ in sensitivity to climate change impacts from increase saltwater exposure, excessive rainfall, wind, flooding, and increased wastewater flow. Pumping facilities will need to be hardened, relocated, rebuilt with better construction materials or expanded in order to achieve an acceptable level resiliency.

Examples: Resiliency options (Steven R. Hilderhoff):

- Stabilize landslide-prone areas by planting trees
- Construct walls around pump stations to prevent ingress of flood waters
- Retrofit structures to be able to withstand stronger hurricanes
- Construct new and climate-resilient facility
- Elevate critical equipment and/or structures above flood level
- Install water-tight doors or temporary flood barriers
- Have provisions to increase pump station capacity due to increasing demand

- Have provisions for temporary or permanent emergency power

Figure 2. Removable Flood Protection

Figure 3. Elevate Critical Structures

1.6 References

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2 APPENDICES

n/a

Caribbean Community Climate Change Centre

GCCA+ THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

SOP 4:

COMMUNITY WATER SUPPLY AND SANITATION

EU-GCCA/SER/006

May 2021

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Developing Standard Operating Procedures (SOPs) for Climate Resilient Water Infrastructure in the CARIFORUM countries

SOFRECO

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LIST OF ACRONYMS

Acronym	In Full
ASCE	American Society of Civil Engineers
CBDWS	Community based drinking water and sanitation
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
NTU	Nephelometric Turbidity Unit
NRW	Nonrevenue Water
SOPs	Standard Operating Procedures
UN	United Nations
USGS	United States Geological Survey
WHO	World Health Organization
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

Community based drinking water and sanitation (CBDWS) refers to the provision of drinking water system capable of delivering safe and sufficient drinking water as well as improve sanitation and hygiene practices in a community. Stakeholders' participation, early buy-in and inclusiveness are all important in developing a SOP and as a result local-level response should include the perspectives of indigenous peoples, women, men, children, and people with disabilities. The SOP for CBDWS was developed to outline a set of procedures to improve resilience of these systems as they withstand environmental shocks caused by climate change. These shocks caused by excessive rainfalls and floods, droughts, hurricanes, heath stress and sea level rise will impact both water quality and quantity. Community response must be within a framework that it is, i) adequate and reliable, ii) quality, iii) cost effective, iv) within the island political and legal framework. Total dependence on a single source is undesirable, and in some cases, diversification is essential for reliability. Adequacy of supply requires that the source be large enough to meet the water demand. From the standpoint of reliability, the most desirable are:

- Supplies that can be replenished, whether from surface or groundwater, which flows by gravity through the distribution system;
- New and improved storage facilities ;
- Treatment and/or pumping systems that are accessible;

The impact of climate change on the small water and sanitation systems in communities can be because existing water and sanitation systems may be ill equipped to cope with changes in the water quantity and quality. This may require more or different treatment to deal with changes in water quality, pumping may need to be added and more storage provided. Hurricane and flood events already impact water infrastructure through landslides that compromise storage integrity, in addition to causing damage to pipelines, intake works and boreholes. Other impacts include damage to pump stations either directly or due loss of electricity, and damage to sanitation facilities which lead to threats to public health. It is important that actions on climate hazards incorporate a gender perspective considering that, according to the UN Convention and the IPCC, climate change will increase the gender gap.

The SOP identifies several options that can be implemented to improve resilience in both drinking water and sanitation. The approach is a combination of land management, infrastructural change, and treatment options.

LAND MANAGEMENT:

In the Caribbean region, areas that lack reliable service and connection from the water utilities which can be the result of their remote location must rely on CBWDS. Even where public services are available, there is still a heavy reliance on local sources. Watershed protection was identified as one of the first area to investigate. Managing the watershed area can make a tremendous difference in the source water's quality and quantity. Controlling land use for the purposes of reducing soil erosion and sedimentation control, is becoming more important as populations increase.

INFRASTRUCTURAL OPTIONS FOR DRINKING WATER:

Impacts will range from increased turbidity to physical damage to infrastructure. The damages often lead to interruption of water supply directly or indirectly due to loss of power supply. Options to improve resilience in water infrastructure in CBDWS range from implementing physical changes to "climate proof" infrastructure in preparation for events to operational procedures during and after and even. Measures that can be taken prior climate change events include: i) Diversification of drinking water sources utilizing varying mix of surface water and groundwater, in times of water shortages or service disruption. Examples of diversified source water portfolios include using a varying mix of surface water and groundwater, with other utilities or communities in times of water shortages or service disruption; ii) Increasing capacity to augment supply in times of shortage; iii) relocation and or elevation of critical equipment and infrastructure; iv) land stabilization and diversion of flood waters; v) installation of flood barriers; vi) retrofitting and reinforcing infrastructure.

Operation procedure during and after events includes; i) timely shut down of system in the case of hurricanes and floods ii) have provisions for backup power such as secondary electrical feed, temporary or permanent emergency generator; iii) reduce ground water pumping to prevent saline intrusion.

WATER TREATMENT SYSTEMS

Traditionally the design of water treatment facilities has been predicated on the underlying assumption that ample source water is available to meet all water use requirements within the design life of the facility and that the quality and quantity of water available from a given source are relatively predictable based on historical data. However, increasing evidence of climate variability is raising questions about the validity of traditional design assumptions, particularly since the service life of many facilities can exceed 50 years. Wastewater treatment infrastructure and operations that may be impacted by climate stressors include: i) storage and buildings; ii) filtration; iii) disinfection; iv) pumping; v) chemical storage and feed systems; vi) electrical and emergency power supply; and vii) Waste stabilization ponds to name a few.

To 'climate proof" these systems, wastewater systems should be designed to accommodate the uncertainty associated with future climate and these should include; i) establishing a location outside of a potential disaster zone where equipment, electronics, or vital records can be relocated in extreme events; ii) substantial improvement to existing treatment processes capacity to account for increased wastewater flow from flooding or increased rainfall; iii) Minimize the exposure of essential utility equipment such as pump stations, treatment systems, generators and fuel tanks, transformers; iv) relocating vulnerable, critical elements to higher elevations or lower-risk areas above base flood elevations; and v) Increase the size and capacity of wastewater ponds and lagoons.

Operation procedure during and after events include; i) timely shut down of system in the case of hurricanes and floods ii) have provisions for backup power such as secondary electrical feed, temporary or permanent emergency generator; iii) Have provisions to increase pump station and storage.

1 STANDARD OPERATING PROCEDURE: COMMUNITY WATER SUPPLY AND SANITATION

The SOP is provided in the following pages. Sections 1.4 and 1.5 relate to Climate impacts and to Utilities responses respectively.

1.1 Purpose

The purpose of this SOP is to provide climate resilient solutions to issues arising from the impacts of climate hazards on community-based drinking water supply and sanitation infrastructure in the Caribbean.

1.2 Introduction

Climate hazards such as floods, droughts, hurricanes and sea-level rise are impacting water-related infrastructure including community-based drinking water supply and sanitation ones in the Caribbean. To mitigate these effects, water utilities need to prepare their infrastructure before, during and after these climate events. This SOP provide guidance to water utilities to adapt their infrastructure so that it becomes more resilient to climate change.

1.3 Scope

This SOP covers the areas of climate resilience of community-based drinking water supply and sanitation infrastructure. The impacts of climate change on surface water and springs including increased turbidity are addressed as well as on wells, various water treatment system. Emergency power sources are also explored. Regarding sanitation, centralised and de-centralised community wastewater treatment have been studied.

1.4 Climate impacts

The impact of climate change on the small water and sanitation systems in communities can be considered to be twofold. Firstly, existing water and sanitation systems may be ill equipped to cope with changes in the water quantity and quality; more or different treatment may be required to deal with changes in water quality, pumping may need to be added and more storage provided. Secondly, it is possible that there could be an increase in hurricanes. Existing hurricane activity already impacts water infrastructure through landslides that compromise storage integrity and damage pipelines, damage to intake works and boreholes through sediment and debris, damage to pump stations either directly due to floods or loss of power, and damage to sanitation facilities which lead to threats to public health. An increase in hurricanes activity could have more detrimental effects. It is important that actions on climate hazards incorporate a gender perspective considering that, according to the UN Convention and the IPCC, climate change will increase the gender gap.

- Excessive Rainfall and Floods
  - Damage to facilities
  - Contamination of wells
  - Increase runoff
  - Increase siltation of reservoir with decreased capacity
  - Increased turbidity in surface water supplies
  - Contamination of water distribution and storage facilities
  - Loss of power
  - Excessive rainfall entering latrines, septic systems
- Drought
  - Decreased surface supply, water intake issues
  - Increased wellfield drawdown, decreased recharge, supply and saline water intrusion
  - Increased concentration of pollutants, varying water quality (algae blooms)
  - Increased water demand and storage requirements
- Hurricanes
  - Loss of power and telemetry
  - Inadequate treatment, fuel and supplies
  - Damage to treatment facilities
  - Damage to collection and distribution facilities
  - Contamination of water distribution and storage facilities
  - Excessive water demand
- Heat
  - Increased water demand
  - Increased evaporation
  - Water quality changes
- Sea Level Rise
  - Damage to facilities including corrosion from increased saline water
  - Well contamination (saline water)

CASE STUDY: THE EFFECTS OF RAINFALL ON CHOLERA DYNAMICS IN HAITI (MARISA C. EISENBERG, 2013)

In October 2010 Haiti experienced a cholera epidemic, it had been noted that cholera case counts, which had been declining, rose sharply with the onset of seasonal heavy rains in the spring of 2011. Rainfall is thought to be associated with cholera, but this relationship has only begun to be quantitatively examined.

The study quantitatively examined the relationship between rainfall and cholera incidence in Haiti on several different spatial scales, using a combination of statistical and dynamic modeling approaches. In all cases a strong relationship between rainfall and cholera was found, regardless of the methodology or spatial scale. Increased rainfall was significantly correlated with increased cholera incidence 4-7 days later.

The study concluded that given the lack of sanitation infrastructure in Haiti, heavy rains would cause sewage to contaminate surface and groundwater that individuals rely on for drinking, bathing, and washing clothes. In this case, the lag between rainfall and increased cholera cases need only incorporate the time needed to wash sewage into the water source, and the incubation period of the disease.

1.5 Utilities or Community Response (SOP)

In the selection of a source or sources of water supply for a community, adequacy and reliability of the available supply could be considered the most important criteria. In a non-stationary climatic future, the reliability of water supplies the next 10 or 20 years could be difficult to predict, therefore a careful review of backup or complimentary water supplies should be investigated. All water supply sources should consider these factors as follows:

- Adequacy and Reliability
- Quality
- Cost
- Legality
- Politics.

These five points should be considered as part of articles in international climate change and risk management conventions/agreements that state that local-level responses should include the perspectives of indigenous peoples, women, men, children and people with disabilities.

Adequacy of supply requires that the source be large enough to meet the water demand. Total dependence on a single source is undesirable, and in some cases, diversification is essential for reliability. From the standpoint of reliability, the most desirable supplies are:

1. Supplies that can be replenished, whether from surface or groundwater;
2. A gravity source supplemented by storage;
3. An inexhaustible source that requires treatment and/or pumping such as sea water desalination;
4. Treatment and/or pumping systems that are accessible

The greatest climate impacts are likely to be in unmanaged water systems and systems that are currently stressed, poorly operated or unsustainably managed due to policies that discourage efficient water use, protection of water sources, inadequate watershed management and the inability to manage variable water supply and demand.

1.5.1 Drinking Water

1.5.1.1 Surface Water and Springs Increased turbidity

Turbidity is a measure of the degree of cloudiness or muddiness of water. It is caused by suspended matter in water like silt, clay, organic matter or microorganisms. Even when caused by factors that do not pose a health risk, turbidity is objectionable because of its adverse aesthetic and psychological effects on the consumers. While some of the suspended materials will be large and heavy enough to settle rapidly to the bottom of a container, very small particles will settle only very slowly or not at all. These small solid particles cause the liquid to appear turbid.

DIVERSIFIED DRINKING WATER SOURCES

Diversified Drinking Water Sources helps to reduce the risk that surface water supply will fall below water demand during high turbidity events. Examples of diversified source water portfolios include using a varying mix of surface water and groundwater, with other utilities or communities in times of water shortages or service disruption.

Examples – Additional water supply sources:

- Surface water
- Rainwater catchment
- Groundwater (wells, springs, infiltration galleries)

WATERSHED PROTECTION

Watershed Protection is the first area to investigate when attempting to control turbidity into surface water. Owning or having control of the land in the watershed area of your source water can make a tremendous difference in the source water's quality. Controlling land use for the purposes of reducing soil erosion and sedimentation control, is becoming more important as populations increase.

Examples – Watershed protection includes:

- Watershed land acquisition
- Conservation easements
- Community education
- Ecosystem restoration and afforestation at the headwaters
- Erosion and sediment control
- Regulations (buffer zones, etc.)

SEDIMENTATION AND LOSS OF CAPACITY

Climate variability may mean an increased frequency of very heavy precipitation events. Increases in heavy precipitation will result in increased sediment loads, since high flows have a much greater erosive capacity than lower flows. This will result in increased sediment yields even if annual precipitation volume remains the same.

Most suspended particles are heavier than water and will settle in quiescent conditions; very fine clay particles may not settle out at all. Most structures that hold water will function as a settlement basin. Natural or manmade ponds or lakes will suffice, but purpose-made structures which incorporate efficient inlet and outlet arrangements and facilities for silt removal are generally more effective.

OFF-RIVER STORAGE

Off-river storage (Impoundment Reservoir) is a means to reduce sedimentation and improve water quality by constructing a small reservoir with an embankment close to and off the main course of the river. The off-river storage acts as a means of controlling and modifying water quality and quantity transferred from the river to the community. The design of the impoundment reservoirs will be wherever possible, to maximize the use of gravity to fill the reservoir via a diversion channel or similar mechanism. Generally, the size of the reservoir accommodates 7 to 14 days of average demand and also acts as a buffer to changes in community demands. This type of solution may not be viable where land is scarce.

Figure 1. Off-river storage

1.5.1.2 Wells

EQUIPMENT FLOODING

Equipment flooding of well systems can impact water quality and operation for many years if not properly addressed at the earliest possible time. Floodwaters can directly influence the well when debris carried by the flood impacts the structure; damaging or destroying caps, vents, piping, and the well casing and pump components. Selecting the right site for a well can also reduce water contamination risks. Constructing wells on higher ground, an adequate distance uphill from potential contamination sources such as latrines and agricultural fields reduces the pollution risks of during flood events. Additionally, by destabilizing the ground around a well, flooding can weaken the structural integrity of a well, jeopardizing the sanitary seal. (Michael Schnieders)

Examples – Well flood protection

- Ensure proper seal of casing, and electrical conduit
- Divert potential flood waters away or around well
- Elevate well
- Elevate or relocated electrical panels and well vents
- Have provisions for backup power such as secondary electrical feed, temporary or permanent emergency generator

DECREASED CAPACITY

Decreased capacity of water supply wells is a possibility in certain locations as the result of over extraction and reduced recharge of groundwater both of which are a direct result of climate change. The reduced capacity or well yield can be increased using several rehabilitation methods.

Example - Increase well capacity options:

- Chemicals to dissolve encrusted or biological materials (Well Development & Rehabilitation, n.d.)
- Brushing or physical cleaning
- Well deepening (re-drilling)

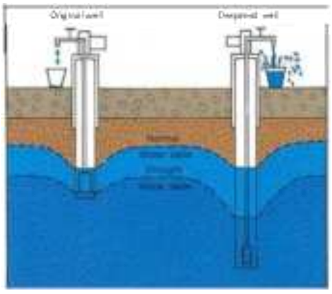

Figure 2. Deepening existing well

Image source: (USGS)

DECREASED WATER QUALITY

When a water-bearing formation is penetrated such as in well construction, a direct route of possible water contamination exists. Water runoff from extreme rain events may contaminate a well which agricultural or sanitary activities are in the vicinity.

Sea-level rise, storm surge in combination with increased groundwater pumping can increase saltwater intrusion into groundwater aquifers. Saltwater intrusion into groundwater aquifers can render groundwater wells unusable. Water resources along the coasts face risks from saltwater intrusion. Rising sea levels, drought and changes in water demand and availability can increase the salinity of groundwater.

Examples – Strategies to reduce climate impacts to water quality

- Relocate well
- Elevate well
- Reduce pumping
- Seek new freshwater sources
- Ensure proper seal of well casing
- Divert potential flood waters away or around well

CASE STUDY: REVITALIZING TRADITIONAL WELLS

Oneisomw (formerly Oneisom) is an island located in Chuuk State lagoon in the Federated States of Micronesia. It has a population of 638 inhabitants (2010 Census of Population and Housing) that is already experiencing the impacts of climate change.

Villages are primarily located along the shoreline and are affected by coastal flooding during typhoons and high tide events. The communities rely on a combination of water tanks, aquifers, streams, and wells but freshwater security is threatened by drought and saltwater intrusion. Human impacts are also adversely affecting these freshwater sources and the coastal environment (e.g., pollution from dump sites, waste from pig pens, inadequate sanitation systems, erosion from unpaved pathways, solid waste dumping, and sediment runoff from inland clearing).

To improve water security and reduce impacts in the coastal environment, Oneisomw residents have rehabilitated traditional water wells by cleaning them, planting vegetation buffer strips around wells and streams to stabilize degraded banks and reduce sedimentation and installing concrete covers over the wells to reduce trash and other pollutants from entering the wells. They also developed agreements with landowners who had wells to allow others to access water during drought. (Mcleod Elizabeth, 2019)

1.5.2 Water Treatment System

Traditionally the design of water treatment facilities has been predicated on the underlying assumption that ample source water is available to meet all water use requirements within the design life of the facility and that the quality and quantity of water available from a given source are relatively predictable based on historical data. However, increasing evidence of climate variability is raising questions about the validity of traditional design assumptions, particularly since the service life of many facilities can exceed 50 years, typically well beyond the design life. (IWA, n.d.)

When planning and designing a community water facility, the construction and operational costs, and the operational and maintenance requirements are key factors that must be considered carefully.

In small community water systems other factors are likely to be as important as climate change relative to their impact on the systems availability to serve water to the community. The problems of affordability and technical complexity associated with small water treatment systems are relevant for large, medium and low-income country economies. Even in developed countrie, small community water systems often face difficulties due to inadequate cost recovery, lack of skilled staff and complex operational and regulatory requirements. Nevertheless, addressing the potential of climate impacts to water treatments facilities at both the urban and community scale will help increase the availability of clean, affordable and reliable water to their customers.

The first step in determining the impacts of climate change on water treatment facilities is to conduct a vulnerability analysis. For small community water treatment systems where records and data may not be available, institutional knowledge by the users could be the only means to determine past impacts due to climatic events. In these cases, the experiences of vulnerable communities need to be taken into account in accordance with the recommendations of the Paris Agreement and the Sendai Framework on local participation and community knowledge management for decision-making.

A more robust and sophisticated assessments can be conducted using CCORAL Tool to understand climate influences on the water utility. Once these climate influences are understood, CCORAL Tool contains many other built-in tools to determine the vulnerability of the water treatment system.

Potential climate related impacts to water treatment facilities and operations include floods, storm surge, wind, hurricanes and sea level rise. Treatment equipment or processes that may be impacted by climate stressors include:

- Storage and Buildings
- Sedimentation
- Filtration
- Disinfection
- Pumping
- Chemical Storage and Feed Systems
- Electrical and Emergency Power
- Instrumentation

Examples – Climate adaptation strategies for treatment facilities or operations

- Establish a location outside of a potential disaster zone where equipment, electronics, or vital records can be relocated in order to move vital resources out of harm's way.
- Existing water treatment systems may be inadequate to process water of significantly reduced quality. Substantial improvement to existing treatment processes or implementation of additional treatment technologies may be necessary to ensure that quality of treated water supply continues to meet water quality standards.
- Minimize the exposure of essential utility equipment such as pump stations, treatment systems, generators and fuel tanks, transformers, and information technology infrastructure to failure. Relocating vulnerable, critical elements to higher elevations or lower-risk areas above base flood elevations can reduce risk from coastal or freshwater flooding and erosion.
- Flood barriers to protect critical infrastructure including seawalls. A related strategy is flood proofing, which involves elevating critical equipment or placing it within waterproof containers or foundation systems.
- Establish redundancy in the supply chain to avoid supply shortages by sourcing chemicals from more than one supplier or from different regions. Make sure delivery contracts are flexible to adjust shipments to account for any temporary storage on site.

1.5.3 Chlorination

Chlorination is the most widely used method of disinfection. It is both effective and economical but must be administered properly and safely. The amount of chlorine required at any given time is varies according to the flow, the impurities in the water, the temperature and the pH value of the water. A contact time with the water of about 20 minutes is necessary to achieve complete reaction. High turbidity in the water source or in the distribution system reduces the effectiveness of chlorination. Turbidity ideally should be below 1 NTU. Large well-run municipal supplies should be able to achieve turbidity of <0.5 NTU at all times, and should be able to average turbidity of ≤0.2 NTU. In lower resource settings including small community supplies the aim should be to keep turbidity below 5 NTU. (World Health Organization, n.d.). Small sedimentation structures, sand filters or other simple treatment systems could be requireed to reduce turbidty to levels low enough to all proper chlorination.

1.5.4 Distribution, pumping and storage

Climate change is likely to lead to increasing risks on the water distribution infrastructure used distribute water to customers. There are significant threats from damage to infrastructure, poor operation and maintenance, and disruption of essential power systems. Warmer temperatures and prolonged drought can change the soil conditions of pipelines, sea level rise and storm surge can introduce corrosion from salt water into pipelines and pump stations. Also, during extreme flood events and tropical cyclone the disruption of power and increased damage from trees and roots can lead to significant disruptions.

1.5.4.1 Pipelines

Materials and methods used in the construction of water supply systems are affected by climate impacts. Understanding how different materials withstand the stresses of wind, storm and landslide damage from extreme climate change-related events can be helpful in designing new climate-resilient systems. Climate related damages to pipelines include:

- Corrosion of metal pipes weaken structures over time
- Physical damage to pipes from flooding, storm surge and landslides
- Contamination of drinking water from pipes damaged by flooding or landslides
- Physical damage to exposed pipes from falling trees and structures
- Physical damage to buried pipes entangled with tree roots that become uprooted with trees
- Corrosion of metallic pipes exposed to seawater from inundation
- Lowering of groundwater levels and consolidation of the soil. The resulting (differential) settlements associated with soil property transitions, may damage underground pipe infrastructure.
- The lack of water demand caused by interrupted water supplies may cause low pressure in the pipeline which can lead to water infiltration and contamination.

One of the biggest issues faced by water distribution pipelines is leakage caused by the above-mentioned climate related impacts. Leakage of water in the distribution system leads to high non-revenue water (NRW) losses which waste resources and leads to higher tariffs. NRW can also impact the quality of water in the pipelines due to the potential of contamination from extraneous sources.

Materials selected for pipelines have a large influence on their ability to withstand climate stressors and if they are exposed or buried. Buried materials are less sensitive to climate-induced damages.

Table 1. Materials Sensitivity from Typhoon Yolanda Damage Assessments

Material	Flooding	Land-slides	Wind	Storm Surge	Sea Level Rise
Metal pipes (buried)	Low	Medium	Low	Low	Low
Plastic pipes (buried)	Low	Medium	Low	Low	Low
Metal pipes (exposed)	High	High	Medium	High	High
Plastic pipes (exposed)	High	High	Medium	High	High

Source: (USAID, 2017)

1.5.4.2 Pumping and Storage

With increased uncertainty and higher demand water storage is one approach for adapting to climate change. Providing more and diverse water storage infrastructures is an imperative for securing reliable supplies of water for the end users. Storage facilities can be community level or household, Household water storage can be used as a means to capture water from a community water system which is interruptible due to lack of water supply or caused by drought.

Appropriate selection of construction materials is vital for climate-resilient water infrastructure such as pump buildings and storage tanks. Building materials differ in sensitivity to climate change impacts from increased salt water exposure, excessive rainfall, wind, flooding, and increased water demand. Pumping and storage facilities will need to be hardened, relocated, rebuilt with better construction materials or expanded in order to achieve an acceptable level resiliency.

Examples – Resiliency options (Steven R. Hilderhoff):

- Stabilize landslide-prone areas by planting trees
- Construct walls around pump stations and tanks to prevent ingress of flood waters
- Retrofit or reinforce structures to be able to withstand stronger hurricanes
- Construct new and climate-resilient facility
- Elevate critical equipment and/or structures above flood level
- Install temporary flood barriers such as sand bags
- Have provisions to increase pump station and storage capacity due to increasing demand
- Have provisions for temporary or permanent emergency power
- Cover storage tanks to reduce exposure to debris and to maintain water quality

The process of identifying strategies for infrastructure resilience should include a participatory process in compliance with international standards that state that vulnerability is reduced by engaging local communities (Sendai Framework, 2015: article g).

1.5.5 Sanitation

Interruption of sanitation services cause by climatic events often compromises the health and social benefits derived from their installation. The damages in sewer systems and wastewater treatment cause contamination of nearby bodies of water, loss of sources of water, and environmental degradation which lead to unhealthful conditions in communities that can potentially affect women and girls more than men and boys. Sustainable sanitation systems implies that they are capable of providing services throughout their serviceable life which results in improved health conditions and quality of life. However, especially in the most vulnerable areas, the occurrence of one or repeatable climatic events during the life of these systems threatens sustainability.

Damages caused by climate change to sanitation systems may exceed the technical capacity and the financial resources of the community or service provider. There is the risk that these systems will be abandoned, that there will be a significant reduction in the quality of services, or that they will be repaired with temporary measures that are inadequate for permanent facilities. Sanitation services in small communities should be given the same level of priority as water supplies.

To withstand the shocks from climate change, sanitation systems can be made 'climate-proof'—more robust to climate hazards. Examples include raising toilets above flood levels, increasing structural strength of treatment systems or sewers adjacent to waterways, and locating sanitation infrastructure to minimise potential damage. Another approach is to deploy low-cost sanitation technologies that can be quickly rebuilt, provided they do not create public health or environmental threats if they fail. For example, households could use temporary, alternative latrines whilst their primary latrines are being rebuilt after a climate event. (Freya Mills, Jeremy Kohlitz, Naomi Carrad and Juliet Willetts (ISF-UTS), 2019). It is important to ensure that female defecation of women and girls in these contexts ensures integral security from risks of physical and sexual violence.

CASE STUDY: SANITATION SOLUTIONS BUILDING CLIMATE RESILIENCE IN TUVALU

The atoll nation of Tuvalu has demonstrated that innovative sanitation solutions can contribute significantly to climate change adaptation efforts.

The successful implementation of "eco-sanitation" in the capital Funafuti has demonstrated significant reductions in sewage pollution to groundwater and coastal waters, reduction in the use of fresh water for toilet flushing, and the generation of organic matter in a country devoid of agriculturally productive soils. Each household that adopted this innovative waterless solution has eliminated their sewage load to groundwater and reduced their use of fresh water by approximately 30% - equivalent to eight to ten 10 000 litres rainwater tanks per household per year (WHO, 2015).

Social and design lessons learnt from this demonstration have made eco-sanitation a key part of Tuvalu's response to climate change. Tuvalu is now a centre of regional expertise on eco-sanitation, and in the Pacific way has been active in sharing its findings with other atoll countries struggling with the pollution impacts and water demand associated with flush toilets.

1.5.5.1 Centralized Community Wastewater Treatment

Many current wastewater systems in small communities do not provide an adequate level of service that maintains and protects health and the environment. Systems are likely to be less effective in the future. The wastewater sector plays a crucial role in protecting public health and the environment. Projected changes in climate and hydrologic conditions have the potential to impact the wastewater treatment infrastructure and operations.

- Screening
- Grit Removal
- Aeration (bioreactor)
- Secondary Clarifiers
- Septage
- Disinfection
- Pumping and Blowers
- Sludge disposal
- Waste stabilization ponds
- Biofiltration
- Anaerobic ponds
- Electrical and Emergency Power
- Instrumentation
- Higher peak flows into the WWTP and reduced biological load

Examples: Climate adaptation strategies for treatment facilities or operations

- Wastewater systems should be designed to accommodate the uncertainty associated with future climate
- Establish a location outside of a potential disaster zone where equipment, electronics, or vital records can be relocated in order to move vital resources out of harm's way
- Substantial improvement to existing treatment processes capacity may be needed to account for increased wastewater flow from flooding or increased rainfall
- Minimize the exposure of essential utility equipment such as pump stations, treatment systems, generators and fuel tanks, transformers, and information technology infrastructure to failure. Relocating vulnerable, critical elements to higher elevations or lower-risk areas above base flood elevations can reduce risk from coastal or freshwater flooding and erosion. Flood proofing, which involves elevating critical equipment or placing it within waterproof containers or foundation systems
- Increase the size and capacity of wastewater ponds and lagoons

1.5.5.2 Decentralized Sanitation-Latrines and Septic Systems

Where annual rainfall increases or there is a shift to higher intensity events, the impacts on sanitation may be more profound. For onsite sanitation, the risks are primarily related to flooding and may have very serious public health implications. All onsite systems are vulnerable to flooding, and under more severe conditions this may result in widespread spillage of fecal matter in the environment and to contamination of drinking water supplies. One way to reduce the environmental impacts of human waste is to practice eco-sanitation.

Eco-sanitation is an approach as opposed to a technology for a possible solution to sanitation issues which are being exacerbated by climate change. Eco-sanitation treats human excreta as a valuable resource, rather than a waste product. It recycles human waste and, uses natural processes to transform it into a safe, natural compost and fertiliser. The urine that is collected from latrines is considered safe to be used as liquid fertiliser. Therefore, this approach is sustainable as it is not about disposal human waste but about recycling.

Figure 3. The poop loop

Source: (Unite for Sight, 2001)

CASE STUDY: SAINT VINCENT VOLCANO ERUPTION, APRIL 2021

Decentralized sanitation systems are frequently used by schools and other facilities that are being used as emergency shelters for hurricanes, volcanic eruptions, floods and other natural disasters. It is critical that these sanitation systems have adequate capacity to handle the increased load caused by the evacuees, therefore these systems need to be designed based on the anticipated shelter capacity. Septic tanks, drainfields, and treatment systems all need to be properly sized, the increased cost of improvements relating to evacuation shelters should be the responsibility of national or local governments.

Example:

In a review of sanitation technologies, dry urine-diverting latrines could be considered resilient, mainly because the absence of water made construction of watertight tanks fully aboveground feasible. Howard et al. considered pit latrines more resilient because of the adaptations that are feasible. Septic systems were considered vulnerable not only because of flooding and discharge of the tank contents into the environment, but also because of the risk of flotation due to increased groundwater levels (Guy Howard, 2016).

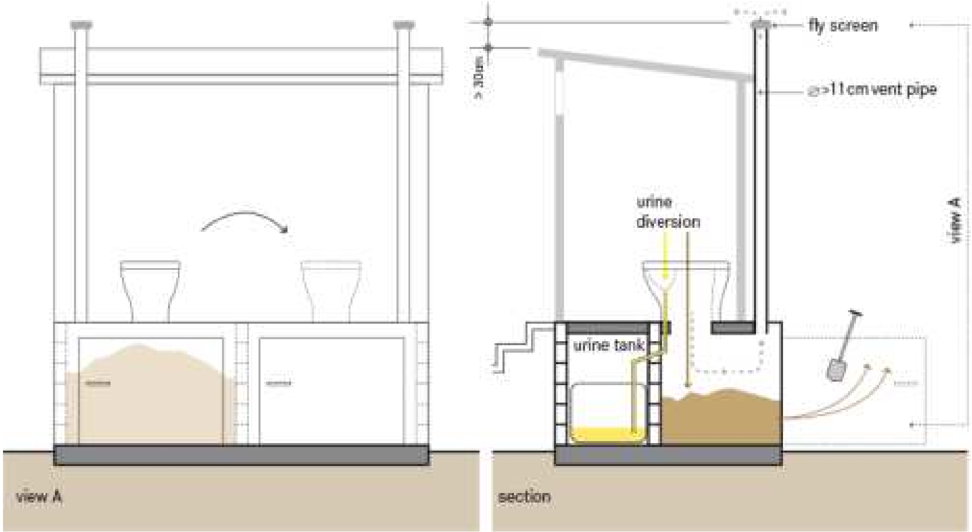

***Figure 4.* Urine-diverting latrine**

Source: Wikipedia, n.d.

1.5.5.3 Operations and Maintenance

In addition to impacts to assets, all utilities urban and community are also having to revise infrastructure and operations in response to climate impacts. The impact of reduced water supply and forced interruption of customer demand use causes some equipment and systems to become idle for a period of time. Reactivation of idled equipment and systems requires modification of operating procedures and in some instances increase maintenance requirements.

Another aspect of climate impacts on water systems is the changing water quality, for example water that remains in a water distribution system for an extended period of time may lose chlorine residual which could increase or reactivate biological activity within the system. In order to manage the decrease in chlorine in the distribution system, flushing of water mains, increased water sampling and/or modified treatment systems operations could be required. The expertise and technology to carry out these enhanced maintenance activities may not be available to community water systems.

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2 APPENDICES

n/a

Caribbean Community Climate Change Centre
GCCA+
THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE
INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

SOP 5:

NATURE-BASED SOLUTIONS

EU-GCCA/SER/006

May 2021

Ref R2390

Developing Standard Operating Procedures (SOPs) for Climate Resilient Water Infrastructure in the CARIFORUM countries

SOFRECO

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LIST OF ACRONYMS

Acronym	In Full
CAP-NET	UNDP International Network for Capacity Development in Sustainable Water Management
IDB	Inter-American Development Bank
NbS	Nature-based Solutions
SOPs	Standard Operating Procedures
UN	United Nations
WRI	World Resources Institute

EXECUTIVE SUMMARY

Nature-based solutions (NbS) for water and sanitation is a move away from human-built, or “grey” solutions that use infrastructure to improve water management to one where ‘green’ infrastructure focuses on preserving the functions of ecosystems, both natural and built to improve the management of water resources.

Historically water utilities have mainly relied on “grey” solution (engineered) to adapt to climate stressors. There is now a shift in the appreciation and realization that NbS offers a no regrets approach in allowing water utilities to fulfil their obligations to offer sustainable, safe, and reliable drinking water. With pumps, motors, and other equipment sometimes operating 24 hours a day, seven days a week, water and wastewater treatment and distribution facilities use a significant amount of energy. In addition, some technologies such as desalination are difficult to operate due to their complicated equipment and expensive parts.

NbS has an important role to play in improving the supply and quality of water and reducing the impact of natural disasters.

Water utilities can reduce energy use through measures such as water conservation, water loss prevention, and sewer system repairs to prevent groundwater infiltration. Any measures to reduce water consumption, water loss, and wastewater will lead to reductions in energy use, and result in savings associated with recovering and treating lower quantities of wastewater. Efforts to reduce the carbon footprint from the facilities would include the use of solar power to supplement existing electrical supply. At present, solar power systems based on existing technology can only supply a portion of the electrical demand at water and wastewater facilities due to the lack of power storage. Solar power can only be used to supplement existing electrical supply. NbS also include using the physical environment to mitigate the impacts of climate change.

Protecting water recharge areas through afforestation and watershed management as well as coastal stabilization through wetland protection and restoration are important in water quality and quantity preservation as well as protecting structural integrity.

NbS are applicable in providing protection against climate risk in i) urban stormwater/flood management; ii) reducing impacts from coastal flooding, storm surge, sea level rise and erosion; iii) inland flooding; iv) water scarcity; v) soil erosion and sedimentation.

NbS case studies in Miami and Tanya River, Kenya demonstrates both the physical and economic benefits. NbS therefore provides opportunities to manage multiple risks.

1 STANDARD OPERATING PROCEDURE: NATURE-BASED SOLUTIONS

The SOP is provided in the following pages. Sections 1.4 and 1.5 relate to Climate impacts and to Utilities responses respectively.

1.1 Purpose

The purpose of this SOP is to provide climate resilient solutions to issues arising from the impacts of climate hazards on nature-based solutions (NBS) or “green” infrastructure in the Caribbean.

1.2 Introduction

Climate hazards such as floods, droughts, hurricanes and sea-level rise are impacting water-related infrastructure including nature-based solutions in the Caribbean. To mitigate these effects, water utilities need to prepare their infrastructure before, during and after these climate events. This SOP provides some guidance to water utilities to adapt their infrastructure so that it becomes more resilient to climate change.

1.3 Scope

This SOP covers the areas of climate resilience of nature-based solutions or “green” infrastructure. The impacts of climate change on natural environments such as wetlands, mangroves and watersheds are explored.

1.4 Climate impacts

- Rainfall and Floods
  - Damage to systems
  - Increased runoff and turbidity
- Drought
  - water supply
- Hurricanes
  - Damage to systems
  - Contamination of systems

- Heat
  - Increased system impacts
  - Water quality changes
  - Increased evaporation
- Sea Level Rise
  - Damage to systems

1.5 Utilities Response (SOP): Natural Environments (wetlands, mangroves, watersheds)

The use of the physical environment to mitigate the impacts of climate change on natural and manmade systems can be termed as Nature Based Solutions (NbS). These solutions work with nature, not against it such as restoring wetlands, which can protect against storms, to conserving forests that stabilize soil and runoff during floods. Mangrove forests, for example, save an estimated $80 billion per year in avoided losses from coastal flooding globally, and protect up to 18 million people. (Fuller, 2021)

NbS serves an important component of water utilities adaptation to existing and future climate stressors. Historically water utilities have mainly relied on grey solution (engineered) to adapt to climate stressors, but there has been a shift in the appreciation and realization that NbS offers a no regrets approach in allowing water utilities to fulfil their obligations to offer sustainable, safe and reliable drinking water. No regret NbS solutions are those which makes sense and offer many other benefits (social, environmental) regardless of the climatic conditions, examples include watershed protection and conservation.

For water utilities the implementation of NbS can have multiple benefits, for example, managing and restoring vegetation can enable the root systems of trees and other vegetation to stabilize and restrain soils and help to reduce landslides, erosion and flood risk. Water supply is not the only benefit of NbS for utilities, water quality is improved when watershed areas are protected by decreasing runoff, erosion and allowing natural percolation into the ground.

Along the coast where water and sanitation facilities are often located and exposed to increasing climate stressors such as erosion, tropical cyclones, sea level rise and storm surge NbS offers effective solutions. The restoration of wetlands, mangroves, marshes, and oyster reefs, and the installation of living shorelines (plants and natural elements designed to stabilize and protect coastlines) help reduce wave impacts during storms. Fifteen feet of marsh can “absorb up to 50 percent of incoming wave energy,” and 330 feet of mangrove trees “can reduce wave height by 66 percent.” By contrast, gray infrastructure redirects, rather than dissipates, wave energy. (Environment and Energy Study Institute, 2019)

Table 1. Engineered and Nature Based Solutions

Climate Risk	Gray Solutions (Engineered)	Nature-based Solutions
Urban stormwater / flood management	• Retrofitted / enhanced urban storm-water drainage systems • Engineered flood protection	• Green roofs • Urban gardens and green spaces • Riparian and wetland vegetation restoration, creation, and management
Coastal flooding, storm surge, sea level rise, and erosion	• Seawalls, dykes, permanent artificial walls, and temporary storm barriers • Improved drainage systems	Conservation, management, restoration, and (in some cases) creation of: • Coral reefs (including using artificial substrate) • Oyster reef • Sea grass • Coastal wetlands, mangroves, and salt marshes • Sand dunes and beaches
Inland flooding	• Alluvial dykes and dams (creation, retrofitting, and maintenance) • Improved pumping, piping, and storage systems	• Upslope vegetation management • Forest restoration • Riparian and wetland restoration/creation and management, living weirs, and check-dams • Floodplain management
Landslides	• Retaining walls • Gabions	• Upslope vegetation management • Reforestation and afforestation (where appropriate)
Water scarcity	• Reservoirs / dams • Concrete catchments • Desalination plants (if coastal) • Aqueducts	• Watershed restoration, including reforestation (where appropriate) • Permeable 'green' areas for groundwater replenishment
Soil erosion and sedimentation	• Retaining walls • Terracing • Dredging programs	• Upslope vegetation restoration and management • Reforestation and afforestation (where appropriate) • Management of littoral vegetation and wetlands

Source: IDB, 2019

CASE STUDY: CITY OF MIAMI PARK

To demonstrate the value of nature-based solutions, The Nature Conservancy is working with the City of Miami to restore and enhance the waterfront of Morningside Park, a busy historic park on the shores of Biscayne Bay.

The park and surrounding neighbourhoods were established before modern stormwater conveyance and detention design standards. Now, extreme high tides are eroding the shoreline and heavy rainfall events are inundating ball fields and the surrounding community.

Figure 1. Miami Park

With support from the Chubb Charitable Foundation, the Morningside Park Coastal Resilience Project will use a living shoreline to reduce flood risk to the park and nearby residents. This new green and hybrid infrastructure demonstration project will likely include restoration of mangroves and intertidal wetlands, the creation of elevated or upland earthen berms (natural barriers) planted with native vegetation, and the installation of limestone riprap to reduce wave energy as well as modern stormwater control structures to complement drainage improvements for the park and surrounding neighbourhood.

The project will enhance the beauty and resilience of Morningside Park. Meanwhile, it is expected to provide significant savings in avoided losses by protecting homes and businesses from future flooding during tropical storms and hurricanes. This demonstration project will benefit the City of Miami, and will influence policy and also serve as a model for other urban areas to follow as they must adapt to climate change. (The Nature Conservancy, 2021)

CASE STUDY: LANDSCAPE RESTORATION IMPROVES MULTIPLE WATER OUTCOMES FOR THE TANA RIVER, KENYA

The Tana River in Kenya provides 80% of the drinking water for Nairobi, generates 70% of the country's hydropower and irrigates about 645 km 2 of farmland. Steep hillsides and areas adjacent to rivers have been converted to agriculture, resulting in erosion. Sedimentation has reduced the capacity of reservoirs and increased the costs of water treatment for Nairobi. A US $10 million investment in sustainable land management will be disbursed over 10 years, leading to a return of US$21.5 million in economic benefits over a 30-year timeframe.

Interventions include: improved riparian management, the terracing of hillslopes, the reforestation of degraded lands, measures to encourage grass strips in farms, and the mitigation of road erosion. In terms of water supply, the storage capacity of reservoirs will be maintained as a consequence of reduced sedimentation. Revenues for the hydropower company will improve as a direct result of this action. The Nairobi City Water and Sewerage Company has also benefited from avoided filtration, lowered energy consumption and reduced sludge disposal costs. The benefits of reduced sedimentation are maintained across a range of climate change scenarios. (UN Water, 2018)

In the context of managing multiple risks, NbS can be used for example to manage flood and mitigate drought. Wetlands can act as natural sponges absorbing excess rainfall, mitigating runoff and storing water during drought conditions. Wetland restoration has become a focus of many large industrial countries such as China which are faced with population growth, limited resources and a recognition of the importance on NbS.

CASE STUDY: TRINIDAD AND TOBAGO: ADOPT A RIVER PROGRAMME

The Adopt A River Programme is an initiative to involve the community and corporate entities in the improvement of watersheds in Trinidad and Tobago in a sustainable, holistic and coordinated manner. The main objective is to implement approved watershed rehabilitation and conservation projects, identified by stakeholders at national and community levels, for water supply and/or water management improvement and to build awareness of local watershed issues in order to improve the status of rivers and watersheds in Trinidad and Tobago. (CAP-NET, 2020)

1.5.1 Vegetation management

Vegetation management strategies within water catchment areas should seek to mitigate the transmission of pollutants, such as sediment, agricultural chemicals, or other liquid and solid waste into the water bodies. The most effective measure is the installation of vegetated buffer zones along the entire length of the water channels, along with the installation of appropriate control systems to stabilize and settle out contaminants from farms and households. This vegetated buffer can be established from natural vegetation, tree crops, or commercially important timber species. In areas where the farmer or landowner already have temporary or annual crops established along the waterway, these may be intercropped with tree crops or timber species. Upland forests with deep soils can help slow and retain runoff, resulting in lower peak flow. Forest management is most effective at retaining and slowing moderate floods of short duration before soils become saturated. The cost of forest restoration (excluding land acquisition costs) varies but is on average between US$2,000 and US$3,500/ ha. A review of restoration studies found that 82 percent reported a decrease in peak flow after restoring upland areas. (World Bank Group and WRI, 2018)

In agricultural watersheds, main strategies to mitigate erosion center around effective vegetation cover management and drainage. Tree crops, commercial timber, or natural tree species are favored in steep areas given their extensive root networks that enhance soil permeability to reduce runoff, and serve to bind surface and sub-surface soil aggregates to reduce landslide risk. (Cox, 2004) Incorporation of vegetative residue such as stems, branches and leaves as trash lines along the contour not only shields exposed soil but also increase surface roughness. These organic features act as physical restraints to the movement of sediment in runoff downslope and enhance infiltration capacity through their incorporation in the soils. Grass barriers perform a similar role in retarding flow but also in terms of soil stabilization, on account of their root network. Whatever the vegetative management strategy, this must be complemented with proper drainage to manage potential erosive flows and conserve moisture within the soil horizons.

Along with reducing flooding risks, nature-based solutions implemented along rivers can have a range of additional benefits for both people and the natural environment. Restoring riverbanks and flood plains can improve downstream water quality and provide important fish and migratory bird habitats. Slowing down flood waters in watersheds can also increase the deposits of nutrient-rich sediments that help to create fertile soils for agriculture. (World Bank Group and WRI, 2018)

1.5.2 Erosion and sediment control

Measures to control upland erosion seek to reduce the effects of channel or sheet erosion. Gullying is accelerated detachment and transport of soil aggregates that become entrained in flow within farm drains or ravines after stabilizing vegetation has been removed. In large storms significant quantities of material can be lost due to gully erosion. Sheet erosion is the dislodgement and transport of soil particles due to raindrop impact and overland flow under conditions when the rainfall exceeds the soil infiltration capacity, usually under saturated soil moisture conditions. The problems of erosion are aggravated over steep terrain, particularly where soil aggregates are loosely consolidated such as low clay and organic matter content, and where land management regimes (inadequate vegetation and residue cover, and poor drainage) leave the soil exposed to rain drop impact and subject to unimpeded runoff. (Cox, 2004)

Figure 2. Water discharge to treatment plant from a poorly managed watershed (left intake)

Image source: Cox, 2004

1.5.3 Mangroves and coastal wetlands

The restoration of wetlands, mangroves, marshes, and oyster reefs, and the installation of living shorelines (plants and natural elements designed to stabilize and protect coastlines) help reduce wave impacts during storms. Due to sea level rise, high tides are becoming higher and higher, and the highest tides—king tides, which usually occur seasonally—are projected to become daily high tides, leading to even further flooding. In addition to this, gray infrastructure built to “control” flooding, especially in the face of extreme weather, is increasingly failing to do its job. Hurricanes Michael (2018), Maria (2017), Irma (2017), and Harvey (2017) created a total of US$290 billion in damages, forced communities to evacuate, and caused more than 3,000 associated fatalities across the United States and Caribbean countries. (Environmental and Energy Study Institute, 2019)

Marshes collect sand and sediments from the water and can grow in elevation as sea levels rise, while gray infrastructures cannot adapt and must be updated or replaced to deal with higher water levels.

A study conducted by the University of North Carolina Chapel Hill after Hurricane Matthew (2016) found living shorelines prevented erosion just as well as bulkheads (retaining walls meant to prevent flooding), but required no repairs after the hurricane, whereas 75 percent of the bulkheads needed repairs. After Hurricane Florence (2018) hit, seawalls experienced “significant erosion and damage,” while living shorelines, such as the Beaufort living shoreline composed of oyster reef and marsh, fared much better. (Environmental and Energy Study Institute, 2019)

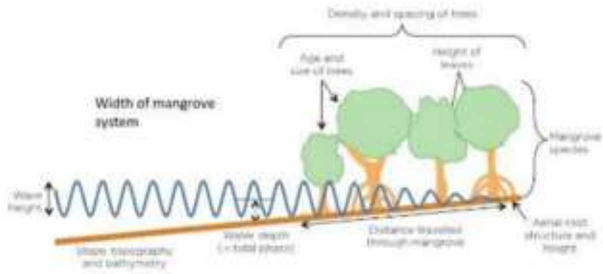

Figure 3. Factors affecting wave attenuation through mangroves

Image source: World Bank Group and WRI, 2018

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2 APPENDICES

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Caribbean Community Climate Change Centre

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

KAP 1:

CLIMATE RISK MANAGEMENT

EU-GCCA/SER/006

May 2021

Ref R2390

Developing Standard Operating Procedures (SOPs) for Climate Resilient Water Infrastructure in the CARIFORUM countries

SOFRECO

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LIST OF ACRONYMS

Acronym	In Full
ACP	African, Caribbean and Pacific countries
CARICOM	Caribbean Community
CARIFORUM	Caribbean Community Forum
CBDWS	Community based drinking water and sanitation
CCCCC / 5C	Caribbean Community Climate Change Centre
CDEMA	Caribbean Disaster Emergency Management Unit
CIMH	Caribbean Institute for Meteorology and Hydrology
CIS	Climate Information Services
DRR	Disaster Risk Reduction
GCF	Green Climate Fund
EU	European Union
GCCA+	The Global Climate Change Alliance Plus Initiative
GWP-C	Global Water Partnership-Caribbean
IDB	Inter-American Development Bank
IFC	International Finance Corporation
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
KAPs	Key Adaptation Protocols
LECZ	Low Elevation Coastal Zone
NbS	Nature-based Solutions
O&M	Operation and maintenance
RCM	Regional Climate Model
RWH	Rainwater harvesting
SIDS	Small Islands Developing State
SLR	Sea Level Rise
SOPs	Standard Operating Procedures
TAC	Technical Advisory Committee
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WRMU	Water Resources Management Unit
WSP	Water Safety Plan
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

CLIMATE RISKS

Disasters pose a significant threat to the sustainability of development projects and investments. At the same time, many development actions provide opportunities to strengthen disaster resilience. The integration of disaster risk reduction into development forms the basis of development strategies. Both land and sea climate hazards bring pressure on water and sanitation infrastructure globally. A 24h early warning can cut damage by 20%, but 1 out of 3 persons worldwide are still not covered by an early warning system[1]. Between 1950 and 2014, natural disasters cost the Caribbean approximately US$53 billion in damages (Centre for Research on the Epidemiology of Disasters, 2015). Nearly one in ten disasters causes damages costing over 30% of Caribbean SIDS' GDP, compared to less than 1% of GDP in larger countries (IMF, 2016).

This is likely to increase due to the fact that most of the Caribbean countries are located in the hurricane belt (Northern Caribbean), and exposed to climatic hazards they provoke such as intense rainfall and flooding. Some Caribbean countries are also impacted by floods and recurring droughts which are becoming more and more frequent throughout the globe and in the region (CIMH Interview, March 2021). Additionally, projections indicate that the global average sea level is set to rise by 254 to 812 mm in the coming century (Church et al., 2013).

CLIMATE RISK ASSESSMENT

The CCORAL Tool (CCCCC) is a system which helps decision makers to see all kinds of activities through a 'climate' or 'climate change' lens, and to identify actions that minimize the climate risks. Link: https://www.caribbeanclimate.bz/caribbean-climate-chage-tools/tools/

CCORAL is designed to breed a risk management ethic in decision making. It takes a pragmatic approach, promoting the right tools and techniques to fit the context of Caribbean decision making, taking into account available time and resources and uncertainty about climate variability and change. Users are encouraged to prioritize their efforts and use components of CCORAL of most value to them.

CCORAL contains a resources database of nearly 80 tools. These were selected from the over 100 tools initially evaluated in a review process. These tools are organized according to key criteria derived from the initial tool evaluation.

There are four main approaches to Climate Risk Assessment using the CCORAL Tool:

- Screening of climate risks of an initiative;
- End-to-end processes assessment of climate risks of an initiative;
- Find tools in the CCORAL Toolbox for climate risk assessments and management;
- Access to the CCCCC Clearing House documents, books and research on the right side of the CCORAL Tool webpage which enables a progressive study of a topic over a period of time.

CLIMATE RISK MANAGEMENT

[1] Climate Development Ministerial Conference, 31st March 2021 (online) conveyed by UK Government for the COP26 preparation. Information from the Global Coalition on Adaptation and the Minister of Energy, UK.

Haiti, the Dominican Republic, Guyana, Jamaica and Suriname all rank highly in terms of vulnerability to climate hazards. Although its GDP per capita and poverty indicators are similar to that of these countries, Belize has better water service coverage and efficiency. The smaller island states tend to rank less highly. However, it should be noted that this can mask local inequalities. For example Saint Vincent & the Grenadines and Saint Lucia both exhibit relatively high levels of poverty and of vulnerability to climate hazards. Yet, physical and socio-economic issues in Saint Vincent are different from those encountered in the Grenadines. Devastation brought by hurricanes on the small islands means that even a relatively wealthy economy can be severely disrupted by the impact of a country scale event (HR Wallingford, 2020). A way to address climate vulnerabilities and facilitate disaster risk reduction is through an integrated water resources management (IWRM) approach, and in particular the preparation of Water Safety Plans (WHO).

The Caribbean Region has traditionally not accessed international climate finance at levels commensurate with its high vulnerabilities and exposure to climate change impacts. Guidance on what climate change adaptation and mitigation funding is available to the Caribbean countries is provided in Annex 2.2.

The Green Climate Fund (GCF) organized an event in March 2021 providing a platform for engagement with National Designated Authorities, Accredited Entities, Delivery Partners and other relevant GCF Stakeholders to improve access to and mobilization of urgently needed climate finance via the development of innovative and transformational projects for a low-carbon and climate-resilient Caribbean. The event aimed to elaborate on the following primary topics: strengthening country ownership of programming in the region, targeting areas of high mitigation potential and adaptation needs, catalyzing private sector finance at scale, improving access to GCF resources, and streamlining operational and institutional priorities.

1 KEY ADAPTATIVE PROTOCOL: CLIMATE RISK MANAGEMENT

1.1 General considerations for the formulation of a protocol

1.1.1 General context and climate impacts on water resources management

All CARICOM Member States rely primarily on either groundwater, surface water or rainwater (harvesting) or various combinations of all three for their potable, industrial, sewerage and agricultural water supply. These sources of water are recharged during the wetter seasons of the year. The onset and duration of wet seasons vary spatially across CARICOM Member States. Regional climate models (RCMs) suggest that while the northern Caribbean will record more-intense rainfall (zone 1 to 4) and fewer rainy days, the southern part (zone 5) will experience the opposite: less-intense rainfall and more rainy days[2] (Figure 1).

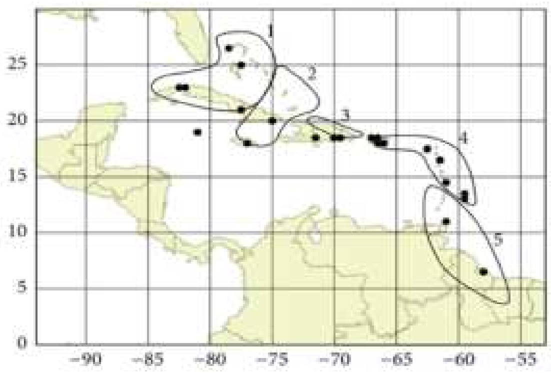

Figure 1. Five rainfall zones over the Caribbean and neighboring regions. Observational weather stations are also shown

Several islands in the Caribbean are defined as water scarce with respect to natural freshwater resources according to the United Nations, that define water scarcity as having a level of annual water resources per capita below 1,000 m^3 per person per year.

CARICOM Member States falling into this category include, but are not limited to, Barbados, Antigua and Barbuda, St. Kitts and Nevis and the Bahamas. In larger islands where water scarcity does not exist at the national level, regional disparities with respect to rainfall and physical conditions can result in water scarcity at the local level. Such water scarce countries and regions are particularly susceptible to drought given the competition for water by various sectors (Farrell et al., 2010). The severity of the 2009-2010 drought conditions highlighted the gaps: significant losses were suffered in key economic sectors across the Caribbean, as infrastructure at the time was inadequate to absorb the impacts. This situation is exacerbated if an integrated approach to water resources management (IWRM) has not been adopted and put in practice.

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[2] Source: Natalie Melissa McLean, Tannecia Sydia Stephenson, Michael Alexander Taylor, Jayaka Danaco Campbell, "Characterization of Future Caribbean Rainfall and Temperature Extremes across Rainfall Zones", Advances in Meteorology, vol. 2015, Article ID 425987, 18 pages, 2015. https://doi.org/10.1155/2015/425987

Table 1. Drought severity levels

Drought Severity	Drought Response Stage	SPI	Percent of Reservoir Storage	Streamflow Percentage Exceedance
Normal	Normal	0.99 to - 0.99	80 to 100	70 to 79
Moderate	Pre-Alert	-1.0 to -1.49	65 to 80	80 to 89
Severe	Alert	-1.5 to -1.99	50 to 65	90 to 94
Extreme	Emergency	< -2.0	< 50	95 to 98

Source: Grenada Draft Drought Management Plan (2019)

CASE STUDY: THE IMPACT OF DROUGHT IN GRENADA

Like on many small tropical islands, drought can affect many economic sectors in Grenada. For example Carriacou, that accounts for 30% of the country's livestock production, experienced 20% and 40% losses due to the drought in 1984 and 1992 respectively; an increase in bush fires which lead to lost wildlife and increased risk of soil erosion and flooding when the rains arrive; reduced crop production and domestic food prices increased by as much as 20%; and the hotel sector, which is a high consumer of water, is challenged due to the unavailability and or shortage of water, leading to increased guests complaints and ultimately reduction in occupancy rates.

Source: Grenada Draft Drought Management Plan, 2019

1.1.2 Other Climate Risks

Approximately 44 million people reside in the Caribbean and more than 50% of this population lives within 1.5 km of the coast (Mimura et al. 2007). In some cities, populations reside in low-elevation coastal zones (LECZs) located less than 10 m above the sea level.

The UNDP 'Full Report' (2010) provides, for all CARICOM Member States, an in-depth assessment of the risks from climate change and sea level rise (SLR). The report focuses on: climate change projections for the Caribbean region under +2.0°C and +2.5°C global warming scenarios; the implications of ice sheet melt for global sea level rise (SLR); the projections and implications of SLR for the Caribbean region; and, using an actuarial approach, the quantification and magnitude of the losses and damages resulting from sea level rise and related coastal erosion (Figure 2).

Figure 2. Vulnerability of tourism resorts in Nassau and Paradise Island, The Bahamas to sea level rise induced coastal erosion

Source: UNDP Full Report (2010) on Sea Level Rise

1.1.3 Climate Risk Management

1.1.3.1 UNFCCC Framework

The United Nations Framework Convention on Climate Change (UNFCCC) acknowledges the vulnerability of all countries to the effects of climate change and calls for special efforts to ease the consequences, especially in developing countries that lack the resources to do so on their own. In the early years of the Convention, adaptation received less attention than mitigation, as Parties wanted more certainty on impacts of and vulnerability to climate change. When IPCC's Third Assessment Report was released adaptation gained traction and Parties agreed on a process to address adverse effects and to establish funding arrangements for adaptation.

The Convention's ultimate objective (art. 2 UNFCCC) gives an indication of support for both human and natural adaptation as an objective of climate governance (Yamin and Depledge 2004). Furthermore, the Convention also specifies that "Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects" (art. 3.3 UNFCCC).

Adaptation actions must be informed by robust data and risk assessment tools that are available to all –families building homes, businesses in coastal regions, farmers planning their crops, etc. (New EU Adaptation Strategy/Climate Action, 2021).

Many major coastal cities throughout the Caribbean utilize structures such as levees or sea walls as a mean to protect densely populated urban areas and strategic infrastructure against erosion and flooding.

Recent economic studies conclude that, based on a cost-benefit analysis, coastal protection from SLR should be widespread in well-populated coastal areas with high value property and strategic infrastructure. Coastal protection is not economic in moderately populated areas, for agricultural lands, or ecosystem areas that must maintain interactions with the sea to retain their function. Similarly, for many tourism developments outside of urban areas, property values are not sufficient to warrant the cost of coastal protection, particularly when the implementation of structural protection would result in loss of coastal tourism aesthetics and not prevent the 'drowning' of critical beach assets (both of which result in diminished tourism property values) (UNDP, 2010).

1.1.3.2 Climate risk management in the Caribbean

Climate risk management in the Caribbean starts with monitoring, with the preparation by CIMH of various thematic climatic bulletins (drought bulletins, tourism climatic bulletins, agro-meteorological bulletins, etc) in order to properly inform decisions that will lead to the appropriate responses, either as prevention or as mitigation measures. Such monitoring also informs the preparedness of the countries.

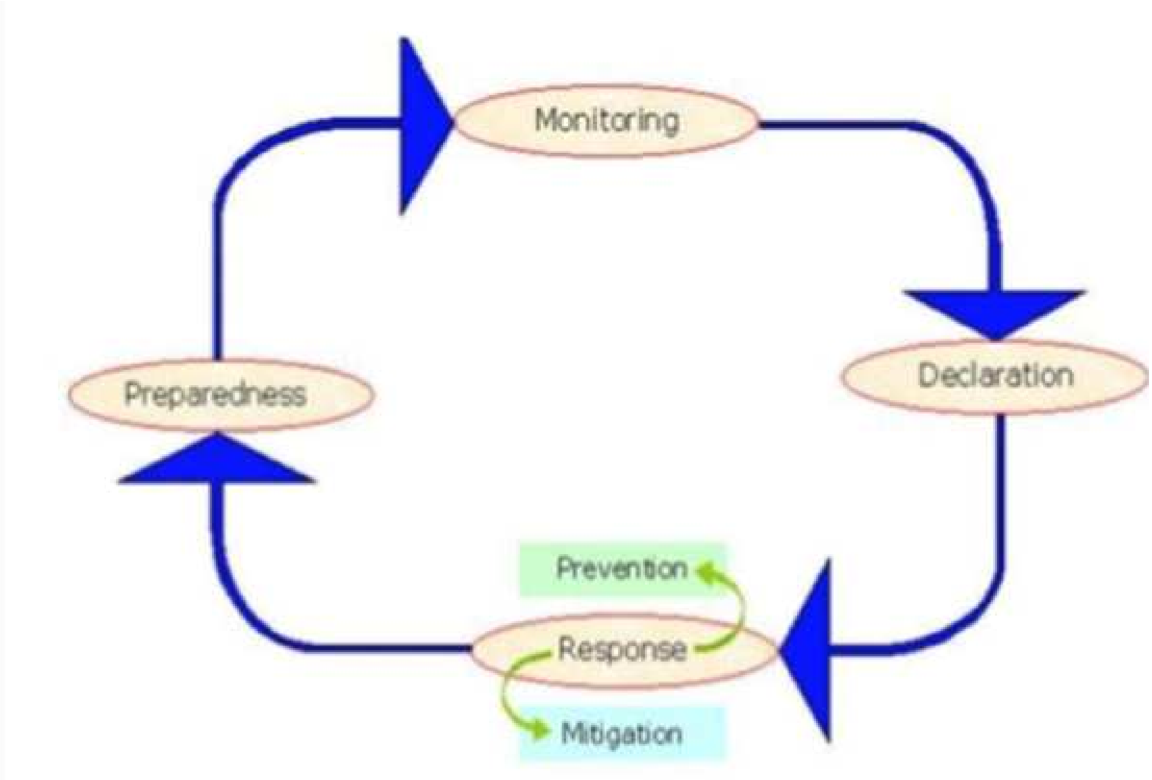

Figure 3. Drought management process

Source: Grenada Draft Drought Management Plan (2019)

CASE STUDY: THE IMPACT OF NATURAL DISASTER IN SAINT VINCENT

The eruption of the La Soufrière Volcano provoked water supply and wastewater treatment disruption in Saint Vincent.

Most wastewater treatment is constituted of septic tanks/adsorption systems, and most of the shelters are schools. In the event of a disaster, the users of schools change from a transient school population to people living there 24/7. This entails a major increase in toilet flushing, and thus in the pressure on the adsorption systems. Though these schools are intended as official shelter facilities, there was no funding from the government to improve their sanitation systems in case of emergency.

Some gaps were found which will eventually need to be retrofitted, which must be raised to the governments. The designated shelters cannot actually meet the requirements of shelters: they need to be improved in order to build up resilience. There are mostly septic tanks in the Caribbean. After disasters, donors send temporary toilet facilities, but finding the chemicals to treat those is a big challenge.

Source: CWWA and CAWASA interviews, April-May 2021

1.2 Recommendations and best practices

1.2.1 Integrating climate risk management into the integrated water resources management (IWRM) approach

Freshwater resources management in the Caribbean must be integrated and climate resilient, using an IWRM approach. When addressing climate risks, it is therefore important to address the impacts on the major water resources (either surface or groundwater or both) and water uses (e.g. drinking water supply and sanitation, agriculture, tourism). Considerations of public health are also key to maintaining a suitable drinking water supply and sanitation during climatic hazards and to fighting vector-borne and water-borne diseases that could affect the impacted populations the most.

Long-term planning for an adequate and safe supply of drinking-water should be set in the context of growing external uncertainties arising from changes in the climate and environment. The water safety plan (WSP) process developed by WHO offers a systematic framework to manage these risks by considering the implications of climate variability and change. A climate-resilient water safety plan guiding document is also useful to other stakeholders, particularly health and environment agencies who are supporting WSP implementation. It discusses how to take into consideration the broader issues of climate change, regional climate vulnerability assessments, disaster risk reduction (DRR) and integrated water resources management (IWRM) within the WSP participatory process. How this is done for any WSP will depend upon local circumstances. The document on climate resilient water safety plans also describes how water suppliers and WSP teams can best make use of information provided by other actors, such as climate vulnerability assessments at the level of the climatic or ecological zone, as inputs to their work on individual water supplies. (WHO)

1.2.2 Providing an efficient organizational framework

A proposed organizational framework for drought event reporting is presented in the Grenada Drought Management Plan. It takes into consideration ongoing initiatives such as the proposed establishment of the Water Resources Management Unit (WRMU) and incorporates three main components: (i) monitoring (Committee 1), (ii) risk assessment (Committee 2) and (ii) mitigation and response (Task Force).

Institutional barriers to effective adaptation will need to be removed if temperatures rise beyond 1.5°C in the Caribbean. Barriers can be overcome with concerted effort, creative management, change of thinking, prioritization and related shifts in resources, land uses and institutions (Moser and Estrom, 2010). Transformational change is recommended to challenge the systems and structures, economic and social relations, and beliefs and behaviours that contribute to climate change and social vulnerability (Myoo, 2017).

Countries can also issue water restrictions during drought conditions through their emergency response protocols. Hence, there is a need for a climate information service and an operational WRMU.

Also, there is a central responsibility of Ministries of Finance to show leadership in the integration of climate change into the planning process and in the delivery of funding for climate actions (Derek Gibbs, 2013).

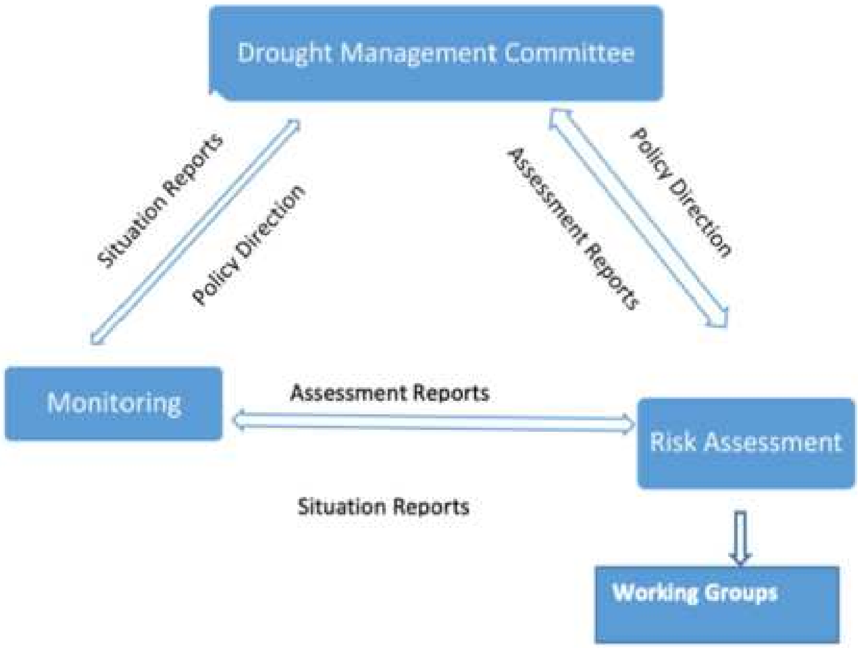

Figure 4. Organizational framework for drought management Promoting transformational change in the Caribbean

Source: Grenada Draft Drought Management Plan, 2019

1.2.3 Developing a regional approach to climate risk assessment in the Caribbean

The Caribbean Community Climate Change Centre (CCCCC) has been supported by HR Wallingford in undertaking a climate vulnerability assessment of the CARIFORUM countries under a Regional Project. The regional approach is key to addressing the diversity of climate risk management options and opportunities in the Caribbean countries.

1.2.4 Ensuring stakeholder engagement at the highest level

Climate risk management should be addressed at the highest level by National Climate Change Focal Points in conjunction with the Caribbean Disaster Emergency Management Agency (CDEMA) and the Permanent Secretaries' Cabinets. Managing climate risks need conjunctive actions that should be channelled through the global, regional and national emergency responses systems. Climate change and disaster risk reduction are closely linked. More extreme weather events in the future are likely to increase the number and scale of disasters, while at the same time the existing methods and tools of disaster risk reduction provide powerful capacities for adaptation to climate change.

Disaster risk reduction plans are key, and a "climate lens" could be adopted to adapt them. For example, natural disasters such as hurricanes can be addressed from the climatic perspective which is looking at preparedness, adaptation, mitigation and the overall resilience of infrastructure to climatic events. This will enable preparing for climate resilient water infrastructure in the CARIFORUM countries.

The goal of the Grenada Dry Season and Drought Management Plan (GDS&DMP) is to achieve the greatest public benefit for domestic water use and sanitation in an efficient and equitable manner during severe dry periods, so as to maintain sustainable economic, social and environmental development. The Plan, which is part of the country's initiatives aimed at improving climate resilience in the water sector, is based on participatory approaches in decision making, gender sensitivity, and the need to urgently address the adverse impacts of climate change on water resources and ensuring social and economic well-being through improved water resources management.

1.2.5 Mainstreaming gender for climate risk management

Gender has some implications for climate risk management actions through a variety of contexts, needs and options. A gender-sensitive approach is needed for taking into consideration the various impacts of climate hazards on men, women, boys and girls.

Climate change Impact on disaster risk management	Gendered Impacts
Displacement / Loss of homes	☐ **Vulnerable,** rural women may not have access to climate-related information, which in turn will impact their ability to cope with natural disasters.** ☐ **Increased** violence against women and girls in shelters or who have been relocated or displaced.
Disaster-linked deaths	☐ **Lack** of access to assets limits available coping mechanisms to deal with the impacts of drought, disproportionately affecting women.*
Post-traumatic stress disorder	☐ **Psychological** stress is likely to be heightened after disasters, particularly where families are displaced and have to live in emergency or transitional housing. Women and men experience and deal with these traumatic events differently.*
Crop failure / destruction of economic assets	☐ **Women's** mobility constraints are exacerbated by extreme events and in turn hinder or further exacerbate their inability to cope.*

Evidence base: **Backed by anecdotal, practitioner reports, or small, sample-sized studies of evidence in the Caribbean.*
***Backed by anecdotal evidence in the Caribbean and global practitioner studies.*
****Backed by anecdotal data, practitioner studies, and data or empirical evidence.*

Figure 5. Gendered impacts of climate change on disaster risk management

Source: IDB. Study of the Impacts of Climate Change on the Women and Men of the Caribbean. Pilot Programme for Climate Resilience Countries (PPCR), IDB Technical Note, December 2020.

According to a recent IDB study (see table above), "women and girls are subject to a disproportionate amount of risk from climate-related natural disasters. Risks during and following natural disasters are often higher for women and girls due to social norms, breakdowns in law and order, and disrupted livelihoods. (…) Reduction in reliable water sources hits women and girls—often responsible for collecting water for families—especially hard.

As women and girls often bear the brunt of risks and vulnerabilities brought on by droughts, floods, and other extreme weather events, they are also at the front lines of adaptation and well-positioned as important and necessary stakeholders in effective adaptation to climate change. Gender-responsive programming can empower women, reduce gender inequality, and improve adaptation, mitigation, and resilience results."

Gender-sensitive lines of action should be developed to prepare communities (and more especially women, girls and especially vulnerable populations) for disasters as well as lines of action for humanitarian assistance. For both, women and girls should be consulted on their specific needs during climate-related disasters.

Preparation involves women, girls and especially vulnerable populations participating in the design of disaster response contingency plans.

Monitoring measures compliance with women's participation planning, and with respective indicators in disaster preparedness. Monitoring therefore assesses the inclusion of proposals from women, girls and especially vulnerable populations as well as their participation.

The evaluation of the response is done through surveys of the people affected by the emergency.

In Nicaragua, women conserve and restore depleted mangroves while increasing their income by sustainably harvesting, preparing, and selling black cockles.

Throughout the world, women are helping to reduce greenhouse gas emissions by switching from traditional, high-emissions cooking methods to using clean cookstoves. Some are also expanding their livelihoods and helping to scale up mitigation efforts by selling improved cookstoves, promoting renewable energy through their work as utility sector professionals, and more. The opportunities to address gender equality are countless. Livelihood resilience programs can ensure that women are prepared for climate change by diversifying sources of income. Agricultural and governance programs expanding formal land tenure can ensure that women’s ability to inherit and own land—and therefore invest in the resilience and sustainability of their lands—is not restricted. And health programs addressing changing infectious disease patterns resulting from climate shifts can take into account the special needs of pregnant women and children”. (https://www.climatelinks.org/sector/gender-and-social-inclusion)

Also, it has been noted that the gender perspective of climate information use is not well studied although necessary for developing gender-responsive climate information services (CIS).

CASE STUDY: CIS AND GENDER IN GHANA

A study in Ghana, showed, among other factors, that it was evident that use of CIS may be influenced by gender.

Men were found to be particularly responsive in adopting CIS use for climate risk mitigation. This was attributed to their ability to easily access and use telephone devices compared with women.

The study revealed that unlike women, men were able to access more financial resources and had control of household income which allowed them to purchase mobile phones. Women generally accessed their husbands’ mobile phones. Despite differences in access to CIS, the study showed both men and women found it beneficial for strategic farm decision-making such as when to begin land preparation, when to plant, and which crop to select. In addition, both men and women were found to face similar constrains (such as poor network connectivity and limited training) to accessing and using CIS. The study recommends the need to explore different CIS dissemination channels and design CIS that meet gender-specific needs. (Partley, 2020)

CONSIDERATIONS	KEY FACTORS	DEFINITION
Country External factors may influence development, implementation, and results of a performance improvement program. While these tend to be outside a training professional's direct control, they may still need to be addressed or considered in the design, implementation, and evaluation of learning programs.	**Social and cultural norms**	Local sensitivities including traditions and cultural customs, religious beliefs and practices, socially imposed identity roles (for example, gender, racial, tribal, religious, class and political affiliation).
	Economic stability	Strength, sophistication, and openness of the market (state-owned versus private sector), level of employment, and potential for business opportunities. Economic conditions and existing regional development programs or stimulus packages could affect the amount of funding available for learning programs or the fees that these programs could charge to participants.
	Legal environment	Local laws, regulations, and policies, including laws affecting women's agency and freedom of movement; ownership, inheritance, and management of assets; and starting and running a business.
	Technology	Accessibility, availability, and reliability of information and communication technology at the program location.
	Infrastructure and logistics	Accessibility, availability, and reliability of venues, utilities, sanitation, transport, catering accommodation, and other services.
	Security and safety	Protection from issues related to political conflict, terrorism, violence, gender-based violence and sexual harassment, or collective post-conflict trauma for participants, program providers, and all those affiliated with the performance improvement program.
Individual Personal factors, characteristics, and circumstances of participants in a performance improvement program. A training professional may be able to influence several of these factors.	**Confidence**[8]	Level of confidence including self-confidence, self-efficacy, and error competency and its effect on the individual's ability to learn, apply, and demonstrate knowledge and skills. *Self-confidence* is the feeling of trust in one's abilities, qualities, and judgment. Confidence is a skill that can be developed. *Self-efficacy* is the belief that one can succeed or accomplish a task. *Error competency* is the ability to recover from errors.
	Leadership	Leadership skills including assertiveness, self-advocacy, and resilience to overcome adversity and aspirational barriers ranging from responding to social norms to dealing with trauma. *Assertiveness* is the skill of standing up for oneself and others. *Self-advocacy* is the skill of taking responsibility for representing one's own views, rather than having others act on one's behalf. *Resilience* is the capacity to recover from difficulties and the ability to persevere in the face of adversity.
	Education & skills	An individual's current level of knowledge, skills, and abilities in a given subject.
	Networks	An individual's formal or informal relationships with peers, mentors, coaches, business links, etc., that complement or support sustained performance before, during, and after a program.[9]
	Finance and assets	An individual's financial capability to engage in a performance improvement initiative (for example, ability to pay for enrollment fees or take time off work or business to participate).
Family Household obligations of participants of a performance improvement program. These often pose additional challenges for women. A training professional may be able to accommodate several of these factors.	**Availability**	Time constraints that participants face in balancing household duties and other responsibilities.
	Care responsibilities	Factors and constraints impacting care-givers in a family.
	Decision making/agency	The ability of women to make decisions and take advantage of opportunities (for example, having a say in household finances and their own personal development).[20]

Figure 6. Definitions of each consideration category for gender-inclusive programs

Source: IFC

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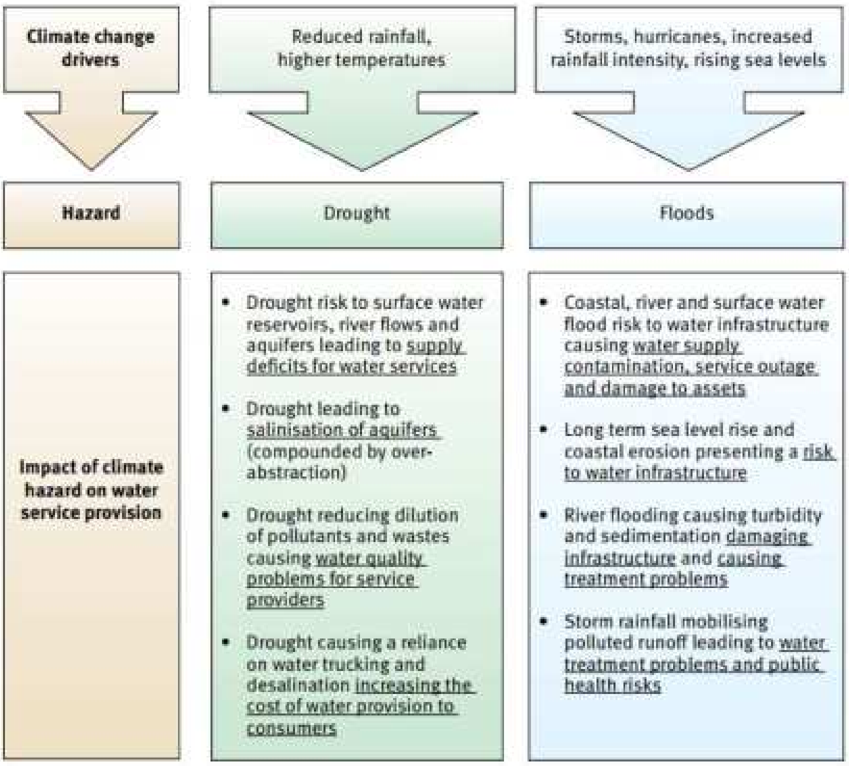
2 APPENDICES

2.1 Threats to water supply

The Figure below summarizes the range of threats to water supply due to climate change.



Source: Global Water Partnership, 2014

2.2 Access to climate finance

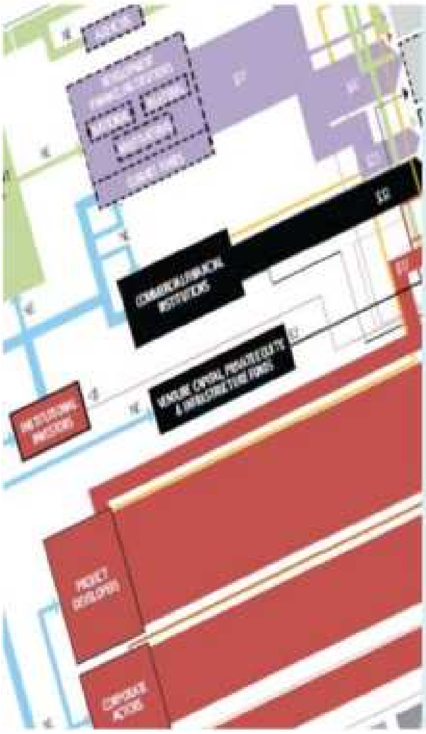
The Figures below summarize the challenges regarding climate change in the Caribbean and the scaling up of climate financing in the region.

Combating Climate Change Challenges

Selected Regional CC Strategy Initiatives			
Climate Area	**Funding Agency**	**Duration**	**Financing -US$M**
Climate Resilience	IDB, WB, Govt of Austria, TBD	2009-2013	6.28
Disaster Mitigation	JICA, IDB	2009-2011	2.76
Disaster Risk Management	CICA, DFID, WB	2007-2013	25.34
Climate Change and Energy	DFID	2009-2010	0.23
Capacity Building	DFID	2008-2011	0.47
Climate Change Adaptation	GEF, DFID	2012-2013	7.55
Climate Change Mitigation	DFID		2.28
		Total	**44.92**

Scaling up Climate Investment In the Region

Note: The Caribbean between 2003 and current, received 6.8% of the funds coming to LAC. Overall, of the estimated $18.83 billion approved funding, the Caribbean Region would have received just 0.85%.



Scaling up Climate Investment In the Region

Climate Change Financial Instruments:

- Grants, concessionary loans, and tax measures **(most commonly used public funding instruments).**
- Carbon Finance, emission trading, risk guarantees (to support clean energy technologies) etc . **(mostly private sources, these instruments are non-existent or at experimental stages).**
- Globally, between 2010 and 2011, an estimated **US$92.7 to US$99.3 billion** in public funds was spend on climate change actions, compared with **US$250 to US$285.5 billion** from private sources. *(Source: CPI, The Landscape of Climate Finance 2012).*
- The region must use public funds to help leverage greater private funds for climate actions.

Source: Climate Actions and Sources of Financing for the Caribbean Region by Derek Gibbs, Chief Economist, Ministry of Finance and Economic Affairs, Barbados (2013)

Caribbean Community Climate Change Centre

GCCA+
THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

KAP 2:

WATER SAMPLING AND TESTING

EU-GCCA/SER/006

May 2021

Ref R2390

Developing Standard Operating Procedures (SOPs) for Climate Resilient Water Infrastructure in the CARIFORUM countries

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LIST OF ACRONYMS

Acronym	In Full
ASTM	American Society for Testing and Materials
DQOs	Data Quality Objectives
ENT	*Intestinal enterococci*
GDP	Gross Domestic Product
NbS	Nature-based Solutions
NEPA	National Environment and Planning Agency (Jamaica)
NTU	Nephelometric Turbidity Unit
OWRB	Oklahoma Water Resource Board
PTFE	Polytetrafluoroethylene
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WASA	Water and Sewage Authority (Trinidad and Tobago)
WHO	World Health Organization
WRA	Water Resources Authority (Jamaica)

EXECUTIVE SUMMARY

Islands in the Caribbean are vulnerable to natural disasters such as hurricanes and droughts, resulting in a negative impact on water supply systems. As a result, adaptation of the water sector to projected impacts of climate change requires continually upgrade and improvement to cope with changes in the hydrological regime.

The primary sources of water supply for Islands in the Caribbean are groundwater, surface water, springs, and desalination. Of those sources, the largest proportion of water supply is from abstraction of groundwater accounting for approximately 52.5% of supply, while surface water accounts for 35.8%, desalination 11.6%, and rainwater harvesting less than 1% (Cole Engineering Group, 2015 cited in Fletcher, 2018).

Assessment of water quality by the supply agency and at the point of use is essential in determining whether there is significant difference between the two and hence, implications for remedial strategies in degradation/pollution. Samples must be taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. Selection of sampling points should be considered in each locality individually (WHO, nd).

1 KEY ADAPTATIVE PROTOCOL: WATER SAMPLING AND TESTING

1.1 Water Resources and Water Quality Monitoring

An example of water resources monitoring in the Caribbean can be found on the Water Resources Authority (WRA) Jamaica website. The WRA routinely monitors streamflow at 133 river gauging stations and groundwater levels at 320 well sites throughout Jamaica. Daily flows are recorded by river gauging stations. Stream flow data is collected from approximately 100 fully automatic gauges and 33 manual gauges. Automatic gauges are housed in pipe wells and stilling wells. Wells are measured monthly by technicians, and these includes, pumping wells, non-pumping wells and small diameter core holes. Records are also kept of underground water levels and water abstractions. Long term underground (non-pumping) water level data is used to establish general flow directions of underground water. The data obtained from these sources are compiled and analysed to produce information that is critical to planning for the development of bridges and water supply schemes (WRA, 2021).

Water quality monitoring can be undertaken by the national environmental agency as well as the utilities and industries. Caribbean Island's dependence on tourism requires regular water quality monitoring of coastal waters which are assessed against generic safe threshold levels. The National Environment and Planning Agency (NEPA) in Jamaica routinely monitors surface, coastal and marine waters across the island. This programme was implemented to i) partially fulfil its mandate to effectively manage Jamaica's physical resources to ensure protection, conservation, proper administration and development and optimal use of the Island's water resources and ii) to assess the data collected to identify trends in changes in water quality. Chemical Parameters measured include nitrate/total N, phosphate/total P, faecal coliform, dissolved oxygen, biochemical oxygen demand, and pH. Physical parameters measured include suspended solids, temperature, and turbidity (Blake, 2014).

Sampling data analysis protocol include:

- Chain of custody form: record the number of samples submitted, the type of sample, sample storage conditions and sample custodian. See example of chain of custody form in Appendix 2.1.
- Analysis performed in accordance with standard procedure outlined from the Standard Methods for the Examination of Water and Wastewater, 21st Edition.
- Distilled water is the blank sample that is treated like a sample and used to calculate the contribution by or correction for chemical reagents.
- Instrument calibration – solutions of specific concentrations used to calibrate an instrument or metal before analysis.
- Completion of quality control charts within two standard deviations representative of a 95% confidence interval (Blake 2014).

The Water and Sewerage Authority (WASA) of Trinidad and Tobago promotes a multi barrier approach which will ensure safe drinking water based on four barriers: i) Source water protection, ii) water treatment, iii) distribution system integrity, iv) public information and legislation. Source water protection through protection of well's recharge area along with concerted public involvement and watershed management are recommendations for implementation of a sustainable approach for drinking water. The aim was to promote good practices needed for assuring acceptable raw water quality at the intake of treatment plants. These recommendations were specifically designed to ensure an adequate design, construction, sampling, maintenance, and operation practices; and a provision of safe and high-quality drinking water in a reliable manner and in a quantity suitable for intended use (WASA 2008).

Coastal water quality in the Caribbean where tourism is one of the main foreign exchange earners requires special attention and protocols. The Caribbean region is more dependent on tourism than any other region in the world—the sector accounts for over 15 percent of GDP and 13 percent of jobs in the region (Nature Conservancy, 2019). Sampling in the sector must consider the spatial and temporal variability. This includes variabilities attributed to rainfall and runoff, monthly and seasonal variability. An obstacle to safeguarding public health is that of the lag time between sampling and results leading beach managers to make decisions reflecting past water quality conditions. Water samples collected at intervals over a relatively brief timeframe of one to two days at beaches along with meteorological data such as air temperature, solar radiation and wind speed along with oceanographic data including tide level, wave heights and water temperature over the same timeframe can yield reliable results. The number of samples is likely to vary according to beach characteristics and the sources of pollution at a beach. (Stanford University, 2021)

1.2 General considerations for the formulation of a protocol

1.2.1 Water quality monitoring

Monitoring water quality and wastewater are fundamental tools in the management of freshwater resources. This also provide essential information characterizing the physical, chemical and/or biological status of water resources, determining trends and changes over time, and identifying emerging water quality issues. Water quality monitoring provide the means to identify policies, reduction, and control of water pollution from specific sources, evaluate the efficacy of pollution control and regulation policies and their implementation as well as measures to deal with water quality emergencies. It is important that water quality issues need to be understood in the framework of hydrological processes based on the water quality and hydrological monitoring (UNESCO, 2019). Water quality standards can be found in the ASTM water testing standards publication (ASTM international, n.d.).

1.2.1.1 Surface Water Sampling

Grab Sample

A grab sample reflects performance only at the point in time that the sample was collected. This represents an individual volume of water taken over a time period not to exceed 15 minutes. The sample is typically taken manually but some automated samplers can be programmed to take grab samples. Often taken for extreme conditions and are preferred for reviewing parameters that change quickly with time such as pH, temperature, and bacteria. A water grab sample is a sample of river, stream or freshwater wetland water collected for the purpose of analyzing water chemistry (USEPA, 2017).

Composite Sampling

Composite samples are collected over time, by continuous sampling or by mixing discrete samples. This represents the average wastewater characteristics during the compositing period (USEPA, 2017). Composite sampling consists of a collection of numerous individual discrete samples taken at regular intervals over a period of time, usually 24 hours. The material being sampled is collected in a common container over the sampling period. The analysis of this material, collected over a period of time, will therefore represent the average performance of a wastewater treatment plant during the collection period (Norweco Inc., n.d.).

PROPOSED SAMPLING PROTOCOL

The sampling method most suited for a site is dependent upon several things such as project data quality objectives (DQOs) and environmental factors. The method used may vary from month to month and will be affected by site conditions at the time of sampling. The determinants of the methods used include the accessibility, depth, and flow of the stream. The Equal Width Increment (EWI) method is the collection of water at intervals, or verticals, over the cross-section of the entire river or stream. Samplers used from bridges require approximately 10-inch (0.25m) minimum sampling depth (MSD) to 8 inch (0.20m) MSD while wadable samplers require approximately 4 inch (0.10m) MSD. If a site does not meet the MSD for bridge sampling, it must be sampled by wading the stream. A site can be considered wadable if the site is accessible by road or safely by foot and if the sampling personnel feels comfortable entering the stream. If the site is not accessible for wading, a composite or point grab sample must be taken. Depth integration may be impossible during extreme flows such as floods. During these situations, a surface grab may be the only possible method. Depth-integration may be impractical during minimal flows. Even though depths may meet the MSD for depth-integrating samplers, the samplers may stir up bottom sediments, which would bias the sample. In other cases, use best professional judgement (BPJ). Guidelines on which techniques to use given different situations are shown in Figures 1 and 2 below.

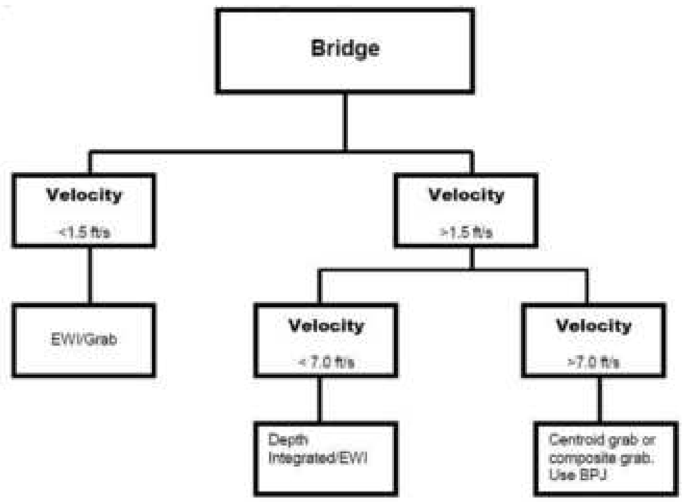

Figure 1. Conditions for various sampling techniques from a bridge

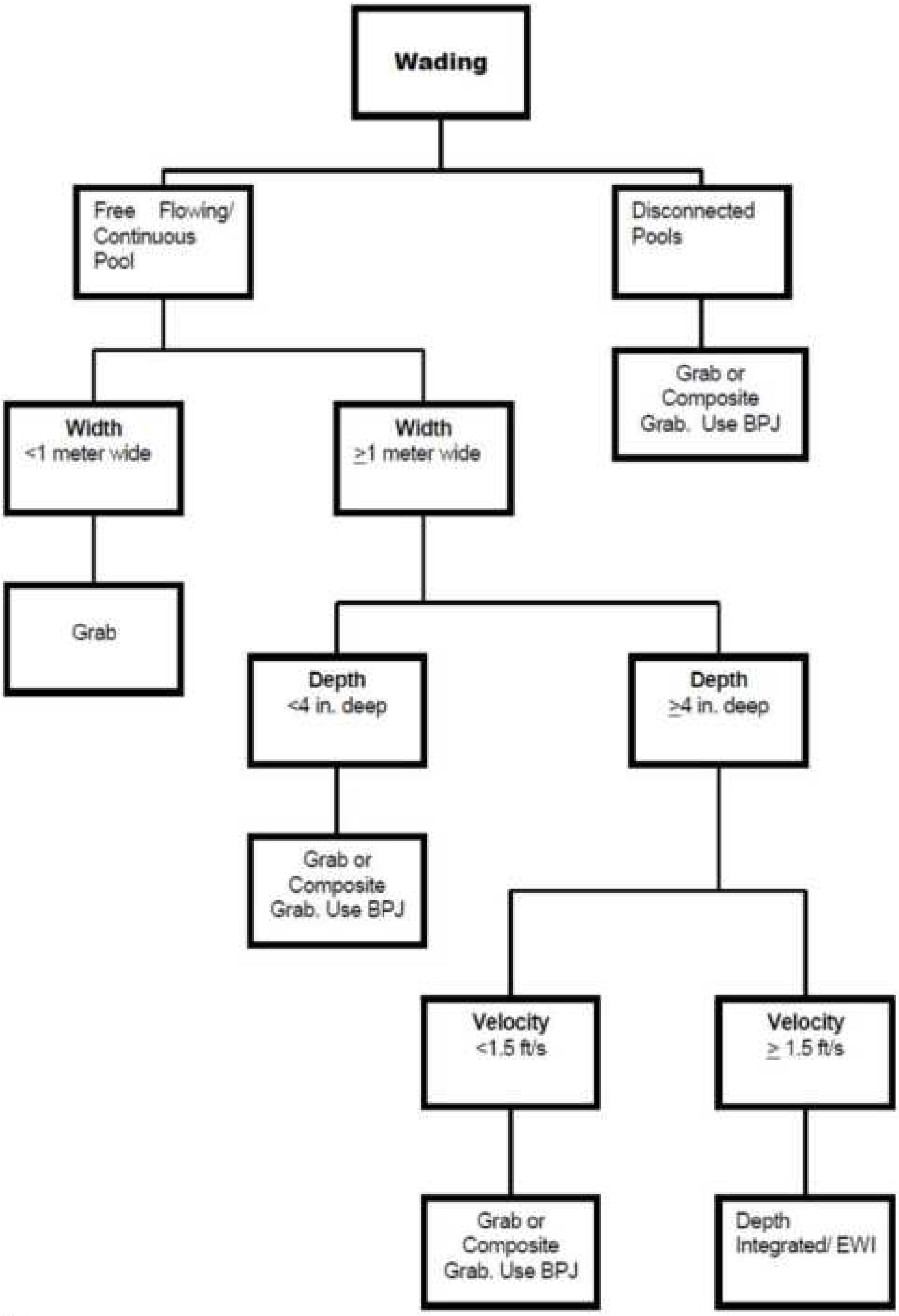

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Figure 2. Conditions for various sampling techniques while wading

Source (fig. 1 & 2): OWRB, 2013

1.2.1.2 Beach Sampling

Given the importance of Tourism to most of the Caribbean Islands, safety of the guests is paramount and as such frequent monitoring of water quality is important. In the case of Jamaica, licensing of recreational beaches is required and water quality monitoring by the environmental agency is conducted at intervals. Below are suggestions on beach monitoring protocols.

HAZARDS IDENTIFICATION

- Point source contamination: sewage discharge, storm water discharge, fecal waste.
- Diffuse source of contamination: domestic and wild animals and birds, storm water runoff, septic waste runoff, contamination from swimmers.
- Chemical hazards: industrial discharges, contamination from marinas or watercrafts, chemical spills.
- Algae Bloom (cyanobacteria).
- Swimmers Itch (schistosomes).
- Physical hazards: litter, poor visibility, adverse weather.
- Complaints of Waterborne illness or disease outbreak (Interior Health, 2018).

SAMPLE COLLECTION PROCEDURE AND FREQUENCY

For depth of water is 1 to 1.5 meters, samples for bacteriological analysis should be taken 15 to 30 cm below the water surface. When the depth of water is less than 1 meter, samples shall be obtained as far offshore as possible within the bathing area (Ministry of Health and Long-Term care, 2018; Near North Laboratories Inc. 2020). Water samples for bacteriological analysis should be collected using sterile bottles. For consistent analysis of water quality, samples should be collected at the same general locations, on the same day of the week, at approximately the same time of day. Sampling considerations should include;

- Approximate length of beach.
- Approximate depth of the water in the public beach area
- Possible sources of pollution and the distances to the bathing area; and
- Numbered sampling points and the sequence the samples are collected.

Table 1 shows a general guideline, however, in the Caribbean where distances between hotel properties are usually less than 1,000 meters, monitoring water quality of each property may be required. Additional sampling points and more frequent sampling may be carried out as determined by the medical officer of health. Where historical data of the geometric mean and environmental surveys indicate that water quality is consistently within the water quality threshold for the previous bathing season and confirmed through the pre-season sampling results, sampling frequency may be reduced to once per month (Ministry of Health and Long-Term care, 2018).

Table 1. Water sampling points are determined by the length of beach

Length of beach	Number of sampling points
1000 meters or less	5 points
Over 1000 meters	1 point per 200 meters
Over 5000 meters	1 point per 500 meters

RECREATIONAL WATER QUALITY STANDARDS

Intestinal enterococci (ENT) are the only parameter suggested by the WHO guidelines and is currently used as a regulatory parameter in the European Union (EU) Bathing Water Directive (BWD). This is also used by several other recreational water regulations throughout the world, as outlined in Table 2 (although many of these regulations are currently under review). The BWD is the only set of major regulations that requires the measurement of both *Escherichia coli* (*E. coli*) and ENT at monitored sites. The classification of BWD is based on percentile measurements, with the calculation method (which assumes that the data are log10 normally distributed)

Table 2. WHO guidelines and selected regulatory levels for ENT in recreational water

Water type	Acceptable water quality/100ml (measure)	Comments	Status	Organization
Fresh and marine	≤ 500 cfu with low to moderate susceptibility to faecal influence (95th percentile)	Based on the lower value for a rating of 'fair' (estimation of up to a 10% GI illness risk)	G	WHO [3]
Fresh and marine	≤35 cfu (GM) and ≤130 cfu (90th percentile) ≤70 cfu (75th percentile) ***or using qPCR*** 470 CCE (median) or 2000 CCE (90th percentile) 1000 CCE (75th percentile)	Based on a GI illness rate of 36/1000 Optional beach action value (BAV) Choice of ENT **or** *E. coli* for fresh water	R	USEPA [4]
Fresh	≤330 cfu (90-percentile) ≤400 cfu (95-percentile) <200 cfu (95-percentile)	Based on 'sufficient' classification Based on 'good' classification Based on 'excellent' classification Measurements for *E. coli* also required	R	EU [5]
Marine	≤185 cfu (90-percentile) ≤200 cfu (95-percentile) <100 cfu (95-percentile)	Based on 'sufficient' classification Based on 'good' classification Based on 'excellent' classification Measurements for *E. coli* also required	R	EU [5]
Marine	≤35 (GM) ≤70 (single sample max)	Minimum of 5 samples	R	Health Canada [6]

G: guideline R: regulation GM: geometric mean cfu: colony forming units qPCR: quantitative polymerase chain reaction CCE: calibrator cell equivalents GI: gastrointestinal USEPA: United States Environmental Protection Agency

Source (tables 1 & 2): WHO, 2018

Appendix 2.2 shows examples of sample handling containers, preservation methods and holding times and Appendix 2.3 shows an example of drinking water quality testing form.

1.2.2 Water Sampling before, during and after flood events

Floods impact water quality in ways that have both short- and long-term impacts on drinking water treatment plants, sewerage treatment plants and aquatic ecosystems. Collecting water quality samples from many sites to characterize changes in water quality is therefore important. During flood events, instrumentation for automated or **continuous water quality monitoring is preferred but cost and logistics must be established for individual islands.** Automated sampling devices are used to collect water samples when it is not possible to collect them manually. For example: i) during flood events when collecting samples manually is unsafe e.g., high river levels and high flows, to capture the rise or fall of a hydrograph for calculating loads, ii) when there are flashy unpredictable flows in stormwater drains. Turbidity and nutrients will be particularly high for this period. Example of sample procedure for turbidity is shown in Appendix 2.4 and for total suspended solids in Appendix 2.5.

1.2.2.1 Site Selection for automated water quality sampling

The purpose of the study is the main driver in determining the general location of sampling site. The specific location however depends on accessibility and safety, protection from vandalism, stream morphology and flow, and proximity to electrical power and telephone service (B.C Ministry of Environment, 2006; Wagner et al., 2006).

ACCESSIBILITY AND SAFETY

Automated water quality sampling stations must be accessible, safe, and have a minimal chance of being damaged or destroyed by natural forces. When establishing the location of the sampling site the following features should be considered. The location should be guided by information obtained from maps, weather records, talking to residents, and a reconnaissance visit.

- The stations should be located near a road for easy access to the station.
- To ensure safe access to the stream, the station should have shallow sloping banks.
- Damage to stations due to the presence of large trees and the potential for windfalls should be assessed.

PROTECTION FROM VANDALISM

To ensure that a valid and useful recorded data record, and because the sampling equipment is expensive, protection from vandalism is important. In general, there are three components to keep secure: the sonde, the accessory equipment (data logger, batteries, & additional power sources), and the cables. In all cases, the sonde is protected in a deployment tube. There are several options that can be used to protect the components.

- In a self-contained system, the data logger and batteries are contained within the sonde, and the sonde is locked in a deployment tube. The deployment tube is anchored to a bridge or other permanent structure and the cable is protected in a casing.
- Systems in which the sonde is physically separated from the accessory equipment present several options for protective structures. The accessory equipment can be protected in a walk-in shed or a locked box. The sonde is then connected to the accessory equipment via a cable that is contained in casing and may be buried (B.C Ministry of Environment, 2006).

Other factors to consider in placement of water quality monitoring systems are shown in Appendix 2.6.

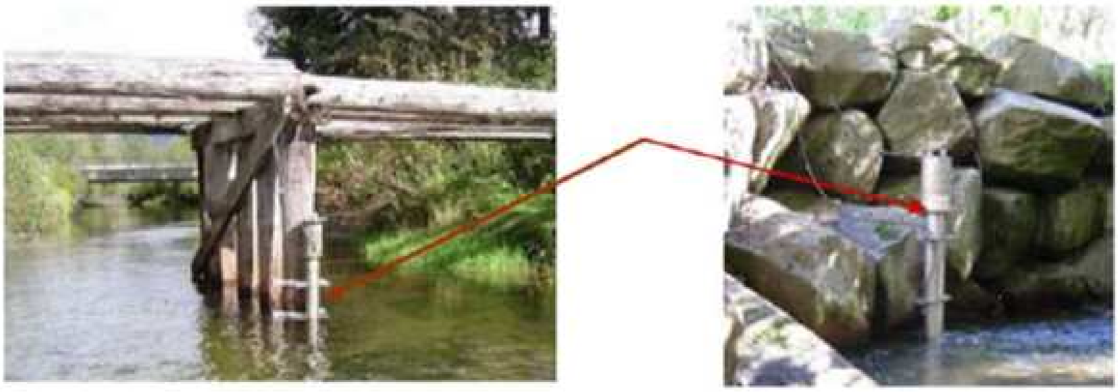

Figure 3. A self-contained sonde provides its own protection and can be attached to a bridge or rock wall

Photos: Rod Shead
Source: https://www.who.in/water_sanitation_health/dwg/2edvol3d.pdf

1.2.2.2 Example of General sampling criteria

Source: WHO, n.d.

- Sampling points should be selected such that the samples taken are representative of the different sources from which water is obtained by the public or enters the system.
- Sampling points should include those that yield samples representative of the conditions at the most unfavourable sources or places in the supply system, particularly points of possible contamination such as unprotected sources, reservoirs, low-pressure zones, ends of the system, etc.
- Sampling points should be uniformly distributed throughout a piped distribution system, taking population distribution into account; the number of sampling points should be proportional to the number of links or branches.
- Sampling points should generally yield samples that are representative of the system as a whole and of its main components.
- Sampling points should be located in such a way that water can be sampled from reserve tanks and reservoirs, etc.
- Where there are more than one water source, the locations of the sampling points should take account of the number of inhabitants served by each source.
- There should be at least one sampling point directly after the clean-water outlet from each treatment plant.
- Sampling sites in a piped distribution network may be classified as:
  - fixed and agreed with the supply agency;
  - fixed, but not agreed with the supply agency; or
  - random or variable.

1.2.3 Water sampling in the case of droughts

Drought conditions can greatly reduce stream flow, which impacts habitat quality and availability for freshwater organisms (Covich et al., 2006). There is also the impact on water quality which include, change in pH, nutrient loads, concentration of contaminants, salinity, filtration capacity, temperature, and increases in aquatic algae growth (Neal et al., 2009; Nemeth and Platenberg, 2007). Drought can impact the amount of freshwater that enters estuaries, resulting in alteration of their composition. Drought conditions leading to a reduction in rainfall results in decreased freshwater entering estuaries due to i) reduced surface flows; ii) reduced aquifer recharge and groundwater flows; and iii) increased human withdrawals - which further drive reductions in surface and groundwater flows. Changes in the distribution and concentration of saltwater can have both short- and long-term impacts on mangroves and other keystone wetlands plant species, with subsequent impacts to numerous ecosystem services such as water filtration and storm surge protection (USGS, 2018).

1.2.4 Water sampling in the case of sea level rise (salt intrusion in aquifers)

Sea level rise produces varied challenges with respect to water resources' sustainability, water management, and water/wastewater facilities and infrastructure. Sea level rise impacts include saltwater contamination of coastal wellfields, infiltration of groundwater with chloride levels into wastewater collection systems, impairing normal operations and maintenance as well as opportunities for beneficial use of reclaimed water as an alternative water supply (Southeast Florida Regional Climate Change Compact, 2014)

According to Intergovernmental Panel on Climate Change (IPCC), sea level may rise up to 0.6 meters in the Caribbean by the end of the century and this could actually flood low-lying areas, posing huge threats, particularly to the smallest islands, and impacting human settlements and infrastructure in coastal zones. Sea level rise also poses serious threats to tourism, as up to 60 percent of current resorts lie around the coast and these would be greatly damaged by sea level increase. Sea level rise also risks saline water penetrating freshwater aquifers, threatening crucial water resources for agriculture, tourism and human consumption, unless expensive treatments operations are put into place (Faieta, 2016). Inundation by salt-water can permanently ruin a karst aquifer's freshwater supply in countries like Barbados and other islands which relies primarily on groundwater from a karst aquifer. Saline water will displace the freshwater, decreasing both its quantity and quality (Polk, 2013). Wells containing groundwater with chloride concentration greater than 150 mg/L, specific conductivity greater than 1000 µS/cm, or total dissolved solids (TDS) >700 mg/L are considered to be affected by saltwater intrusion (Klassen et al., 2014)

To prevent saline intrusion, Jamaica WRA for example in their Master Plan (currently under review) will provide guidance for water allocation by stipulating safe yields. Applications for water abstraction licenses will be taken on their own merits, examining the targeted source, examination of well performance under pumping condition, predicted yield and potential effects. License are granted with conditions such as not pumping below sea level and no pumping above a particular yield. Water budget calculation and resulting calculation of aquifer's recharge are areas being considered in the Master Plan (interview WRA Jamaica March 2021). Continuation of groundwater monitoring and modeling will be critical in predicting sea level rise scenarios anticipated over the next several decades and adaptation efforts should continue to be refined in accordance with predicted and realized trends. A model of sampling frequency for unpiped water supply is shown in Appendix 2.7.

1.2.5 Lab testing quality assurance and control

When sampling for all programs, Quality Assurance/Quality Control (QA/QC) samples are essential to assure that environmental samples meet the Data Quality Objectives (DQOs) that are outlined in the controlling Quality Assurance Project Plan (QAPP). The quality control programme in the laboratory has two primary functions. First, the programme should monitor the reliability of the reported results. It should provide an answer to "How good (true) are the results submitted" (UN/ECE, 2002). QA/QC sampling is designed to control each step of the sampling process. The use of blanks to ensure that field personnel are properly cleaning the plastics and glassware used in field sampling. In addition, duplicate samples should be collected to ensure that composite samples are properly processed. Replicate samples may be collected to ensure that the sampling methodology employed is collecting a representative sample. Spike or known samples may be submitted to test the efficacy of the analytical laboratory (OWRB, 2013). Definition of QA/QC samples are listed below.

- **Lab Blank Sample:** Collected to ensure that laboratory cleaning methods are adequate and are not contaminating samples.
- **Field Blank Sample:** Collected to ensure that field cleaning methods are adequate and are not cross-contaminating samples
- **Analytical Blank Sample: S**ubmitted to control the methods of the analytical laboratory.
- **Duplicate Sample:** Collected to control the sample splitting method. This sample ensures that composite samples are being collected appropriately.
- **Replicate Sample:** Collected to control the general sampling methodology that is being employed. This sample ensures that a representative sample is being collected. Replicate samples may also be submitted to verify the accuracy of analytical results.
- **Spike Sample:** A known stock solution diluted by environmental sample.
- **Known Sample:** A known stock solution diluted in the laboratory with reagent grade water (OWRB, 2013).

Standard field equipment cleaning decontamination procedures include; i) Wash equipment thoroughly with Luminox® detergent and hot tap water using a brush or scrub pad to remove any particulate matter or surface film. ii) Rinse equipment thoroughly with hot tap water. iii) Rinse equipment thoroughly with organic-free water. Iv) Allow to air dry for at least 24 hours. V) Wrap equipment in one layer of aluminium foil. Roll edges of foil into a "tab" to allow for easy removal. Seal the foil wrapped equipment in plastic and label.

Procedures for Decontaminating Glass Pans includes; i) Wash equipment thoroughly with Luminox® detergent and hot tap water using a brush or scrub pad to remove any particulate matter or surface film. ii) Rinse equipment thoroughly with hot tap water. iii) Rinse equipment with 10 percent nitric acid solution. Fresh nitric acid solution should be prepared for each decontamination session. Iv) Rinse equipment thoroughly with organic-free water. V) Allow to air dry for at least 24 hours. Vi) Wrap equipment in one layer of aluminium foil. Roll edges of foil into a "tab" to allow for easy removal. Seal the foil wrapped equipment in plastic and label (USEPA, 2015)

Appendix 2.8 outlines a decision network for selection of a sampling analysis which should be guided by documentation provided above.

1.3 Nature-based Solutions (NbS)

The impact of deforestation and fragmentation due to agricultural practices in the watersheds are common concern of most government officials and technical experts. The need to control deforestation and the resulting erosion and sedimentation exists to protect and preserve water quality and quantity. Development of comprehensive watershed and basin management plans is needed to curb these impacts. Anthropogenic pollution must also be considered. The intent of a watershed management plan is to achieve a comprehensive view of water and land resources problems within a watershed and to identify opportunities and authorities to address such problems (US Army Corp of Engineer, 2004). In the Caribbean region, watershed conservation is the responsibility of the Forestry Department and Environmental Agency with the water authorities being a member of the committee in a role where they provide comments or will take the initiative when there is a foreseeable need to alert the Forestry Department (interview WRA Jamaica March 2021). The approach to systematic watershed planning to preserve water quality requires, i) evaluating alternative uses of water and land resources, ii) identifying conflicts and trade-offs among competing uses, and iii) making contemplated changes through informed decisions (US Army Corp of Engineer, 2004). Nature based solutions to protect water quality is therefore one strategic approach.

1.4 References

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2 APPENDICES

2.1 Example of Chain of Custody forms

MASSDEP DRINKING WATER-BACTERIOLOGICAL CHAIN OF CUSTODY

Page ___ of ___

Date Rec'd in Lab | ALPHA Job #

Westborough, MA — TEL: 508-898-9220 — FAX: 508-822-3288
Mansfield, MA — TEL: 508-822-9300 — 508-822-3288

Client Information	Project Information
Client:	Project Name:
Address:	PWS Name:
	Project Location:
	Project PWS ID#
	Project Manager:
Phone:	ALPHA Quote #:
Fax:	**Turn-Around Time**
Email:	Standard ☐ Due Date: / Rush (only if pre approved) ☐ Time:

Report Information	Data Deliverables	Billing Information
☐ FAX	☐ EMAIL	☐ Same as Client Info
☐ ADEx	☐ Add'l Deliverables	PO #

Please Indicate PWS Class Below

☐ COM
☐ NTNC
☐ TNC

SUBJECT TO MCL REPORTING

These samples have been previously analyzed by Alpha ☐

Other Project Specific Requirements/ Comments/Detection Limits

Sample Type, DEP Location Code and Location Name must correspond to the sample information on your MassDEP Coliform Sampling Plan.

ANALYSIS

Sample Filtration: ☐ Done ☐ Lab to do
Preservation: ☐ Lab to do
(Please Specify below)

ALPHA Lab ID (Lab Use Only)	Sample Type (1)	DEP Location Code	DEP Location Name	Collection Date	Collection Time	Sample Matrix	Sampler's Initials	Analysis	Chlorine Result (mg/L)	Total Bottles

Container Code: P = Plastic; A = Amber Glass; V = Vial; G = Glass; B = Bacteria Cup; C = Cutie; O = Other; E = Encore; D = BOD Bottle

Preservative Code: A = None; B = HCl; C = HNO_3; D = H_2SO_4; E = NaOH; F = MeOH; G = $NaHSO_4$; H = $Na_2S_2O_3$; I = Ascorbic Acid; J = NH_4Cl; K = Zn Acetate; D = Other

(1) Sample Type: RO - Routine Distribution Sample; RO - Original Site Repeat; UR - Upstream Repeat; DR - Downstream Repeat; AR - Additional Repeat; RW - Raw Water; PT - Plant Tap; SS - Special Sample

Container Type
Preservative

Relinquished By:	Date/Time	Received By:	Date/Time

Please print clearly, legibly and completely. Samples can not be logged in and turnaround time clock will not start until any ambiguities are resolved. BY EXECUTING THIS COC, THE CLIENT HAS READ AND AGREES TO BE BOUND BY ALPHA'S TERMS & CONDITIONS. (See reverse side.)

Form No: 01-24-Micro HC (rev 18-Sept-2013)

MASSDEP DRINKING WATER CHAIN OF CUSTODY

ALPHA	Page ___ of ___	Date Rec'd in Lab:	ALPHA Job #

Westborough, MA — TEL: 508-898-9220 — FAX: 508-898-9193
Mansfield, MA — TEL: 508-822-9300 — 508-822-3288

Client Information	Project Information	Report Information / Data Deliverables	Billing Information
Client:	Project Name:	☐ FAX ☐ EMAIL	☐ Same as Client Info
Address:	PWS Name:	☐ ADEx ☐ Add'l Deliverables	PO #
	Project Location:	Please Indicate PWS Class Below	
	Project PWS ID#	☐ COM	
	Project Manager:	☐ NTNC	
	ALPHA Quote #:	☐ TNC	
Phone:	Turn-Around Time		
Fax:	Standard ☐ Due Date:	SUBJECT TO MCL REPORTING	
Email:	Rush (only if pre approved) ☐ Time:		

These samples have been previously analyzed by Alpha ☐

Other Project Specific Requirements/ Comments/Detection Limits

ANALYSIS

Sample Filtration
☐ Done
☐ Lab to do
Preservation
☐ Lab to do
(Please Check Below)

ALPHA Lab ID (Lab Use Only)	DEP Location Code	DEP Location Name	Collection Date	Collection Time	Sample Matrix	Sampler's Initials	Analysis								Source(1) Multiple	Source(1) Single	Type Raw	Type Finished	Sample(2) Routine	Sample(2) Special	Total Bottles

Container Code:
P = Plastic
A = Amber Glass
V = Vial
G = Glass
B = Bacteria Cup
C = Cube
O = Other
E = Encore
D = BOD Bottle

Preservative Code:
A = None
B = HCl
C = HNO3
D = H2SO4
E = NaOH
F = MeOH
G = NaHSO4
H = Na2S2O3
I = Ascorbic Acid
J = NH4Cl
K = Zn Acetate
O = Other

(1) List connected sources if Multiple

(2) Explain if sample type is Special

Container Type								
Preservative								

Relinquished By:	Date/Time	Received By:	Date/Time

Please print clearly, legibly and completely. Samples can not be logged in and turnaround time clock will not start until any ambiguities are resolved. BY EXECUTING THIS COC, THE CLIENT HAS READ AND AGREES TO BE BOUND BY ALPHA'S TERMS & CONDITIONS. (See reverse side.)

Form No: 01-24 HC (rev 18-Sept-2013)

Source: https://alphalab.com/index.php/support-services/chain-of-custody-forms

2.2 Sample handling container, preservation methods and holding times

The information in this appendix is sourced from the *AS/NZS 5667.1:1998*, unless otherwise noted. **This table is not comprehensive but provides an overview of the most common analytes sampled.** Where analytes are not listed in this table please refer to Australian Standards, International Standards, ASTM or APHA. This information is reproduced with the permission of Australian Standards.

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
physical and aggregate samples						
acidity and alkalinity	plastic or glass	500	fill container completely to exclude air	refrigerate	24 hours	preferable to analyse sample in field
colour—true	plastic or glass	500	fill container completely to exclude air	refrigerate and store in the dark	2 days	
conductivity (at 25 °C)	plastic or glass	100	fill container completely to exclude air	none required	24 hours	preferably carried out in field for samples of low conductivity (<20 μS/cm)
oxygen, dissolved	glass			fix oxygen in the field and store in the dark (as per method of analysis used)	24 hours	preferably determined in the field
pH	plastic or glass	100		refrigerate	6 hours	carry out test as soon as possible and preferably in situ
solids (dissolved or suspended)	plastic or glass	500	dissolved: fill container completely to exclude air	refrigerate	24 hours	
turbidity	plastic or glass	100	fill container completely to exclude air	none required	24 hours	preferable to analyse sample in field or in situ

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
metals						
aluminium barium beryllium cadmium chromium cobalt copper lead manganese molybdenum nickel silver tin vanadium zinc	acid washed, plastic or glass	100		acidify with nitric acid to pH 1 to 2	1 month	
antimony	acid washed, plastic or glass	100		acidify with nitric acid or hydrochloric acid to pH 1 to 2	1 month	hydrochloric acid should be used if hydride technique is used for analysis—consult laboratory
arsenic	acid washed, plastic or glass	500	fill container completely to exclude air	acidify with nitric acid or hydrochloric acid to pH 1 to 2	1 month	hydrochloric acid should be used if hydride technique is used for analysis—consult laboratory
boron	plastic	100	fill container completely to exclude air	none required	1 month	
chromium (VI)	acid washed, plastic or glass	100	fill container completely to exclude air	refrigerate	1 day	sample container should be rinsed thoroughly

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
iron (II)	acid washed, plastic or glass	500	fill container completely to exclude air	acidify with hydrochloric acid to pH 1 to 2	24 hours	
iron, total	acid washed, plastic or glass	500		acidify with nitric acid to pH 1 to 2	1 month	
lithium	plastic	100		none required, but may acidify with nitric acid to pH 1 to 2 and refrigerate	1 month	acidification allows the sample to be analysed for lithium as well as other metals
magnesium	acid washed, plastic or glass	100	fill container completely to exclude air	none required	1 week	samples with pH > 8 or high carbonate content to be analysed solely for calcium, magnesium or hardness should be acidified
				acidify with nitric acid to pH 1 to 2	1 month	acidification permits determination of other metals from same sample
mercury	acid washed, glass	500		acidify with nitric acid to pH 1 to 2 and add potassium dichromate to give a 0.05% (m/v) final concentration	1 month	particular care is needed to ensure that the sample containers are free from contamination
potassium	acid washed, plastic or glass	100		none required/acidify with nitric acid to pH 1 to 2	1 month	acidification allows the sample to be analysed for potassium as well as other metals
selenium	acid washed, plastic or glass	500		acidify with nitric or hydrochloric acid to pH 1 to 2	1 month	
uranium	acid washed, plastic or glass	200		acidify with nitric acid to pH 1 to 2	1 month	

inorganic (non-metallic)

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
ammonia	plastic or glass	500		refrigerate	6 hours	strict protocol required to reduce effects of contamination store in area free of contamination (ammonia vapour may permeate the walls of even high density polyethylene containers) pressure filtering is preferred
				field filter through 0.45 µm cellulose acetate membrane and refrigerate	24 hours	
				field filter and freeze	1 month	
chlorine	plastic or glass	500		keep out of direct sunlight, analyse immediately	5 minutes	this analysis should be carried out in the field within 5 minutes of sample collection
cyanide, total	plastic or glass	500		if no interfering compounds are present, then add sodium hydroxide to pH >12, refrigerate and store in the dark	24 hours	the preservation technique will depend on the interfering compounds present sulfides and oxidising agents potentially cause large errors in the determination of different cyanide forms refer to the analytical method for suitable preservation techniques
iodide	plastic or glass	500		refrigerate	1 month	
fluoride	plastic	200		none required	1 month	PTFE containers are not suitable
nitrate	plastic or glass	250		field filter through 0.45µm cellulose acetate membrane and freeze	1 month	

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
				refrigerate	24 hours	unfiltered sample
nitrite	plastic or glass	200		immediate analysis		analyse as soon as possible after collection
				freeze	2 days	
				field filter through 0.45µm cellulose acetate membrane and freeze	1 month	
phosphorus, total	plastic or glass	500		refrigerate	24 hours	acidification not recommended for persulfate oxidation method
				freeze	1 month	
				acidify with sulfuric acid or hydrochloric acid to pH 1 to 2, refrigerate and store in dark	1 month	
phosphorus, dissolved	plastic or glass	50		field filter through cellulose acetate membrane and refrigerate or field filter and freeze	24 hours–1 month	
sulfate	plastic or glass	200		refrigerate	1 week	
sulfide, total	plastic or glass	500	fill container completely to exclude air	none required for field measurement. Preserve with zinc acetate for laboratory analysis	1 week (preserved)	
nitrogen, total	plastic or glass	500		refrigerate or freeze	24 hours–1 month	

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
TKN: total Kjeldahl nitrogen	plastic or glass	500		acidify with sulfuric acid or hydrochloric acid to pH 1 to 2, refrigerate	24 hours	
				refrigerate	24 hours	
				freeze	1 month	
Organics						
biochemical oxygen demand (BOD)	plastic or glass	1000	do not pre-rinse container with sample fill container completely to exclude air	refrigerate and store in the dark	1 day	glass containers are preferable for samples with low BOD (<5 mg/L)
chemical oxygen demand (COD)	plastic or glass	100	fill container completely to exclude air	acidify with sulfuric acid to pH 1 to 2, refrigerate and store in dark	1 week	glass containers are preferable for samples with low COD (<5 mg/L)
	plastic	100		freeze	1 month	
Hydrocarbons, oil and grease	glass, solvent washed	1000	do not pre-rinse container with sample do not completely fill container*	refrigerate	1 day	extract on site where practical extract sample container as part of the sample extraction procedure
				acidify with sulfuric acid or hydrochloric acid to pH 1 to 2 and refrigerate	1 month	

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
MAH: monocyclic aromatic hydrocarbons	glass, vials with PFTE lined septum	500	fill container completely to exclude air.	Acidify with hydrochloric acid to pH 1 to 2 and refrigerate. If residual chlorine is present, for each 40ml of sample add a) 25 mg of ascorbic acid; b) 3 mg of sodium thiosulfate; or c) 3 mg of sodium sulfite	1 week	2 x 40mL vials are recommended for purge and trap analysis
PAH: polycyclic aromatic hydrocarbons	glass, solvent washed	500	do not completely fill container do not pre-rinse	refrigerate and store in the dark if sample is chlorinated, add 80 mg of sodium thiosulfate for every 1000 mL of sample to container prior to sampling	1 week	extract on site where practical extract sample container as part of the sample extraction procedure
PCBs: polychlorinated biphenyls	glass, solvent washed with PTFE cap liner	1000–3000	do not completely fill container do not pre-rinse	if sample is chlorinated, add 80 mg of sodium thiosulfate for every 1000 mL of sample to container prior to sampling	1 week	extract on site where practical extract sample container as part of the sample extraction procedure a 40 mL vial with PTFE-lined septum is recommended for micro extraction

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
pesticides (organochlorine, organophosphorus and nitrogen-containing)	glass, solvent washed with PTFE cap liner	1000–3000	do not pre-rinse container with sample do not completely fill sample container with air	refrigerate if sample is chlorinated, add 80 mg of sodium thiosulfate for every 1000 mL of sample to container prior to sampling	7 days	extract on site where practical extract sample container as part of the sample extraction procedure
phenolic compounds (including chlorinated phenols)	amber glass, solvent washed with PTFE cap liner	1000	do not pre-rinse container sample do not completely fill container	refrigerate and store in the dark	24 hours	
				acidify to pH 1 to 2 refrigerate and store in dark if sample is chlorinated, add sodium thiosulfate to container prior to sample collection	3 weeks	
TOC: total organic carbon	amber glass with PTFE cap liner	100		acidify with sulfuric acid to pH 1-2, refrigerate and store in the dark	1 week	analyse as soon as possible phosphoric acid can be used instead of sulfuric if necessary inorganic carbon needs to be purged before analysis so volatile organic compounds will be lost
	plastic			freeze	1 month	
Microbiological / biological						

Analyte	Container type	Typical volume (mL)	Filling technique	Filtration and preservation	Holding time	Notes
faecal coliforms or *E.coli*, etc	glass or plastic, sterilised.	Confirm with laboratory	do not completely fill container	for chlorinated/ chloraminated water add sodium thiosulfate to concentration 100 mg/L for samples with high heavy metals add EDTA refrigerate	24 hrs (preferably < 6 hrs)	from AS/NZS 2031:2001
chlorophylls	plastic or glass	1000		refrigerate filter and freeze residue	24 hours 1 month	refrigerate in dark
radiochemical analysis						
alpha and beta activity (gross)	plastic or glass	1000	no air gap	acidify with nitric acid to pH 1 to 2	1 month	
alpha and beta activity except radio-iodine	plastic	as required	no air gap	filter for soluble analysis immediately add 20 ±1 ml of 50% (v/v) nitric acid per litre of sample the pH should be <1 refrigerate and store in the dark	analyse as soon as possible	safety precautions and shielding are dependent on the activity of this sample it is imperative that radioactive dust is not inhaled or left on clothing
gamma activity	plastic	consult laboratory		see endnote b	depends on the half-life of the radionuclide	safety precautions and shielding are dependent on the activity of this sample it is imperative that radioactive dust is not inhaled or left on clothing

Endnotes:

a. Samples for oil and grease analysis should be collected in glass containers with teflon-coated equipment as these analytes will stick to the rubber tubing of automated sampling equipment resulting in an unrepresentative sample.

b. If there is suspended matter and a separate measurement is required, or the solids are not readily dissolved, filter the sample and treat as two separate samples. Add quantitatively to the sample a known amount of solution containing non-radioactive isotopes of interest.

For samples containing metals, the solution is usually acidified to a pH of less than 2; the acid used should not precipitate or volatilise the elements of interest. Refrigerate and store in the dark.

Plastic = plastic containers, eg polyethylene, PTFE, polypropylene, PET and similar. Glass = borosilicate glass container. Vials are flatbottomed borosilicate glass vials, typically 30-50 mL capacity with screw caps. The caps should have PTFE faced septa, or liner.

The preservation technique will depend on the method of analysis to be used. Other methods of preservation may be suitable and prior liaison with the analytical laboratory is required.

Refrigerate = cool to between 1oC and 4oC (see clause 11.2.2 of AS). Freeze = freeze to -20oC (see clause 11.2.3 of AS)

Source: EPA Guidelines: Water and wastewater sampling, 2007

2.3 Example of Drinking Water Quality Testing Form

Introduction to Drinking Water Quality Testing — Appendix 6: Data Recording Forms

6.2 Data Recording Form 2

Technician Name:____________________________ **Sample Date:**____________________

Sample Location	Sample Description	*E. coli* Plate Count (CFU/100 mL)	X Dilution Factor Total Count (CFU/100 mL)	Comments and Observations

WHO Guidelines	pH -	Turbidity <1 NTU (large supplies) <5 NTU (small supplies)	Iron -	Manganese -	Arsenic 0.01 mg/L	Fluoride 1.5 mg/L	Chlorine 5 mg/L	Nitrate 50 mg/L
Country Standards	pH	Turbidity NTU	Iron	Manganese	Arsenic	Fluoride	Chlorine	Nitrate
Test Results								

Conclusions and Recommendations:

CAWST — A6.3

Source: https://www.pseau.org/outils/ouvrages/cawst_introduction_to_drinking_water_quality_testing_2013.pdf

2.4 Sampling procedures for turbidity

Collection technique using hand-held meter	Meter should be kept in gentle motion through the water column while a reading is being taken. Allow several minutes for the reading to stabilise. Measurements using probes must be made at least 1 m below the water surface and deeper in clear waters to ensure that there is no influence from ambient light.
Sample collection technique for laboratory analysis	Unfiltered sample
Sample requirements	Unfiltered sample
Volume	250 mL
Container	Plastic [A] or glass Use new pre-cleaned bottles
Collection technique	Direct collection into sample bottle or transfer into a sample bottle from collection vessel. Ensure sample bottle is pre-rinsed three times with sample water (3 × 20 mL) before final collection. It is important not to increase the turbidity of the water while collecting a sample, so do not disturb the bottom or the aquatic plants.
Treatment to assist preservation	Store container in dark Refrigerate at 1–4°C, do not freeze
Filling technique	Excessive turbulence should be avoided to minimise presence of air bubbles in the water. Fill to just below shoulder of the bottle.
Maximum sample holding time and storage conditions	Analyse directly as soon as possible after sample is collected and preferably in the field (only if you have an accurate probe, measuring accurately), but within 24 hours if the sample is refrigerated at 1–4°C. Keep cold but do not freeze.
Units of measurement	NTU (nephelometric turbidity units)
Comments	Freezing must be avoided, as irreversible changes in turbidity will occur if the sample is frozen.

[A] *Plastic sample bottles should not be made from low-density polyethylene (LDPE) as these tend to leak. Appropriate sample container plastics are high-density polyethylene (HDPE), polypropylene, polycarbonate or a fluoropolymer (e.g. teflon).*

Source: Govt. of Western Australia, 2009

2.5 Sampling procedures for total suspended solids

Sample requirements	Unfiltered sample
Volume	1 L
Container	Plastic [A] Use new pre-cleaned bottles
Collection technique	Direct collection into sample bottle or transfer into a sample bottle from collection vessel. Ensure sample bottle is pre-rinsed three times with sample water (3 × 20 mL) before final collection. It is important not to increase the turbidity of the water while collecting a sample, so do not disturb the bottom or the aquatic plants.
Treatment to assist preservation	Refrigerate at 1–4°C, do not freeze
Filling technique	Excessive turbulence should be avoided to minimise presence of air bubbles in the water. Fill to the shoulder of bottle.
Maximum sample holding time and storage conditions	Analyse directly as soon as possible after sample is collected, but within 24 hours if the sample is refrigerated at 1–4°C. Do not hold samples longer than 7 days Keep cold but do not freeze Alternative holding time is 3 days at 4°C[D]
Units of measurement	mg/L (mg total suspended solids/L)
Analysis method	Total suspended solids dried at 105°C 2540-D. (APHA, 1998) Method also in accordance with AS 3550.4:1990 Sample is filtered through a glass fibre (GF/C) filter of nominal pore size (WIN has nominated a pore size of 0.45 µm). The Gooch crucible, filter and the retained material is dried at 105°C. TSS is determined as the weight of the retained material.
Comments	Take care not disturb bottom sediments or plants during collection.

[A] *Plastic sample bottles should not be made from low-density polyethylene (LDPE) as these tend to leak. Appropriate sample container plastics are high-density polyethylene (HDPE), polypropylene, polycarbonate or a fluoropolymer (e.g. teflon).*

[D] *Guideline experimentally derived by Hosking Chemical Services for CSIRO and the Waters and Rivers Commission.*

Source: Govt. of Western Australia, 2009

2.6 Factors for consideration in the placement and installation of continuous water-quality monitoring systems

Site characteristics
Potential for water-quality measurements at the site to be representative of the location being monitored.
Degree of cross-section variation and vertical stratification.
A channel configuration that may pose unique constraints.
Range of stream stage (from low flow to flood) that can be expected.
Water velocity.
Presence of turbulence that will affect water-quality measurements.
Conditions that may enhance the rate of fouling, such as excessive fine sediments, algae, or invertebrates.
Range of values for water-quality field parameters.
Need for protection from high-water debris damage.
Need for protection from vandalism.
Monitor installation
Type of state or local permits required before installation can begin.
Safety hazards relevant to monitor construction and installation.
Optimal type and design of installation.
Consideration of unique difficulties or costs of installation.
Logistics (maintenance requirements)
Accessibility of site, including parking or boat access.
Safe and adequate space in which to perform maintenance.
Presence of conditions that increase the frequency of servicing intervals needed to meet data-quality objectives.
For stream sites, proximity to an adequate location for making cross-section measurements.
Accessibility and safety of the site during extreme events (for example, floods or high winds).
Availability of electrical power or telephone service.
Need for real-time reporting.

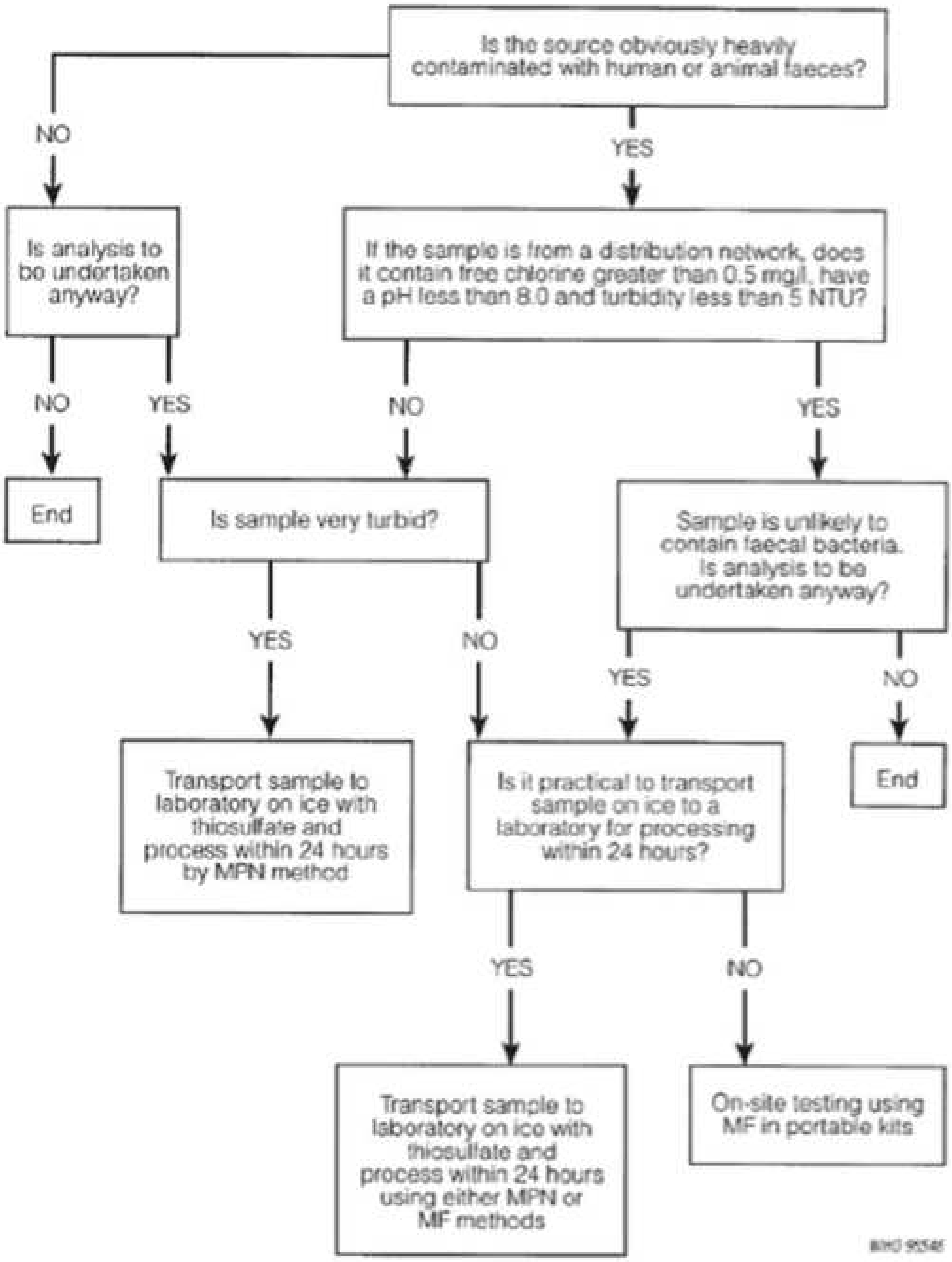
2.7 Minimum sampling frequency for unpiped water supply

Source and mode of supply	Minimum frequency of sampling and analysis		Remarks
	Bacteriological	Physical/chemical	
Open wells for community supply	Sanitary protection measures; bacteriological testing only if situation demands	Once initially for community wells	Pollution usually expected to occur
Covered dug wells and shallow tubewells with hand-pumps	Sanitary protection measures; bacteriological testing only if situation demands	Once initially, thereafter as situation demands	Situations requiring testing: change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases
Deep tubewells with hand-pumps	Once initially, thereafter as situation demands	Once initially, thereafter as situation demands	Situations requiring testing: change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases
Protected springs	Once initially, thereafter as situation demands	Periodically for residual chlorine if water is chlorinated	Situations requiring testing: change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases
Community rainwater collection systems	Sanitary protection measures; bacteriological testing only if situation demands	Not needed	—

Source: WHO, n.d.

2.8 Sample decision-making network for selection of method of analysis

Note: Analysis may sometimes be necessary because of specific local circumstances, e.g. where legislation demands that such analysis should be undertaken, or where legal action may be taken on the basis of analytical results.



Source: WHO, n.d.

Caribbean Community Climate Change Centre

GCCA+

THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

KAP 3:

WATER COLLECTION AND STORAGE

EU-GCCA/SER/006

May 2021

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LIST OF ACRONYMS

Acronym	In Full
CARPHA	Caribbean Public Health Agency
CEHI	Caribbean Environmental Health Institute
CWSA	Central Water and Sewerage Authority (Saint Vincent and The Grenadines)
DOWASCO	Dominica Water and Sewerage Company Limited
DWRH	Domestic Rainwater Harvesting
GWP-C	Global Water Partnership-Caribbean
IDB	Inter-American Development Bank
NbS	Nature-based Solutions
PPCR	Pilot Program for Climate Resilience
RWH	Rainwater harvesting
WRA	Water Resources Authority (Jamaica)

EXECUTIVE SUMMARY

RAIN WATER HARVESTING (RWH) AND DOMESTIC RAIN WATER HARVESTING (DRWH)

There are three approaches to RWH (GWP-C 2016, 2021b):

- **Traditional approach**, whereby it forms part of household storage and supply. In the early-to-mid 20th Century, before the advent of centralized conventional potable water supply systems, RWH was the only means of water security in all the Caribbean islands. Now with expanded access to potable, pipe-borne water supply, there has been a move away from RWH as this is a practice seen as outdated alongside the stigma of being practiced solely by low-income groups. Still in some mountainous areas where there is no coverage, RWH is still a primary strategy used by the local communities.
- **State-led approach**, which sees RWH as a disaster–resilience and risk reduction strategy to support communities in their adaptation to climate change. RWH is a key element to build climate resilience and enhance disaster risk reduction into the water sector in the Caribbean, especially to augment existing municipal or local water supplies through networks development plans.
- **Transformation approach**, which re-frames RWH as a business opportunity for water utilities to expand the scope of services they provide to customers and consumers. In this, water storage is reconceptualized from being a matter of private initiative at the individual level to a public initiative at the utility level.

HARNESSING EXCESS WATER SUPPLY FOR USE IN THE EVENTS OF DROUGHT, FLOODS, HURRICANES AND SEA LEVEL RISE

DRWH could be set to become a part of the region strategic planning to tackle climate change effects and water scarcity. If as a practice desalination is used at a national level, rainwater can provide an additional, alternative and emergency supply at the household level. Approximately 500,000 people in the Caribbean currently utilise rainwater harvesting, especially in countries like The Bahamas, Antigua and Barbuda and Saint Vincent and the Grenadines (GWP-C, n.d). Water quality monitoring and treatment should be considered too in the light of any additional storage services, as adding storage may affect the water quality.

NATURE-BASED SOLUTIONS (NBS)

NbS such as watershed restoration, including reforestation or conservation or Management of coastal vegetation and wetlands, can contribute to mitigate multiple hazards (e.g. flood risk, landslides, and water stress), while also generating a variety of co-benefits (e.g. biodiversity conservation, income-generating opportunities, and recreation), demonstrating greater versatility than grey infrastructure alone in the face of multiple challenges (Watkins, G. et al. 2019).

GENDER MAINSTREAMING

Gender mainstreaming is a crosscutting theme to IWRM processes, as well as to climate change adaptation. According to international frameworks for climate action and IWRM, women's participation and ensuring that all people benefit equally regardless of their gender is part of processes related to providing water and mitigating the effects of climate disasters, which tend to affect women and girls the most.

1 KEY ADAPTATIVE PROTOCOL: WATER COLLECTION AND STORAGE

1.1 General considerations for the formulation of a protocol

In the Caribbean, RWH is expected to become more important as a water security measure in the context of climate change, with the probability of changing rainfall patterns, prolonged droughts and extreme storm events. There is a need to provide redundancy into Caribbean water supplies, ensuring access to multiple water sources if one supply is disrupted (e.g. groundwater and water surface water supplies).

1.1.1 General context and climate impacts

Climate change studies suggest that there will be drier and longer dry seasons across most of the Caribbean basins in the future. When it does rain, rainfall events are likely to be heavy downpours that will increase the probability of flooding. Regarding precipitation patterns, previous work projected a broad drying trend with precipitation decreasing by 25–50% by 2080. However, in the northernmost part of the Caribbean, as well as in the southern parts, increases in precipitation were predicted. A look at the seasonal distribution of rainfall shows that models indicate significant decreases in wet season precipitation across the Caribbean. Extreme rainfall events are of particular interest, as water availability depends strongly on rainfall. Regional climate models (RCMs) suggests that while the northern Caribbean will record more-intense rainfall (zone 1 to 4) and fewer rainy days, the southern part (zone 5) will experience the opposite: less-intense rainfall and more rainy days[1] (Figure 1).

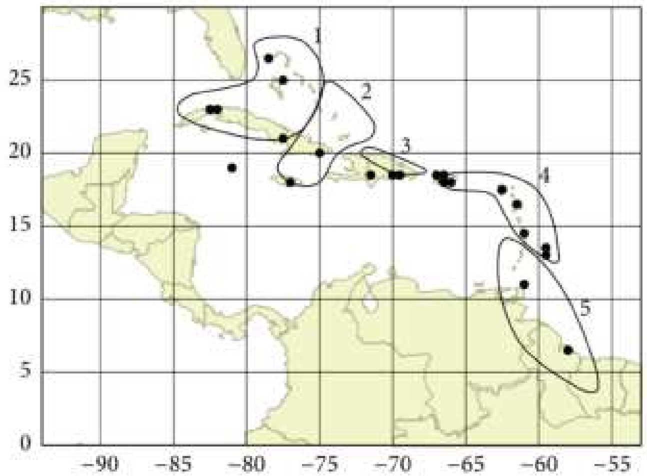

Figure 1. Five rainfall zones over the Caribbean and neighbouring regions. Observational weather stations are also shown.

Increased temperatures, more intense hurricanes and sea level rise are also expected. Such changes will affect the freshwater resources of every country in the region. As sea levels rise,

[1] Source: Natalie Melissa McLean, Tannecia Sydia Stephenson, Michael Alexander Taylor, Jayaka Danaco Campbell, "Characterization of Future Caribbean Rainfall and Temperature Extremes across Rainfall Zones", Advances in Meteorology, vol. 2015, Article ID 425987, 18 pages, 2015. https://doi.org/10.1155/2015/425987

there will be a greater probability of saltwater intrusion into aquifers in coastal areas. This threat of saltwater contamination will leave the Caribbean islands especially vulnerable, as many depend heavily on groundwater for their drinking water supply (e.g. Barbados, Saint Kitts and Nevis, etc.).

Many poor and rural communities throughout the Caribbean live without a pipe-borne supply of water — often, their only source is coming from rivers and streams, rainwater or paying for delivery by water trucks or at water kiosks (GWP-C, n.d).

Harvested rainwater is used for both domestic and commercial purposes. Domestic rainwater harvesting (DRWH) means collecting rainwater from roofs and storing it in containers of varying sizes for household uses. It has historically been the primary source of accessible potable water, particularly in remote communities.

1.1.2 Water collection and storage outside distribution lines for communities in times of climate extreme events

The severity of the 2009-2010 drought conditions highlighted the gaps, as significant losses were suffered in key economic sectors across the Caribbean, given that the infrastructure at the time was inadequate to absorb the impacts. This uncertainty prompted policy makers, water managers, the private sector and the general public to explore new water management approaches that emphasized the value of storage based on the deficits suffered. This period also represented a paradigm shift in terms of self-sustainability and domestic water use efficiency (GWP-C 2021a).

RWH has proved to be useful when conventional water supplies have become polluted or unavailable after natural disasters like hurricanes and floods, when the municipal water distribution system is damaged and out of service for extended periods (GWP-C, n.d.).

RWH involves catching and storing rain where it falls, in most cases by saving the rainwater which flows from a roof and down the drainpipes, diverting it through a filter in a storage tank for later use. Rainwater collection systems can be as simple as collecting rain in a barrel, or as elaborate as harvesting rainwater into large plastic tanks or concrete cisterns to meet an entire household or workplace demand. Whatever system is used, the collected water must be covered with mesh or netting to prevent mosquitoes from breeding. This is very important to prevent the spread of diseases like malaria, dengue and chikungunya. If water is to be used for drinking, it should be passed through a filter, an ultraviolet (UV) system, or it should be chlorinated (GWP-C, n.d.).

By late 2000, the Caribbean Environmental Health Institute (CEHI) had carried out comprehensive research in the region about best practices in RWH, suggesting that this practice could be significantly improved by the introduction of simple technologies and that most water quality standard could be met by application of basic practices. The principal focus was domestic water supply. In 2010, GWP-C, with the help of CEHI/Caribbean Public Health Agency (CARPHA), promoted a portable RWH model for the Caribbean region: a mock-up house with guttering, downspouts and water storage tank. The model was used in different countries (Grenada, St Lucia and Trinidad and Tobago) to demonstrate RWH best practices. The model was updated and replicated in 2014. The Jamaica Water Resources Authority (WRA) produced a model of their own, following the original GWP-C/CEHI design.

Figure 2. Cross-section of the GWP-C/CEHI Rainwater Harvesting Model (2014)

Source: http://www.caribbeanrainwaterharvestingtoolbox.com/Images/demos/New%20Caribbean%20Rainwater%20Harvesting%20Model.pdf

The GWP-C through its improved RWH model and related activities, committed to share knowledge with stakeholders at all levels on best practices in RWH in the Caribbean. Across the region, there have been repeated requests for the inclusion of financial incentives to compensate the cost of equipment and materials for RWH construction and maintenance (CEHI et al. 2008). In 2016, the Pilot Program for Climate Resilience (PPCR), conducted economic analyses to facilitate investment in RWH (CARPHA et al. 2014). Some examples of pilot implementations in the region show that so far, the introduction of RWH schemes has relied mostly on grant aid funding and solely focused on community-scale rainwater harvesting – often focused on rural schools and health post (interview DOWASCO March 2021; IDB 2020).

In **Grenada** after Hurricane Ivan, a DRWH project was commissioned to build resilience in water communities in terms of access to water in a post-disaster context and to increase supply during droughts (CEHI, 2006).

In **Dominica**, RWH has being incorporated into community emergency shelters, the Pan-American Health Organization (PAHO) has championed RWH as part of climate smart clinics and health care centres.

In **Trinidad and Tobago**, the National Institute of Higher Education, Research, Science and Technology (NIHERST) has been supporting the RWH installations in schools and community centres, which act as disaster shelters for water scarce communities.

In **St. Kitts and Nevis**,17 RWH systems have been set to ensure water security in vulnerable schools.

The **Caribbean Community Climate Change Centre** helped in the rehabilitation and cleaning of community RWH & cisterns in the Grenadines.

In **Jamaica**, several UN Agencies worked with the Government of Jamaica to support RWH in schools, farms, health clinics and community centres.

In **St Lucia**, there was a Rainwater harvesting project implemented by the Integrating Watershed and Coastal Area Management (IWCAM) Project in North Dennery (IDB 2020).

In **Suriname**, there was the project ‘Enhancing Access to drinking water for the maroon community of Asigron’ project in District Brokopondo (IDB 2020).

But even with the promotion of guidelines for the design and implementation of DRWH system (cf. GWP-C and CEHI/CARPHA online Rainwater Harvesting ToolBox), the existence of legal requirements for the installation of rainwater storage in The Bahamas and Barbados and several pilot program and projects in the Caribbean, the actual use has been low (GWP-C 2021b). There were, and still are, concerns raised by some health authorities and governments over improperly installed tanks and possible breeding ground for disease-spreading mosquitoes (interview DOWASCO 2021).

This situation is related to a lack of standards and codes of practices governing the installation of RWH systems, a robust system of public health surveillance in the region and a clear definition of responsibility for the operation and maintenance of RWH systems. There is also a need for supportive environmental guidelines and regulations to proactively encourage the construction and operation of rainwater storage tanks on a wider scale across communities (Peters, 2016).

Historically, water utilities have been reluctant to engage in the provision of DRWH systems, seeing them as a form of competition. There are, however, notable initiatives that demonstrate a change in attitude. Since 2017, the Barbados water authority has sought to implement a Personal Tank Programme (PTP) in response to supply interruptions to ensure water availability to affected households. The PTP has two lines of action: one supporting vulnerable households and the other providing low-cost financing to encourage their use through a programme. But it is a loan that has to be repaid, no other financial benefits, refunds or other incentives are offered; households still have to pay their water bill, with or without interruption. Only the wealthiest and sustainability-minded households are willing to invest, in the absence of regulatory or financial incentives.

1.1.3 Harnessing excess water supply for use in the events of drought, floods, hurricanes and sea level rise

Cf. Annex 1: Typology of climate-related risks per country

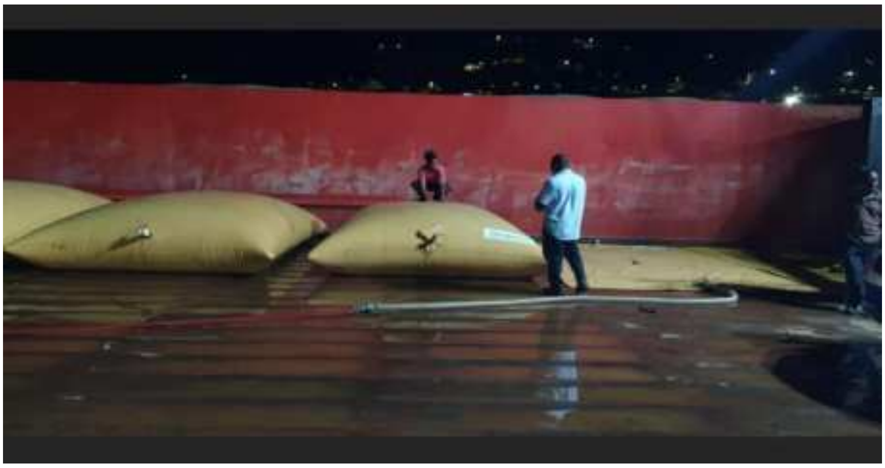

Figure 3. Water storage in Dominica

Storage secures a reliable provision of water supply to meet demands when and where it is needed, and in times of reduced capacity. Storage performs a variety of functions: it allows for the capture of resources for future needs and provides a buffer for emergency or during the aftermath of natural disasters. Lacking storage capacity and adequate storage seems to be the challenge in the region even for a country like Dominica where the water is abundant, as they have surplus water in many of their systems, rivers and streams but not readily where people live (interview DOWASCO, 2021).

Image source: Facebook page Dominica Water and Sewerage Company Limited, April 15th 2021

An example of cooperation and mutual aid to counteract the difficulties surrounding water supply problems during a disaster is given by DOWASCO, which as a sign of solidarity sent 150 cases of water to the Central Water and Sewerage Authority (CWSA) in St. Vincent and the Grenadines (April 15th, 2021) after the eruption of la Soufrière Volcano.

The diversification of storage options by using an optimal mix of engineering (reservoirs, dams, etc) and nature-based solutions should be discussed when looking at the overall strategy to meet water demand. An integrated approach to storage requires conceptualizing it as a service provider, and not as a set of individual storage facilities. Storage in natural water bodies (soil moisture, groundwater in aquifers, lakes, rivers, wetlands, etc.) contributes to ecosystem goods and services, such as the regulation of water quality and sustenance of aquatic life. (GWP 2021) Water quality monitoring and treatment should be considered too in the light of any additional storage services, as adding storage may affect the water quality.

All projects related to RWH and climate change have a component on awareness raising, capacity building and mention the need of a comprehensive communication plan to build consciousness about water security and consumption. Some water utilities try to increase the number of partnerships, as DINEPA with international NGOs or DOWASCO with Caribbean Development Bank (CDB) to support their outreach programmes and strengthen their institutional, social, and communicational engagement and relations with the consumers (interview DINEPA, 2021; interview DOWASCO, 2021).

1.1.4 Nature-based Solutions to climate change

Man-made infrastructures are generally driven by engineers, technocrats and politicians as the solution to meet all water demands (interview DINEPA March 2021; interview DOWASCO March 2021). While their importance is undeniable, an important link and opportunity to quantify and maximize the potential of Nature-based Solutions[2] is being overlooked, especially considering the high capital cost of structures and their susceptibility to damage from extreme weather events.

The 2018 UN World Water Development Report called for Nature-based Solutions for water (NbS). NbS use or mimic natural processes to enhance water availability (e.g., soil moisture retention, groundwater recharge), improve water quality (e.g., natural and constructed wetlands, riparian buffer strips), and reduce risks associated with water-related disasters and climate change (e.g., floodplain restoration and management, wetland and coastal wetlands management, restoration/creation) (Watkins, G. et al. December 2019).

NbS for water has the potential to address multiple water resources management challenges, simultaneously contributing to both climate mitigation and adaptation and delivering numerous benefits for people and nature (UN 2018). NbS are, however, largely understudied and undervalued throughout the Caribbean. NbS remains underutilized, as water management remains heavily dominated by traditional, human built infrastructure (GWP-C 2021). NbS can play an important role in building resilience to climate change in an infrastructure context. For example, managing and restoring vegetation can enable the root systems of trees and other vegetation to stabilize and regenerate soils in the respective watersheds and help to reduce landslides, erosion and flood risk. DOWASCO (interview March 2021) is working closely with the Forestry Division to reforest areas that were destroyed by hurricanes, and main catchment areas to help reduce turbidity level in the rivers.

[2] The term Nature-based Solutions (NbS) covers a range of ecosystem-related approaches to address societal challenges. NbS can encompass natural infrastructure (NI) and green infrastructure (GI), as well as approaches that combine green and gray elements (referred to as 'integrated' approaches) (Watkins, G. et al. 2019).

The British Virgin Islands example: through the restoration and conservation actions of mangroves, this Nature-based Solution invests in regaining the ecosystem services decimated by hurricanes Irma and Maria.

Source: https://www.iucn.org/sites/dev/files/content/documents/2021/mangrove_restoration_british_virgen_islands.pdf.

Figure 4. Post Disaster Restoration of Mangroves in the British Virgin Islands, Southeast sector of Anegada Island

1.1.5 Gender mainstreaming

"Studies have shown that men and women have different abilities to adapt to climate change because of gender inequalities in access to and control of assets, services, and decision-making. Women's ability to adapt to climate change is further limited by gender norms, roles, and biases present in communities, societies, places of work, and institutions of the Caribbean. Climate change can exacerbate gender inequalities and in turn increase the vulnerability of communities and countries during extreme events" (Watkins, G. et al. decembre 2020: 9).

Climate Change Impact in Natural Resources Management	Gendered Impacts
Deforestation / Scarcity of wood and fuel	☐ **Women**, who are in charge of firewood collection, may have to spend more time and resources obtaining firewood.
Water scarcity	☐ **Asset:** Water scarcity means less time available for personal, household, and productive activities by women as they spend more time collecting, harvesting, and carrying water. ☐ **Space:** Women are not always involved in the decision-making of community water boards or leadership of water services when decisions are made to solve water scarcity problems. ☐ **Service:** Agricultural water management has been effective in increasing yields and food production worldwide. If water professionals continue to be men, then the knowledge and information of new agricultural water management techniques such as rainwater harvesting (RWH) and flood control will be dominated by men.
Changes in rainfall	☐ **Rainfall** shocks result in income shocks that trigger a range of household-level coping strategies and policy responses, where women and female-headed households may have fewer assets to cope.

Figure 5. Gendered Impacts of Climate Change on Natural Resources Management.

Source: IDB. Study of the Impacts of Climate Change on the Women and Men of the Caribbean. Pilot Programme for Climate Resilience Countries (PPCR), IDB Technical Note, december 2020.

1.2 Recommendations and best practices

1.2.1 Integrating innovative freshwater storage services in the water management framework

The approach to freshwater management in the Caribbean must be integrated and resilient, and secure access to water resources and to drinking water supply for future development. Water storage will become an increasingly important part of the water sectors adaptation to climate change and variability. Some of the infrastructure investments identified will include building water storage capacities, drilling new wells and creating new rainwater harvesting systems.

RWH can be encouraged as a way to increase resilience to extreme events that disrupt utility water supplies and address wider water security issues. Accordingly, DRWH provides a degree of insurance in the form of a back-up water supply for those times when the impact of extreme events or operational issues lead to extended interruptions in water supply.

Efforts are being made to make rainwater harvesting systems mandatory in building codes. In Antigua and Barbuda, and Barbados, all new houses must be equipped with rainwater storage infrastructure (e.g. regulatory best practices). In addition, Jamaica's draft rainwater harvesting planning policy guideline, when approved by Cabinet, will provide local planning authorities with instructions on RWH systems that must be included in building plans as a requirement for approval of new residential and commercial construction. Currently, the National Environment Planning Agency in Jamaica, in its development approval process advises that all developers include plans for RWH systems for the environmental approval process. It is also specifically mentioned in Jamaica's National Water Policy and Implementation Plan (GWP-C 2021).

An alternative option, which has not yet been explored, is for water utilities to consider RWH as an adaptation to climate change in the form of distributed storage. If the economic cost of developing distributed rainwater harvesting storage is lower than other alternatives, it should be considered as an option for a water utility. The implication would be that the cost of installation would be assumed by the utility. The households willing to participate would receive some form of incentive along the lines of a feed-in tariff for renewable energy, to compensate for domestic use. For the utility, the potential benefits could be a reduction in operational costs, such as treatment and energy (GWP-C 2021).

The document on climate-resilient Water Safety Plans discusses how to take into consideration the broader issues of climate change, regional climate vulnerability assessments, disaster risk reduction (DRR) and integrated water resources management (IWRM) within the WSP participatory process. How this is done for any WSP will depend upon local circumstances. The document on climate resilient water safety plans also describes how water suppliers and WSP teams can best make use of information provided by other actors, such as climate vulnerability assessments at the level of the climatic or ecological zone, as inputs to their work on individual water supplies. (WHO)

1.2.2 Developing an assessment system of national DWRH programs and projects

Although governments, non-government organizations (NGOs) and international development organizations are actively promoting RWH in the Caribbean, no empirical and coordinated studies have been conducted to measure the success of such projects by evaluating the efficiency and effectiveness of this technology as an alternative and/or a primary water source. In 2006, CEHI (2006) proposed a program for promoting RWH and DWRM in the Caribbean region, which recommended that there should be a coordination of monitoring of the success of national DRWH programs.

1.2.3 Ensuring a high level of stakeholder engagement and O&M over time

In general, the success of RWH projects is assessed in terms of some specific objectives, such as quantity, water availability, water quality, improved household water supply and sanitation, as well as increased household productivity, as reflected in time and energy savings (Peters, 2016). The inclination is to measure the success of DRWH projects by the number of expected results, based on the project design, that have been realized in the short term, during the project implementation period. Evaluations of the long-term viability and sustainability of the initiatives are lacking. The success of RWH projects should also be measured by a high level of stakeholder participation, levels of adaptation (as indicated by increased household participation in DRWH), increased numbers of installations, and improved operations and maintenance of established systems over time (post-project evaluation) (IDB 2020).

1.2.4 Water utilities in the Caribbean require additional skills, methodologies, tools, and capacity to incorporate NbS into infrastructure projects

It is necessary to raise awareness of NbS, and enhance capacity to integrate them into decision making, within ministries responsible for planning, financing, and implementing infrastructure and/or environmental projects, and within water utilities to incorporate them into infrastructure projects planning and O&M.

1.2.5 Mainstreaming gender and developing gender sensitive actions

Gender is a complex and multifaceted issue. “While women in the Caribbean lead many climate resilience efforts, they continue to be under-represented in the leadership of local decision-making bodies like agricultural enterprises, water councils, and cooperatives that make important decisions regarding climate resilience” (Inter-American Development Bank, IDB, decembre 2020: 9). A dialogue between countries and their respective water utilities could help to assess their gender sensitive action planning and the challenges encountered.

The methodological guide of the World Water Assessment Programme (UNESCO WWAP) "Gender-Sensitive Water Assessment, Monitoring and Reporting" could be used to generate concrete lines of action: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/water-and-gender/gender-sensitive-water-assessment-monitoring-and-reporting/

The guide "Gender equality and water in the Americas. Considerations and guidelines for incorporating a gender approach in water management programmes, plans, projects and activities" of the Organisation of American States (OAS) could also be used (Andrés Sánchez, Alexandra Carlier, Mauricio Cerna 2021, in press). To ensure that both guides are well used, a short training process could be undertaken.

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2 APPENDICES

2.1 Typology of climate-related risks per country

Country / type of disaster	River flood	Urban flood	Costal flood	Water scarcity	Extreme heat	Wildfire	Cyclone
Antigua y Barbuda	Very low	High	Medium	No Data	Medium	Very low	No Data
Barbados	Very low	Low	Medium	No Data	Low	Very low	No Data
The Bahamas	Very low	Very low	High	Very low	Medium	Very low	High
Belize	High	High	Medium	Medium	High	High	High
Cuba	High	High	High	Low	Medium	High	High
Dominica	Very low	High	Medium	No Data	Low	Very low	No Data
Dominican Republic	High	High	High	Medium	Medium	High	High
Grenada	Very low	Low	Medium	No Data	Low	Very low	No Data
Guyana	High	High	High	Very low	Medium	High	Low
Haití	High	High	Medium	Medium	Medium	High	High
Jamaica	High	High	High	Low	Medium	High	High
Saint Kitts and Nevis	Very low	Low	Medium	No Data	Medium	Very low	No Data
Saint Vincent and the Grenadines	Very low	Low	Medium	Low	Low	Very low	No Data
Saint Lucia	Very low	Low	Medium	No Data	Medium	Very low	No Data
Suriname	High	High	High	Very low	Medium	High	Very low
Trinidad y Tobago	High	High	Medium	Low	Medium	High	High

Source: Global Facility for Disaster Reduction and Recovery. Think Hazard (2020).

Caribbean Community Climate Change Centre

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund

Regional SOPs for Climate Resilient Water Infrastructure

KAP 4: WATER RESOURCES USE

EU-GCCA/SER/006

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Developing Standard Operating Procedures (SOPs) for Climate Resilient Water Infrastructure in the CARIFORUM countries

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LIST OF ACRONYMS

Acronym	In Full
CARIFORUM	Caribbean Community Forum
IWRM	Integrated Water Resources Management
MLD	Million Litres per Day
NRW	Nonrevenue Water
RCM	Regional Climatic Model
RWH	Rainwater harvesting
SCADA	Supervisory Control and Data Acquisition System

EXECUTIVE SUMMARY

Water use conservation and demand management programs are an essential component of climate resilience of water resources. In many instances, it is less expensive to manage the existing water resources and customer behaviour than to fund new water supply and treatment systems. In addition, efficient use of existing water resources allows more water to be available for competing users such as the environment, tourism and agriculture.

Approaches to water demand management span the legislative and societal as well as the technical sides. A solid legislative framework is the first prerequisite on which other management strategies can be built, especially an integrated approach to reach sustainable practices in water use, especially within water supply and sanitation, agriculture, tourism and public health. Stakeholder engagement at all levels is fundamental to enable an integrated approach that takes into account all different water users and sectors including the environment. Technical solutions include reducing demand physically through rainwater harvesting, water audits and increasing household use and irrigation efficiency, enabling and encouraging water reuse and targeting the utility infrastructure by reducing non-revenue water (NRW).

1 KEY ADAPTATIVE PROTOCOL: WATER RESOURCES USE

1.1 General considerations for the formulation of a protocol

1.1.1 General context and climate impacts

The CARIFORUM states have access to limited water resources. For some countries or regions within countries, precipitation is the sole source of freshwater supply, while others are dependent on a thin freshwater groundwater lens. Often, countries depend on various combinations of sources for their domestic, industrial and agricultural water supply. The wet season(s) provide the main recharge of these precious water resources. The onset and duration of wet seasons vary spatially across CARIFORUM Member States. Regional climate models (RCMs) suggests that while the northern Caribbean will record more intense rainfall over fewer rainy days, the southern part will experience the opposite: less intense rainfall and more rainy days.

Several islands in the Caribbean are defined as water scarce with respect to natural freshwater resources according to the United Nations, which defines this condition as having an annual water resources per capita of below 1,000 m^3 per person per year. CARIFORUM Member States falling into this category include, but are not limited to, Barbados, Antigua and Barbuda, St. Kitts and Nevis and the Bahamas. On larger islands that are not classified as water scarce at a national level, regional disparities with respect to rainfall and physical conditions can result in water scarcity at the local level, resulting in seasonal water rationing. Such water scarce regions are particularly vulnerable to drought given the competition for water resources by various sectors (Farrell et al., 2010). Due to the ever-increasing pressures on water resources and increasing water use as a result of ongoing development and growing population, this situation is exacerbated if an integrated approach to water resources management (IWRM) including a demand management strategy is not adopted into practice.

1.1.2 Water conservation and demand management

Water conservation and demand management programs are an essential component of climate resilience of water resources and are considered to be the “low hanging fruit” of ensuring ample water supply for customers. In many instances, it is less expensive to manage the existing water resources and customer behaviour than to fund new water supply and treatment systems such as seawater reverse osmosis. These desalination systems can be costly especially in island states where fuel has to be imported. In addition, efficient use of existing water resources allows more water to be available for competing users such as the environment, tourism and agriculture.

To ensure that an adequate supply of water is available throughout the year, the water resources must be used wisely year-round, especially during the dry season, and water must be managed at both the water production and user level. In some CARIFORUM countries, water rationing in the dry season is common, often also locally, depending on the location and availability of supply sources. Water conservation should be promoted and practiced within all water use sectors (water supply, agriculture, tourism, environment, etc.) and at all household levels (household, commercial, and industrial).

CASE STUDY: WATER CONSERVATION IN GRENADA

Grenada, as part of their recently completed drought management plan, has included water conservation as part of their response to a drought event. The plan also contains language stating that water conservation applies year-round, which instils into the customer the importance of conserving water.

The plan includes the statement "An aggressive water conservation program is an essential component of drought mitigation", which clearly recognises the value of water demand management (Grenada, 2019).

1.2 Recommendations and best practices

1.2.1 Framework and social measures

1.2.1.1 Integrating water resources use into the integrated water resources management (IWRM) approach

Water resources management is the key aspect of the IWRM approach, as water use is the main pathway of impact of people and services on the water resources. When addressing water use, it is important to address all sectors, such as drinking water supply and sanitation, agriculture, tourism, industry, and others, while taking into account considerations around public health as well as the needs and impact of the environment. The issue of water allocation plays a major role especially on island states where freshwater resources are often very limited. Many CARIFORUM countries struggle with increasing water demand from ongoing developments, resorts and housing construction. In addition, increasing stresses from climate change impacts as well as more frequent climate extreme events and disasters impact water use in different ways, such as seawater inundating the well field in case of flooding.

1.2.1.2 Providing a legislative framework

An effective and appropriate legislative framework is imperative for establishment of water resources use management measures and enhancing climate resilience. Limited regulation of water resources is seen as the fourth largest factor contributing to water sector vulnerability by the CARIFORUM countries (HR Wallingford, 2020), after agricultural expansion in watersheds, watershed degradation, and limited financial resources for investments in water services.

In some CARIFORUM countries, including but not limited to The Bahamas, St Kitts, and Nevis, the water utility is both the implementer and the regulator. While generally there is a push from the utility to separate these tasks, the existence of this double role usually entails less attention is paid to the regulator tasks, i.e. managing water resources, due to a lack of human and financial resources.

Without an adequate legislative framework clarifying the mandate of the utility and other institutions such as the relevant ministries and regulator, development and implementation of needed policies and SOPs is not possible. An appropriate legislative framework also includes strong and appropriate policies that enable the utility to develop and coordinate plans to implement demand management measures such as water restriction practices, voluntary and mandatory, if a drought is either imminent or exists. For example, appropriate building codes and specifications can generate long-term water savings, through for example compulsory inclusion of a water reuse system or rainwater harvesting for new developments.

1.2.1.3 Stakeholder engagement at all levels

Engaging of stakeholders on all levels is imperative for the support for and uptake of water demand and conservation measures. Often there are some public awareness activities through for example a Facebook page or around themes like World Water Day. However, for a comprehensive communication plan all levels of government, the private sector, and stakeholders should be involved in conservation activities and should actively develop new water conservation programs where needed. For example, the Grenada Drought Management Plan (2019) aims to encourage the key entities farmers, schools, hotels and government departments to develop their own water conservation plans.

1.2.1.4 Public information campaigns

Public education is a key element of successful climate hazards including drought preparedness. Educational programs such as workshops, newsletters, public service announcements, press releases, community meetings, school curricula, and interactive participatory decision-making processes can increase awareness of the value of preparing and planning for climate hazards and droughts. Dissemination of information to the public about water conservation measures is also part of the Grenada Drought Management Plan (Grenada, 2019).

1.2.1.5 Mainstreaming gender when implementing water conservation and demand management

Gender aspects play a role in water demand management especially at the household level and in rural areas, where women are traditionally responsible for collecting water. A gender-sensitive approach is needed to adequately take into consideration the various impacts of water conservation and demand management measures on men, women, boys and girls.

The first step is to carry out a gender analysis, in order to identify gender gaps and barriers at the local level. Secondly, based on the gender analysis, a gender and water action plan is developed that addresses the key issues in each area. This is also done by raising awareness and building the capacity of water utilities working in the communities' areas.

1.2.2 Technical measures

1.2.2.1 Rainwater Harvesting

Rainwater harvesting means capturing rainfall and storing it for future use. Rainwater harvesting systems have been constructed since ancient times in many parts of the world. Today, in many areas of the world rainwater continues to be the only source of domestic water supply. In arid and semi-arid areas rainwater harvesting can be a necessary means of providing water for domestic purposes, especially where groundwater resources are unavailable or costly to develop. In many developing countries, rainwater is used to supplement the piped water supply, due to the lack of water infrastructure or unaffordability of the tariffs (Smet & van Wijk, 2002).

In general, rooftop rainfall capture has been the main method of domestic rainwater harvesting, by conveying excess water to a storage tank. Rainwater harvesting can also be the capture of excess water in catchments areas and local streams. The use of captured and stored water includes providing water to people, livestock, agriculture, increasing soil moisture, and groundwater recharge, or maintaining the freshwater lens.

Rainwater harvesting has the potential to increasing household and community water access and resilience to climate change. Rainwater harvesting was the main form of water supply in the Caribbean region prior to the establishment of effective water utility service providers in the early-to-mid 20th century. The practice of rainwater harvesting is now much reduced across the region, for example in Nevis where there is a history of rainwater harvesting, but its importance diminished throughout the years due to the advent of piped water supply. However, across the region rainwater harvesting has received renewed attention over the last decade, with an increasing interest in water security as the result of climate change (University of the West Indies, Mona). NAWASA Grenada with support from GIZ has focussed on RWH systems for hospitals, while they have also identified potential for RWH systems for hotels to reduce consumption. In Anguilla, RWH is common and the community prefers the taste over the desalinated water. In Jamaica, RWH is common in rural areas for both domestic and agricultural purposes. People find creative ways to build concrete walls to divert the water.

The design and use of rainwater harvesting systems require consideration of rainfall patterns, both historical and future based on climate projections. As a drought mitigation measure, the effectiveness of a rainwater system to alleviate water stress during a drought requires careful consideration of the projected drought duration and recurrence. Due to the limited size of rainwater capture areas such as rooftops, water storage tanks and the requirement to maintain adequate water quality, rainwater harvesting at the household scale can rarely fully fulfil the domestic water demands during a dry season or drought. Nevertheless, at a holistic level, the use of rainwater harvesting is an important component of the conservation and proper management of valuable water resources.

More on rainwater harvesting can be found in the Key Adaptive Protocol on Water Collection and Storage.

1.2.2.2 Water Audits and Household Water Use Efficiency

A home-based water audit provides a better understanding of customer water use patterns, characteristics, and consumption. The data gathered during a water audit in customer's homes will also assist in establishing a baseline for various customer segments and for future strategic and policy planning. The results of the free water audits will provide customers with a specific understanding of where water is used, as well as water-efficiency opportunities, including achieving water savings from leak detection. Water audits are great opportunities to motivate and educate customers on efficient water use behaviour. These measures can be stimulated by development of incentive programs or tax credits for installing water saving fixtures. The on-site audit is an opportunity to customize the recommendations to each customer and allows a person-to-person discussion of water use, savings potential, and recommendations, for example leaky toilets.

The main focus of an on-site water audit is to identify water-using fixtures and measure performance in order to determine water flow and volume rates. The auditors use a stopwatch and graded bucket to measure flow rates, and visually check fixtures for leaks. After data are captured, calculations are done in order to provide water usage and potential water savings. Those fixtures which are identified as having excessive water usage can be replaced with water saving or efficient type.

The requirement to use water efficient plumbing fixtures though national or local plumbing codes or standards can significantly reducing indoor water use by residential and commercial customers. Generally, the plumbing codes or standards impose a maximum on the amount of water used per flush by toilets and per minute by faucets and showerheads. Efficiency standards for plumbing fixtures typically rely on the manufacturers to meet these goals without compromising performance. The standards can also apply to the sale and installation of plumbing fixtures in addition to their manufacture. In the United States, nine states have their own mandatory standards for plumbing fixtures, while others are using financial incentives, community outreach efforts, and water conservation requirements for public buildings to promote the adoption of efficient fixtures.

The implementation of water efficiency standards for plumbing fixtures can save large quantities of water. For instance, toilets were once made to operate using 7 gallons/26 litres per flush but are now available using only 1.3 gallons/5 litres (a savings of over 80%). Water-saving plumbing fixtures are required in many countries by building and plumbing codes (Green Education Foundation, 2021).

1.2.2.3 Water Tariff Structure

Another method to conserve water by controlling the customer behaviour is through a conservation water rates schedule, which has been proven to be an effective tool for influencing water use by customers. For example, in Grenada the tariff is so low that the population is using drinking water to water their garden. By implementing increasing tiered rates and noticeable jumps in rate tiers for high water users, customers are incentivized to manage their water use more efficiently and practice conservation.

CASE STUDY: WATER AUDITING AND TARIFFS ON BARBADOS

On Barbados, the monthly domestic water bills include a household-level daily Garbage and Sewage Contribution. This makes water auditing challenging in the Barbados setting. The lowest value bill an individual can achieve after installing plumbing fixtures and utilizing excessive water conservation practices etcetera, is BDs$80 (US$40). This is already a struggle for most persons and negatively perceived by the public, thus there is not much room to adjust tariffs upwards. Audits are conducted via a sectoral approach, where equipment and practices which require water are investigated, resulting in advice on best water management and conservation practices.

1.2.2.4 Agricultural water use

Water demand management by the agricultural sector often requires a dedicated approach by the regulator, as they are often a major water user and key economic sector in the CARIFORUM countries. The agricultural sector was also identified as the sector that is most impacted by water shortages and service interruptions by CARIFORUM countries (HR Wallingford, 2020). They either receive water from the supply system, often resulting in a large demand on the system, or have their own private supply such as groundwater wells, which often are not monitored by the regulator. Decoupling of agricultural water use from the centralised system results in lower strains on the system, especially if the system’s water sources are far from the agricultural water user, requiring substantial pumping, with the associated fuel costs.

However, decoupling of agricultural users, switching private wells, makes regulation of groundwater or spring/river abstraction rates more difficult, which is an issue especially in those areas where the freshwater lens is vulnerable and, abstractions need to be carefully managed. Thus, whether agricultural water supply should be centralised or decentralised depends on the local conditions – this can even differ within the same country or island. Hybrid systems, such as small localised systems supplying only agricultural water users but otherwise managed by the utility to ensure compliance, can be considered. It should be noted that in some cases, providing water for agriculture falls outside of the responsibility of the national water utility, for example in Belize and Dominica.

CASE STUDY: AGRICULTURAL WATER USER GROUPS ACROSS THE CARIBBEAN

To address and manage agricultural water use, water management committees can be established. Water User Groups (WUG) from an agricultural perspective are established in several countries. For example, in Guyana, there are reservoirs for irrigation of rice and sugar cane fields and the producer associations are organized in WUGs. In Jamaica, the National Irrigation Commission Ltd is also coordinating farming groups. In St Lucia, committees are managed through WRA and in Grenada through the Department of Agriculture.

Whichever source is used to provide agricultural users with their water demands, as with the domestic sector, there is a large role to play for demand management and conservation. As mentioned, it is less expensive to manage the existing water resources and customer behaviour than to fund new water supply and treatment systems. Thus, as part of the integrated approach, support and encouragement for water-conserving irrigation systems, appropriate irrigation water management practices and other water conservation practices, such as windbreaks and cover crops, should be included in demand management and stimulated with customers. CARIFORUM countries mentioned that inefficient use of water in agriculture is a factor that increases the vulnerability of the sector (HR Wallingford, 2020).

CASE STUDY: VOLCANIC ERUPTION IMPACT ON AGRICULTURAL WATER USE IN ST VINCENT AND THE GRENADINES

The La Soufrière volcano eruption on 9th April 2021 had large impacts on the water supply of Saint Vincent and the Grenadines, as 13,000 persons were evacuated and relocated to safe zones. While all productive sectors were impacted by the blanket of ash, it was the country's agriculture sector that was particularly hard hit, as approximately 27% of registered farmers are located in the evacuated zones. Some properties in these zones faced 100% damages and losses, and the majority of most crop types were rendered unmarketable by the ashfall. Livestock watering was an issue as there was a lack of water and forage.

1.2.2.5 Non-Revenue Water

As climate change increases the recurrence and severity of droughts and urbanization rapidly increases, water loss is a critical issue. Some cities have experienced system water losses as high as 70%. However, even small losses that accumulate over time can have significant financial impacts on community water departments and economic impacts on water customers (Duffy, 2016). Water losses can be real (leaks) or apparent (poor meter operation, water theft); collectively, these losses are known as non-revenue water (NRW). NRW is typically stated as percentage, such as 50 % meaning half of the water that leaves a water source or production facility is not recorded by customer meters. It is not uncommon for some Caribbean water systems to have NRW as high as 50 to 60%, therefore a major focus in reducing water use and thus increasing climate resilience should be directed to reducing NRW. However, it is noted that many technological solutions to control NRW are complex or rely on SCADA[1] or artificial intelligence, which require historical data to train the system, which is often not available. The capacity of staff skillsets and institutions to absorb these new technologies needs to be considered.

CASE STUDY: JAMAICA'S NON-REVENUE WATER PROGRAMME

In Jamaica, citizens are routinely encouraged to invest in water harvesting systems, conserve water, report leaks and ensure that they properly regularize their water supplies through the water authorities.

In addition, the Kingston and St Andrew Non-Revenue Water (NRW) reduction co-management programme, which received recognition with an Innovation for Infrastructure global award, targets an area that is home to just under 50% of Jamaica's population.

The program, which entails a full social study, universal metering, and comprehensive customer follow-up, is guaranteeing a sustainable future to the utility. The social benefits in Kingston are significant, especially in challenging areas, through reducing the system input volume and granting a much more efficient water distribution within the network. It boosted the billed water volume from 85 million litres per day (MLD) in 2017 to 92 MLD in June 2020, bringing huge economic benefits by increasing the billed water by US$5.8 million per year.

Starting at an initial 60% NRW in the system in 2017, the project is making progress to achieving the final target for 2021, which is approximately 30% NRW (Christie, 2020).

The project accomplished the reduction of NRW through a holistic combination of pressure management, leak control, meter reading error reduction, timely leak repair, meter replacement, capacity building, leak detection, hydraulic modelling, and data management.

1.2.2.6 Water Reuse

The reuse of water is not a widespread practice in the Caribbean region. However, it is receiving increasing attention as a response to periodic and longer term water scarcity. When exploring the potential of this resource, the appropriate levels of treatment that reflect the different categories

[1] Supervisory control and data acquisition system

and accompanying quality standards required for hygiene and public health need to be taken into account.

CASE STUDY: GRENADA WATER REUSE

Grenada is encouraging water reuse as part of their Drought Management Plan.

The plan states: "Once a centralised wastewater treatment plant is operational, implementing alternative water supplies such as recycled water and greywater can also increase Grenada's resilience to drought impacts, particularly in the south of the island."

The Drought Management Plan encourages water reuse at the household level, for example the use of bath and shower water for flushing or external yard cleaning. For large hotels, the plan encourages implementation of water reuse facilities to provide non-potable water for internal use and landscape irrigation (Grenada, 2019).

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2 APPENDICES

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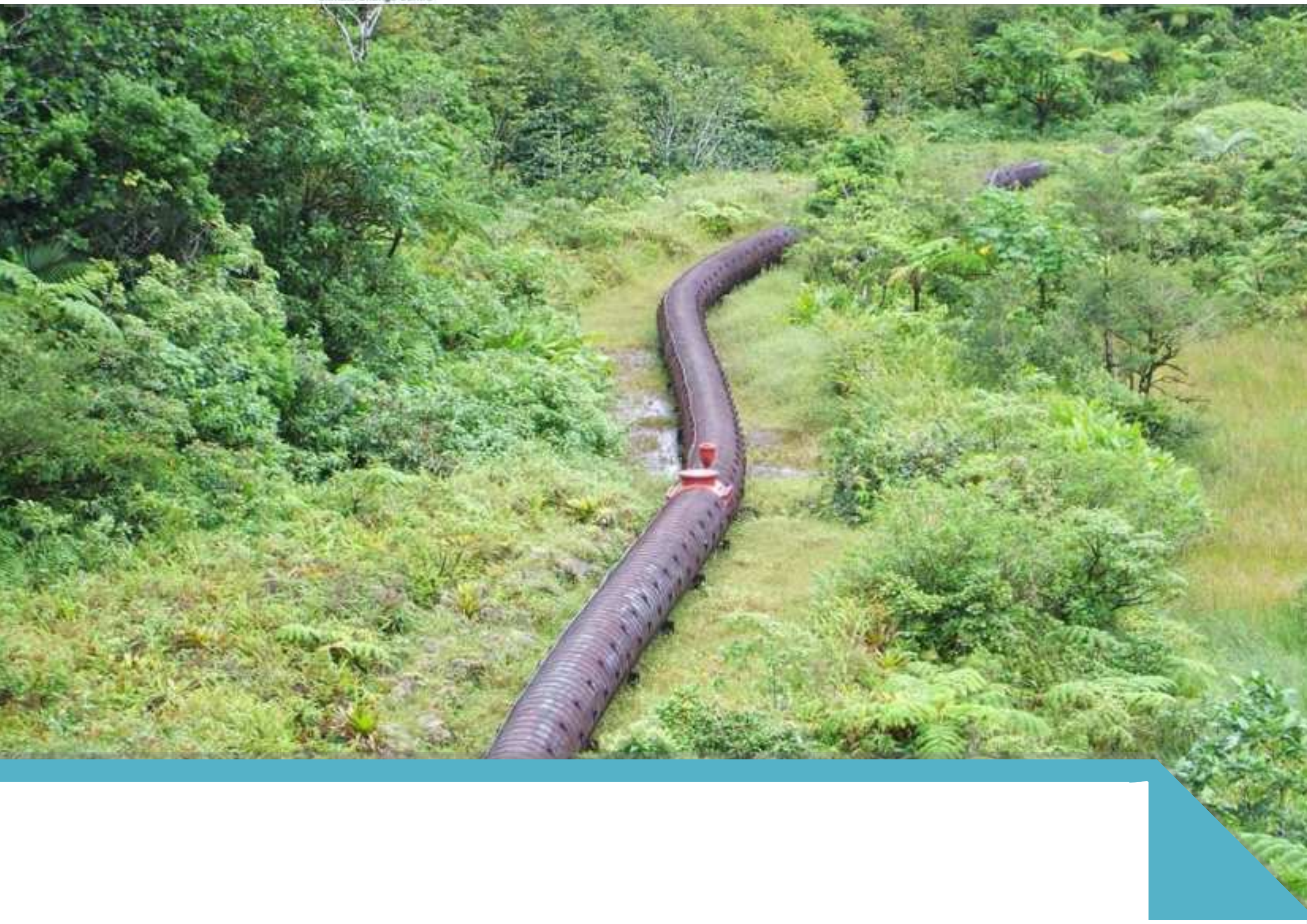
GCCA+
THE GLOBAL CLIMATE CHANGE ALLIANCE PLUS INITIATIVE

INTRA-ACP GCCA+ PROGRAMME An initiative of the ACP Group of States funded by the European Union's European Development Fund



Regional SOPs for Climate Resilient Water Infrastructure

KAP 5:

WATER DISTRIBUTION AND INFRASTRUCTURE

EU-GCCA/SER/006

May 2021

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Developing Standard Operating Procedures (SOPs) for
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LIST OF ACRONYMS

Acronym	In Full
CCCCC	Caribbean Community Climate Change Centre
CDKN	Climate and Development Knowledge Network
CEHI	Caribbean Environmental Health Institute
CReWSIP	Caribbean Climate Resilience and Water Security Investment Plan
GWP-C	Global Water Partnership-Caribbean
IWRM	Integrated Water Resources Management
KSA	Kingston and St. Andrew
MGD	Million Gallons per Day
MW	Megawatt
NbS	Nature-based Solutions
OECD	Organisation for Economic Co-operation and Development
RWH	Rainwater harvesting
SIDS	Small Islands Developing State
UN	United Nations
WRA	Water Resources Authority

EXECUTIVE SUMMARY

Water distribution network consists of infrastructure to pump, divert, transport, store, treat, and deliver safe drinking water to the general population. This infrastructure consists of vast numbers of groundwater wells, surface-water intakes, dams, reservoirs, storage tanks, drinking-water facilities, pipes etc. The main characteristic of climate-resilient infrastructure is that it is planned, designed, built, and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. Climate-resilient infrastructure can also withstand, respond to, and recover rapidly from disruptions caused by these climate conditions. New infrastructure assets should be prioritised, planned, designed, built, and operated to account for the climate changes that may occur over their lifetimes as existing infrastructure may need to be retrofitted, or managed differently, given climate change. Additional infrastructure will need to be constructed to address the physical impacts of climate change. This additional infrastructure can include traditional infrastructure, such as hard defences and other engineered solutions, as well as natural infrastructure, such as wetlands and other nature-based solution (OECD, 2018).

1 KEY ADAPTATIVE PROTOCOL: WATER DISTRIBUTION AND INFRASTRUCTURE

1.1 Distribution of potable water during climate extreme events

The challenge to the Caribbean region during extreme events is that of maintaining accessibility under these emergency situations. After hurricane Tomás in St. Lucia, the principal storage reservoir was damaged by a landslide, which led to damage to the electricity supply and pumping facilities. This resulted in approximately 80% of the population having to cope with limited water supply. Siltation blocked the lower intake, significantly reducing the available storage supply volume. Along with structural damages, systems cannot operate without electricity, and water becomes non - potable if it cannot be properly treated (Cashman, 2013).

Where drought is concerned, the experience of 2010 drought in Jamaica was documented. Daily stream flows into the two reservoirs supplying the Kingston and St. Andrew (KSA) area were approximately 50% – 75% less than the normal daily flows. The drought situation affected nearly 600,000 people living and working in the KSA area, and water production at the height of the drought had to be reduced by some 40%. In some instances, daily outputs from some water production facilities were reduced by as much as 90%. Response to ensure supply was maintained included, i) reducing the number of hours of supply, ii) rotational cuts to distribution areas, iii) reduced water pressure, iv) increased trucking of water (especially to areas at higher elevation), and v) reactivation of unused wells to augment supplies. In the longer term, priorities included, i) constructing new water treatment facilities and rehabilitating and upgrading old ones; ii) undertaking mains replacement to improve the condition of the distribution system and reduce leakage; and iii) a comprehensive customer meter installation programme.

1.2 General considerations for the formulation of a protocol - Climate proofing of the water infrastructures

Source: US EPA, n.d.

1.2.1 Build infrastructure needed for aquifer storage and recovery.

Increasing climate resilience for seasonal variation in climate or extended periods of drought and in so doing, taking advantage of seasonal variations in surface water runoff. Increasing the amount of groundwater storage available will promote recharge when surface water flows are in excess of demand. Depending on whether natural or artificial aquifer recharge is employed, the required infrastructure may include percolation basins and injection wells.

1.2.2 Diversification for water supply, recycle and expand current sources.

Reducing the risk that water supply will fall below water demand includes diversifying sources. For examples varying mix of surface water and groundwater, including employing desalination when the need arises and establishing water trading with other utilities in times of water shortages or service disruption. This is also an option to address saltwater intrusion.

Recycling of water is already practiced in some Caribbean islands on for example golf courses, but the potential exists to expand this source. Governments and regulatory agencies can create incentives for adding new commercial, government and industrial recycled water customers, with only a modest investment in additional distribution pipes. Using recycled water instead of potable water will expand the potable water supply and help to secure a “drought-proof” supply of recycled water for any number of uses. It is less costly than using valuable potable water for non-potable applications such as construction watering, street sweeping and sewer flushing. Recycled water can be used for residential landscaped common areas, schools, parks, government buildings, agriculture, golf courses, and a few other uses (Water Solutions Inc. 2015).

1.2.3 Increase water storage capacity

Increases in available storage can be accomplishing this and may include raising a dam, practicing aquifer storage and recovery, removing accumulated sediment in reservoirs, or lowering water intake elevation. Stormwater storage tanks could be used to reduce flooding and to improve wetland productivity through controlled release. Rainwater harvesting (RWH) can augment water supply and reduce stormwater pollutant and therefore can be economically feasible both in terms of reducing annual damage in the catchment by up to approximately 30 percent. The limitations such as the provision of storage space and temporal distribution of rainfall within an event were important factors affecting tank performance for flood reduction (Jamali et al., 2020).

Rainwater harvesting can be used in a variety of municipal applications. This includes direct roof capture off city buildings or capture of excess runoff from paved surfaces can be used to fill cisterns and other storage facilities. This storage of rainwater can be used for irrigation of green spaces and recreational facilities, washing and cleaning of streets and facilities, or for firefighting. RWH bulk water storage can be used to augment emergency water supplies following natural disasters when the potable supply is out of operation (CEHI, 2009).

RWH ENABLING ENVIRONMENT

- Knowledge sharing and capacity building while good can only go so far. Policies and legislation have proven the most effective way of advancing RWH at the domestic level and this is needed in countries where they do not exist. RWH is mentioned in Section 5.13 of the National IWRM Policy of Trinidad and Tobago and states as follows, “Rainwater harvesting is an important water augmentation technique providing an owner operated independent water supply if access to the municipal water supply is disrupted after storms or hurricanes. If enough water is captured and stored during rainy periods, a rainwater supply can also provide water during drought and periods of water restrictions. Rainwater storage can also help mitigate flooding of low-lying areas, reduce hillside erosion and reduce demand on wells which may enable groundwater levels to be sustained.” (Ministry of Public Utilities, n.d.)
- The development of a market for specialised RWH equipment as supplies is another area that needs attention. This is often difficult to obtain, and maintenance services are often unavailable. The business sector, as well as the region at large, will greatly benefit from the development of RWH products and services, inclusive of equipment installation and maintenance.
- There is also the need for more financial incentives for individuals and funding for RWH projects. RWH resource mobilization for RWH is a key aspect of the Climate and Development Knowledge Network (CDKN) funded GWP-C and the Caribbean Community Climate Change Centre’s (CCCCC) Caribbean Climate Resilience and Water Security Investment Plan (CReWSIP) project. This project focuses on the identification, prioritization, and sourcing of finance to increase climate resilience in the Caribbean water sector (GWP-C, 2016).

1.2.4 Monitor surface water conditions

Understanding surface water conditions and the factors that alter quantity and quality is an important part of projecting how climate change may impact water resources. Monitoring data for discharge, reservoir or stream level, upstream runoff, streamflow, in-stream temperature, and overall water quality can be incorporated into models of projected supply or receiving water quality.

It should be noted that WRA Jamaica is addressing some of the protocols (monitoring surface water condition, storage capacity, expansion of current source etc) in their management plan currently under review (interview WRA Jamaica March 2021).

1.2.5 Practice water conservation and demand management

Public awareness and outreach are essential component of any water conservation program and typically include basic information on household water usage, the best time of day to undertake water-intensive activities and information on and access to water efficient household appliances such as low-flow toilets, showerheads and front-loading washers. Different sectors such as commercial, institutional, industrial, public sectors organizations should be targeted in education and outreach. Incentive programs to promote conservation include those that provide rebates or help install water meters, water-conserving appliances, toilets, and rainwater harvesting tanks.

Another measure to encourage conservation is to promote regulatory strategies for water conservation. These should be reviewed to make sure they are in line with the island current, and evolving, water conservation goals.

1.2.6 Plan and establish alternative or on-site power supply

Water utilities are one of the major consumers of electricity. The development of "off-grid" sources can be a good strategy for electricity shortfalls. In addition, redundant power supply can provide resiliency for situations in which natural disasters cause power outages. On-site sources can include solar, wind, inline microturbines and biogas (i.e., methane from wastewater treatment). Microturbines have the ability to work alone or in groups. If one microturbine fails while in use, this does not necessarily mean that the entire system of microturbines will fail. In Wisconsin USA, the Sheboygan Regional Wastewater Treatment Plant has a permitted flow of 18.4 million gallons per day (MGD) and an average flow of 11 MGD. With a goal of becoming energy self-sufficient, in 2006 a combined heat and power project consisting of ten 30 kW Capstone microturbines and heat recovery systems was commissioned. By using the biogas produced from the WWTP's anaerobic digesters, the microturbines produced 2,300 megawatts (MW) of electricity annually which translated into energy cost savings of $78,000. The microturbines also produced 84,000 therms of heat, which was equivalent to $60,000 in prevailing natural gas rates. These turbines were installed at a capital cost of $300,000 (USEPA 2013). These new and/or back-up electrical equipment should be located above potential flood levels.

1.2.7 Develop models to understand potential water quality changes

Increased water temperatures will reduce drinking water quality due to eutrophication and excess algal growth. Another source of water quality reduction in drinking water includes increased sediment or nutrient inputs due to extreme storm events. These impacts may be addressed with targeted watershed management plans. Also, re-oxygenation of eutrophicated water bodies can be practiced to restore aquatic ecosystems.

1.2.8 Source Protection

The amount of treatment and quantity of chemicals needed can be reduced by decreasing contamination of source water and as a result, effective catchment management has many benefits. This may reduce the production of treatment by-products and minimize operational costs. Effective resource and source protection include the following elements:

- developing and implementing a catchment management plan, which includes control measures to protect surface and groundwater sources;
- ensuring that the planning regulations include protection of water resources (land use planning and watershed management) from potentially polluting activities and ensuring enforcement; and
- promoting awareness of the impact of human activities on water quality at the community (Davison et. al., 2005).

Examples of source water, storage and extraction control measures are shown below.

Source water and catchments

- Designated and limited uses
- Registration of chemicals used in catchments
- Specific protective requirements (e.g. containment) for chemical industry or
- refuelling stations
- Reservoir mixing/destratification to reduce growths of cyanobacteria, anoxic
- hypolimnion and solubilisation of sedimentary manganese and iron
- pH adjustment of reservoir water
- Control of human activities within catchment boundaries
- Control of wastewater effluents
- Land use planning procedures, use of planning and environmental regulations
- to regulate potential water polluting developments
- Regular inspections of catchment areas
- Diversion of local stormwater flows
- Protection of waterways
- Runoff interception
- Security to prevent sabotage and tampering

Water extraction and storage systems

- Use of available water storage during and after periods of heavy rainfall
- Appropriate location and protection of intake
- Appropriate choice of off-take depth from reservoirs
- Proper well construction including casing, sealing and wellhead security
- Proper location of wells
- Water storage systems to maximise retention times
- Roofed storages and reservoirs with appropriate stormwater collection and
- drainage
- Securing tanks from access by animals
- Security to prevent unauthorised access, sabotage and tapping and tampering. (Davison et. al., 2005).

1.2.9 Model and monitor groundwater conditions

Climate change projection in the Caribbean may lead to diminished groundwater recharge in some areas because of reduced precipitation and decreased runoff. Water budgets and modeling groundwater conditions will inform water utilities and water resources agencies on projected water quantity and quality changes. Monitoring data for aquifer water level, changes in chemistry and detection of saltwater intrusion can be incorporated into models to predict future supply.

1.2.10 Model and reduce inflow/infiltration in the sewer system

There is an expected increase in the amount of wet weather infiltration and inflow into sanitary and combined sewers due to more extreme storm events. Sewer models can be used to estimate the impact of increased wet weather flows on wastewater collection system and treatment plant capacity and operations. Potential system modifications to reduce those impacts include infiltration reduction measures, additional collection system capacity, offline storage, or additional peak wet weather treatment capacity.

1.2.11 Implement saltwater intrusion barriers and aquifer recharge

The injection of fresh water into aquifers can help to act as a barrier, while intrusion recharges groundwater resources. Injection wells are used for a variety of purposes, including: i) preventing saltwater intrusion; ii) managing groundwater supplies and iii) storing water for future use. For the use of injection well, stormwater is collected, treated, and distributed to underground aquifers by use of abandoned wells, dry wells or newly constructed wells designed specifically for this purpose (the best option for medium to large scale projects – see Appendix 1). Well-design and well-construction techniques will vary according to the specific purpose of each well (Water Solutions Inc. 2015).

1.3 Opportunities for an integrated approach

Integrated urban water management (IUWM) is an approach to aligning urban development and basin management to achieve sustainable economic, social, and environmental goals. This approach brings together water supply, sanitation, storm- and wastewater management and integrates these with land use planning and economic development. IUWM provides a framework for planning, designing, and managing urban water systems that provides stakeholders with a flexible process that responds to change that enables them to predict the impacts of interventions. IUWM includes environmental, economic, social, technical, and political aspects of water management that brings together fresh water, wastewater, storm water, and solid waste. This approach enables better management of water quantity and quality. Aligning urban development with basin management to ensure sustainable economic, social, and environmental relations along the urban-rural continuum. This will allow urban water planners to shift from being resource users to resource managers, change their consumption patterns, waste management, and planning to better balance resource flows to and from cities. IUWM principles encompasses the following: i) alternative water sources; ii) matching of water quality with various water uses; iii) integration of water storage, distribution, treatment, recycling, and disposal; iv) protect, conserve and exploit water resources at their source; v) account for non-urban users, community groups etc.; vi) recognise and seek to align formal and informal institutions and practices; vii) recognise relationships among water, land use, and energy; viii) pursue efficiency, equity and sustainability; and ix) encourages participation by all stakeholders (GWP, 2013).

Integrated Water Resources Management (IWRM) and Policy

Water scarcity is an issue in a number of countries, and this is expected to intensify going forward. Increasing water scarcity due to unaccounted water in the distribution system is an issue in some countries, and there is, therefore, an urgent need in the Community and its Member States to substantially increase water-use efficiency (WUE) across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity. There is also an urgent need to implement IWRM at all levels including, inter alia, the protection and where necessary, the restoration of water-related ecosystems such as mountains, forests, wetlands, rivers, aquifers, and lake as well as the building of capacity to implement water harvesting, desalination. All existing Policy Frameworks are intimately linked in some manner to the environmental and natural resources base. (CaribInvest Ltd, 2017).

Good water management includes policies that present a broad, integrative vision of the contribution that good water management can make to national development. The development of master plans for sectors and for water resources and services, providing a long-term national planning perspective, represents an expression of how water policy goals are to be translated into action (Cashman, 2012). A key requirement of IWRM is the involvement of other economic and social sectors that would not normally focus directly on water issues but whose activities either have impacts on water or water has an impact on them. IWRM seeks to move away from a purely sector based to a more cross-sectoral based water management approach. It is argued that water issues need to be mainstreamed into the business of ministries of finance and national planning (GWP, 2008). IWRM is not about the government but the governance of the water sector, and hence water policy has to be more than the role of government. One of the tasks of government is therefore, to facilitate and encourage economic development by providing an enabling environment and access to infrastructure. Political commitment is needed to advance the implementation of an IWRM agenda, and this can only come about by water sector professionals communicating more clearly and establishing the consequences of not doing so in terms that will resonate with politicians and policy-makers (Cashman, 2012).

1.4 Nature-based solutions to water distribution and infrastructure

Nature-based solutions (NbS) or ‘green’ infrastructure, as opposed to traditional ‘grey’ infrastructure, focuses on environmental engineering rather than civil engineering to improve the management of water resources and in doing so, preserving the functions of ecosystems, both natural and built. Green infrastructure can help reduce pressures on land use while limiting pollution, soil erosion and water requirements by contributing to the development of more effective and economic irrigation systems. NBS recognize water not as an isolated element, but as an integral part of a complex natural process that involves evaporation, precipitation, and the absorption of water through the soil. The presence and extent of vegetation such as grasslands, wetlands and forests influence the water cycle and can be the focus for actions to improve the quantity and quality of available water. Examples of the use of this technology includes New York City which has been protecting its three largest watersheds since the late 1990s. Disposing of the largest unfiltered water supply in the USA, the city now saves more than US$ 300 million yearly on water treatment and maintenance costs. Another example is that of China which recently initiated a project entitled “Sponge City” to improve water availability in urban settlements. The goal is to recycle 70% of rainwater through greater soil permeation, retention and storage, water purification and the restoration of adjacent wetlands (UN water, 2018).

The use of NbS in Latin America and the Caribbean was investigated by Watkins et. al. (2019) and these following are some key findings which could help guide the adaptative protocols for water distribution and infrastructure.

1.4.1 Mainstreaming NbS into policy, legislation, and regulations

The use of NbS is typically not represented in most policy frameworks and ministries and departments associated with management and governance of natural capital (e.g., environment) are commonly separated from those responsible for major economic functions and sectors (e.g. planning, transportation, energy, and agriculture).

Recommendations to address this include i) enhancing capacity to integrate NbS into decision making by raising awareness within ministries responsible for planning, financing, and implementing infrastructure projects; ii) Integrating NbS into infrastructure planning and procurement processes. Integrating NbS into the early stages of the decision-making process for infrastructure projects.

1.4.2 Training to provide additional skills, methodologies, tools, and capacity to incorporate NbS into infrastructure projects

NbS must be considered and integrated from the pre-planning stages to be successful. Different skillsets will be required at different stages of infrastructure project development (e.g., planning, design, financing, operations, and maintenance).

1.4.3 Developing business case to build support and secure finance for NbS projects

Creating and disseminating cost-benefit analyses and financial models that illustrate the business case for NbS investment over appropriate time and geographic scales.

There is a need to build on local knowledge in NbS. The application of NbS in Caribbean SIDS to develop appropriate context-specific options based on local and external knowledge have been applied in Haiti and Belize. Many local level projects implemented by donors and their local partners stress the need to incorporate local knowledge into project activities and as a result, increased attention is being paid to local knowledge and the need to integrate this with external knowledge (Mercer et al., 2012).

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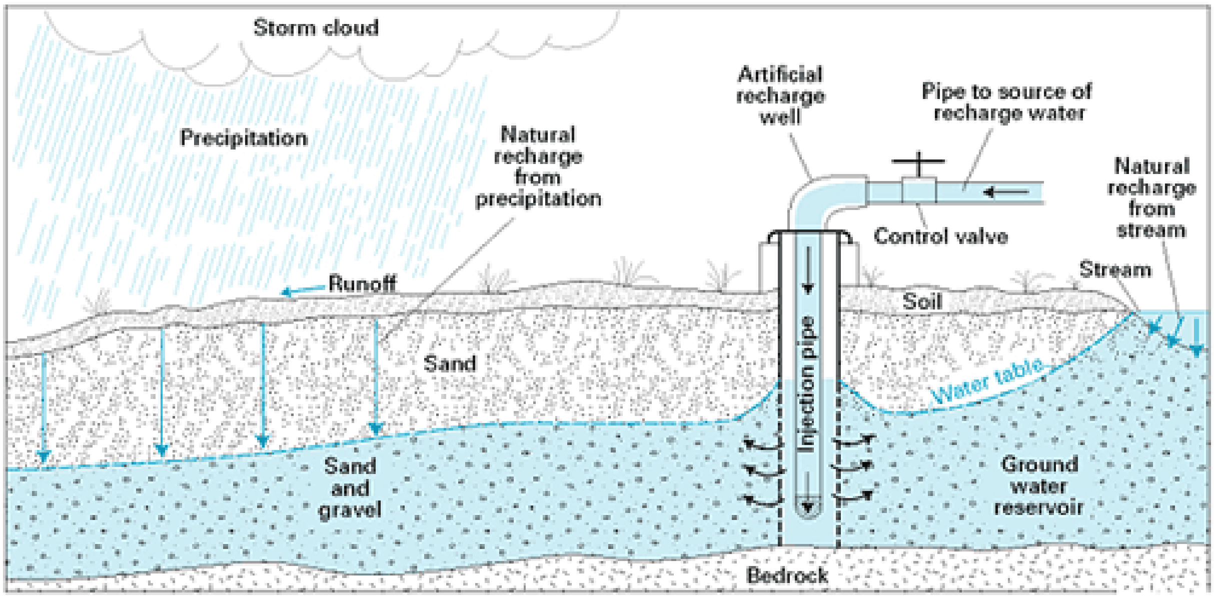
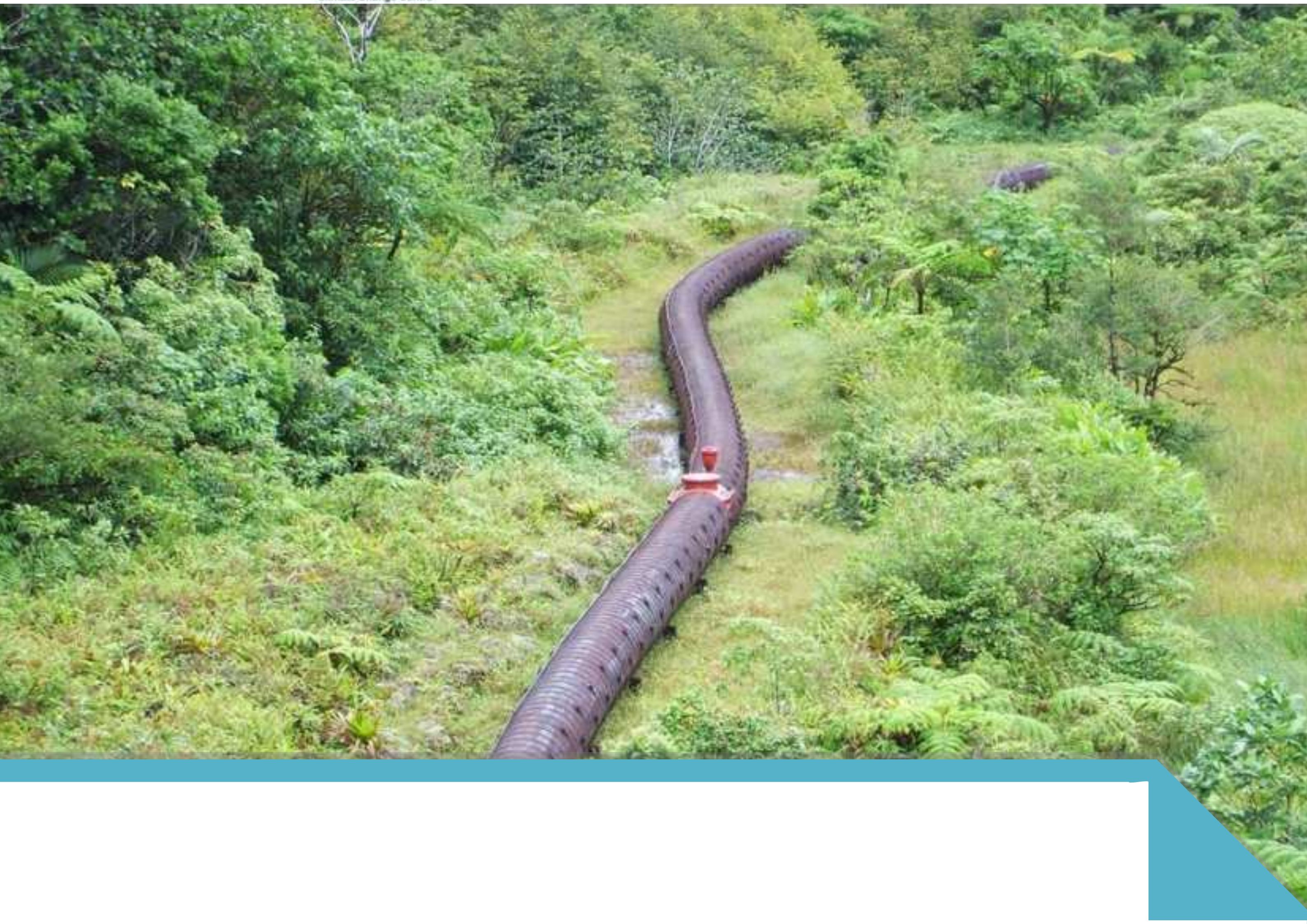
2 APPENDICES

2.1 Artificial Groundwater Recharge by use of injection well

Source: https://usgs.gov





Regional SOPs for Climate Resilient Water Infrastructure

KAP 6:

DATA COLLECTION

EU-GCCA/SER/006

May 2021

Ref R2390

Developing Standard Operating Procedures (SOPs) for
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LIST OF ACRONYMS

Acronym	In Full
CARIFORUM	Caribbean Community Forum
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
COPERNICUS	previously known as GMES (Global Monitoring for Environment and Security)
ESRI	Environmental Systems Research Institute
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food and Agricultural Organization
GEOSS	Global Earth Observation System of Systems
GSM	Global System for Mobile Communication
HYCOS	Hydrological Cycle Observing System
HYPE	Dynamic rainfall–runoff model which describes the hydrological processes at the catchment scale
SDG	Sustainable Development Goal
UNOSAT	UNITAR's Operational Satellite Applications Programme
WMO	World Meteorological Organization
WRA	Water Resources Authority
WEAP	Water Evaluation and Allocation Planning

EXECUTIVE SUMMARY

Adequate collection of data forms the foundation that enables informed planning and decision making for climate resilient infrastructure. Data collection enables us to quantify and track climate change impacts as well as predict them. Water utilities collect a range of data in their daily operations, such as production volumes, while other entities and sectors collect their own data, such as rainfall and evapotranspiration. Data sharing between entities is often not formalised, in the absence of a central body such as a dedicated water resources regulator. These protocols give an overview of types of data to be collected as well as the quality criteria, to enable integrated decision making approach as well as hydrological modelling for future development scenario evaluation. The advent of remote sensing and satellite-based data opens doors for applications that were previously not possible due to the prohibitive cost of gathering the data on-site.

Water sampling for drinking water production is covered in the Key Adaptive Protocol on Water Sampling and Testing.

1 KEY ADAPTATIVE PROTOCOL: DATA COLLECTION

1.1 General considerations for the formulation of a protocol

1.1.1 General context and climate impacts

The ultimate goal of data collection in hydrology, be it precipitation measurements, water-level recordings, discharge gauging, groundwater monitoring or water quality sampling, is to provide a set of sufficient good quality data that can be used in decision-making in all aspects of water resources management (WMO, n.d.). Decisions may be made directly from raw data measurements or based on derived statistics or the results of modelling, but it is the collected data that form the basis for these decisions. Data sets are of great intrinsic value as they are collected through a huge commitment of human and financial resources and often during a long period of time.

The collection of hydrological data is an important task which must be performed effectively, in order to maximize the investments, put in data collection and the possibility of data being effectively used downstream by planners and decision makers. Annex 1 provides a template for hydrological data collection and management processes.

Adequate data collection and analysis allows for planning and decision making for current and future conditions, especially planning for the impacts of climate change thereby increasing climate resilience. Ultimately, collection of data enables us to quantify and track climate change impacts as well as predict them. Appropriate data collection and analysis is also a prerequisite for designing and implementing Nature-based Solutions, as well as monitoring their impact after implementation, such as reduced turbidity after precipitation events or higher groundwater levels.

1.2 Recommendations and best practices

1.2.1 Framework

1.2.1.1 Integrating data collection into the integrated water resources management (IWRM) approach

The availability of data forms the basis for the capacity for informed decision making. Without a clear view of the water balance (in- and outputs, such as precipitation and groundwater abstractions), long-term planning is hampered. Relevant data for a comprehensive IWRM approach can span from social to economic (regarding water uses) and from ecological to hydrological data (regarding water resources). These protocols are focused on the type of data usually gathered in the context of operation of a water utility.

1.2.1.2 Digitization

Data value resides in their easy use for producing analysis, forecasts and other information products: computer based software for undertaking these activities makes it necessary that data sets be available in such a form. Digitization of measuring stations such as weather stations and streamflow gauges such as WMO/HYCOS ones, results in lower operating costs and enables data collection also under extreme weather. A good station should continue collecting quality data without interruption. The main guiding principle is to ensure that the data collected at a station remain relevant to present and future needs of water resources management and development.

Digitization of existing analogue (e.g. paper) data preserves the data through avoiding physical deterioration through for example humidity, while making the data sets that have been collected accessible for use in digital analysis tools.

1.2.1.3 Data Sharing

Water observation data is fundamental to our understanding of water resources and their spatial and temporal variability. Water resource management around the world is often highly distributed with many organisations typically involved in the collection and management of water-related data, even within single countries. In addition, geographic features such as river basins and aquifers generally do not align with the boundaries of nation states and 90% of people live in countries that share transboundary hydrological features with their neighbours. As a result, to understand water resources within basins or aquifers, hydrological data sharing both within and between countries is usually required.

However, there are still steps to be made in most CARIFORUM countries with regards to data sharing or centralised data collection. For example, in the Bahamas each sector would collect their own data. While there is a move towards consolidation, the legislative framework with one central managing body for water resources is still in its infancy stages, with the Department of Planning and Protection having been implemented only in 2021.

Successful consolidation, centralised data collection, or data sharing structures are mutually beneficial to all data-dependent agencies. To this end, the various water institutions in a country need to develop sampling and data collection protocols and standards. After establishing the collection mandates of each entity, areas of overlap and gaps can be identified, which enables efficient use of monitoring resources. Appropriate data management systems can then be identified that facilitate data sharing between institutions, by streamlining the data formats used between institutions.

The collected information can be disseminated between the stakeholders in different ways. For example, over the last 100 years a hydrological yearbook has been published in Italy, featuring data such as temperature, precipitation, river water levels, groundwater levels, and water balances, collected by the respective institutions (water regulator, meteorological office, etc.). All these data are published digitally after a validation process and represent the official hydrological-hydraulic reference data available for the country (WMO, n.d.).

Special consideration needs to be given to international data sharing with regards transboundary waters, such as aquifers and rivers. Transboundary data sharing is widely recognised as a necessary element in the successful handling of water-related climate change issues, as it is a means towards integrated water resources management (IWRM). Sustainable Development Goal 6 has a specific indicator related to transboundary water management[1] (SDG 6.5.1), highlighting its importance, as lack of data sharing poses a risk for overexploitation of water in upstream areas. Data sharing can only happen in the context of robust transboundary cooperation. To this end, the SDG states a joint body needs to be established, with regular, formal communication between

[1] Indicator 6.5.2 “Proportion of transboundary basin area with an operational arrangement for water cooperation” tracks the percentage of transboundary basin area within a country that has an operational arrangement for water cooperation. An arrangement for water cooperation is a bilateral or multilateral treaty, convention, agreement or other formal arrangement between riparian countries that provides a framework for cooperation.

partner countries, joint management plans or objectives, which then enables regular exchange of data and information, commonly compiled by relevant national line ministries and institutions (e.g. for Water, Environment, Natural Resources, Hydrology, Geology).

1.2.2 Meteorological Data

Precipitation data is the foundation for understanding availability of water resources – it is usually the main input of water into the system. For any prediction and modelling purposes, multiple decades of precipitation data are needed, as well as evapotranspiration data for any hydrological modelling that includes rainfall-runoff processes. There are four main ways of collecting rainfall data, namely:

1. Non-recording gauges, which includes standard rain gauges, and storage gauges;
2. Recording gauges that include tipping bucket or autographic gauges;
3. Radar gauges; and
4. Satellite rainfall estimates, and the transmission of rainfall data in real or near real time.

The most used is the manual or standard rain gauge. A network of rainfall stations needs to be created to improve accuracy and reliability. Rainfall data is used in the establishment of the rainfall-runoff relationship and the estimation of rainfall intensity which is critical in the design of storm water drains. Rainfall stations often also include measurement tools for temperature, humidity and wind speed.

Evaporation is measured from evaporation pans that have a hook or ruler to measure the loss or gain of water in the pan (see Figure 1). It can also be estimated from other parameters such as sunshine, solar radiation, wind and air temperature. These instruments are usually combined in an automatic weather station, which normally have a logger and the capability to transmit data. Evaporation is important in the estimation of how much water is lost from open water surfaces or transpired from vegetation.

Figure 1. Evaporation pan

Image source: Wikimedia

It is important to establish evaporation measurements in the different climatic regions that might occur within a country, especially where irrigated agriculture is prevalent. For example, an evaporation pan on the windward side of an island will not always give accurate data for calculating crop irrigation demand on the leeward side.

1.2.3 Surface Water

Surface water data collection includes the collection of water level (stage), flow and often meteorological data for the estimation of the surface water resources potential. Surface water data can consist of river or spring flows and quality, sediment load and pond/lake level and quality measurements.

River flows are measured at hydrometric stations. These stations measures the water level (stage), sediment load, water quality, sometimes combined with a meteorological station. Ideally, discharge measurements are supposed to be made continuously at each station. However, due to resource limitations this is often not feasible. Instead, a good frequency of stage data is collected at least once a day to get daily flows. There are many methods of stage measurement, including:

- Manual readings of a staff gauge by a gauge reader;
- Data loggers that collect stage and other parameters using probes and record or save them electronically for later down loading or for transmitting by different methods like satellite, GSM, GPRS and radio.

Discharge measurement is one of the key activities in surface water assessment. It helps to determine the response of the basin to rainfall. Ideally, this should be done continuously, but in practice this is not feasible. In order to have a reasonable understanding of the available water at a station, occasional manual (by wading or boat) discharge measurements and the stage at the time of the measurement are required. A stage-discharge relationship is then developed for the particular station, called a rating curve.

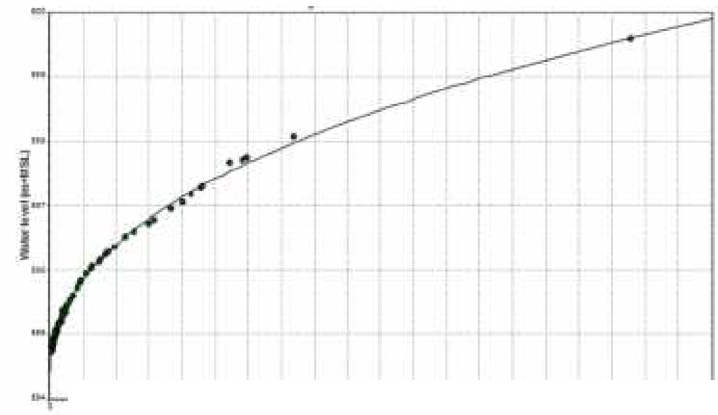

Figure 2. Example of a typical simple rating curve

A rating curve is a tool used to establish a stage-discharge relationship, allowing conversion from measured water levels to associated river discharge. It consists of a graphic plot of stage on the y-axis and discharge on the x-axis (see Figure 2). To define this relationship, a hydrologist must take into account the reach of the river, the characteristics of the hydrometric station, the water level series and discharge measurements which are often available in different quantities and quality. Rating curves depend on the channel shape and size – thus, in a river with significant sediment loads (e.g. due to soil erosion) the channel shape can change significantly over the course of a few years, impacting the accuracy of the rating curve and thus the calculated river discharge. It is therefore imperative that in highly dynamic rivers, stations' rating curves are regularly checked and updated, by mapping the river bed, as well as redoing discharge measurements.

Image source: Braca, 2008

Monitoring of the marine environment and offshore waters, especially water quality, is part of surface water monitoring, targeting coral reefs, bathing waters and offshore oil and gas industry. Water quality sampling including sampling data analysis protocol is covered in the Key Adaptive Protocol on Water Sampling and Testing.

CASE STUDY: SURFACE WATER MONITORING IN JAMAICA AND GUYANA

An example of water resources monitoring in the Caribbean can be found on the Water Resources Authority (WRA) Jamaica website. They routinely monitor streamflow at 133 river gauging stations. Daily flows are recorded by approximately 100 fully automatic gauges and 33 manual river gauging stations. Automatic gauges are housed in pipe wells and stilling wells.

In Guyana, there is an existing surface water network, Automatic Weather Stations and a water quality laboratory. However, there are limitations in the number of trained and competent personnel to implement monitoring and maintain these networks, as well as further develop and validate hydrological models. This poses challenges to the consistency in the data collected, as manual recordings and GSM based water-level loggers have been used to record water data.

CASE STUDY: DATA COLLECTION DURING EXTREME EVENTS IN SAINT VINCENT AND THE GRENADINES

The La Soufrière volcano eruption in early April 2021 had large impacts on the water supply of Saint Vincent and the Grenadines, as 13,000 persons were evacuated and relocated to safe zones. In response to the pressure on the WASH systems in the shelters, an assessment form – soon to be app – was developed, enabling 8 groups of data collectors to assess 85 shelters.

In addition, pictures taken during the event could be used as resource materials for dialogue among utilities and communities. It could enable utilities get information on challenges and how to time solutions properly. For example, tanks usually overflow at night and residents can take their photos in the night, while utility staff might be off-duty. However, some people might be hesitant to provide flooding pictures of their homes as they feel this might affect the property value.

1.2.4 Groundwater

The objective of groundwater monitoring is to measure inputs to the groundwater systems, which is mostly recharge from rainfall, and to measure the changes in storage in the main aquifer systems and to determine the outputs (e.g., in form of baseflow and water abstractions), in order to obtain an estimate of the water budget of the aquifers. The monitoring can be done using manual measurements of water level fluctuations and/or automatic recorders set to measure water levels at specific intervals (Karen et al. 2017). In order to be representative, data should cover at least two years, which must not be years of extreme hydrological conditions.

Typically, the following parameters are monitored:

- Water level
- Water quality
    - Physical parameter
    - Chemical parameters
    - Biological parameters
    - Location
    - Type of water point
- Aquifer characteristics
- Record of boreholes construction and other details

The purpose of the monitoring must be clear from the beginning. Unlike with rainfall monitoring, it is less efficient to cover the area with a grid network of groundwater monitoring stations. Monitoring should concentrate on the aquifers of interest or those under specific threats. The number and type of monitoring boreholes must be defined accordingly. One monitoring borehole in an aquifer is likely to be insufficient. It is only with two or more boreholes that the analysis of flow conditions in an aquifer is possible. Regarding water quality, it makes also sense to locate monitoring upstream and downstream of potential threats. The importance of an aquifer also determines the effort needed for monitoring. While crucial aquifers should be monitored with automatic records, for others manual measurements twice a year might suffice.

CASE STUDY: GROUNDWATER MONITORING IN JAMAICA AND GUYANA

The Water Resources Authority monitors groundwater levels at 320 well sites throughout Jamaica.

Wells are measured monthly by technicians and these includes, pumping wells, non-pumping wells and small diameter core holes. Records are also kept of underground water levels and water abstractions. Long term underground (non-pumping) water level data is used to establish general flow directions of underground water.

In Guyana, there is no groundwater monitoring network or system currently in place, but there is ongoing work towards the development of a roadmap for groundwater monitoring and identification of groundwater wells across the country to determine the current state of the country's aquifers. However, as mentioned under surface water monitoring, there are staff resource limitations, while in addition, there is a lack of infrastructure for groundwater monitoring and limited financial resources for newer technologies to improve data collection such as through telemetry.

1.2.5 Water Resources Use (irrigation, industry, mines, domestic, tourism)

A key metric in daily operation of a water utility is the flow rates for production and distribution, as well as consumption data of those customers that are metered. The difference between distribution and metered water use is the Non-Revenue Water, which can consist of losses due to leakages as well as theft and metering inaccuracies.

However, often there is unmetered water use, often water users that have their own water source, such as private boreholes. This is in particular the case for agriculture. In some areas, groundwater will be or already is affected by overpumping, causing salinization of the freshwater lens which requires costly treatment. For the purpose of groundwater management at the basin scale, the natural input of baseflow from the aquifer needs to be quantified. Therefore, also the rates of abstraction have to be monitored and it is advisable to establish mandatory flow meters on private boreholes.

To enable long-term planning as well as scenario modelling for example using a Water Evaluation and Allocation Planning (WEAP) Model, comprehensive water use data needs to be available for each economic sector. The water use data needs to:

- Ideally cover a few years of usage data to account for any dry years
- Be reported on at least monthly level – ideally daily or biweekly
- Contain information whether the water source for that user is surface or groundwater
- Contain location data for the abstraction points, i.e. where the water is actually taken from, rather than the location of the water user – for surface water this is the location of the intake point, for groundwater this is the borehole.

1.2.6 Remote Sensing

The paucity and often poor quality of information on water resources required for IWRM is a key limitation for informed decision making and planning. However, with the advent of satellite-based data sets, analyses can be made even in the absence of local on-the-ground monitoring stations, or to bridge historical gaps in measurements. The range of information available from global datasets is staggering; base mapping, water cycle monitoring (seasonal and long-term), land cover use and change, wetland identification, wetlands typology mapping, Digital Elevation Models – drainage networks, terrain dynamics (subsidence), coastal dynamics monitoring, urban mapping and cartography for sanitation services, and biophysical parameters such as water quality (turbidity), evapotranspiration, water temperature, and precipitation (Fusco, n.d.). There are many datasets that are available for free (such as through Google Earth Engine[2], HYPE[3], GEOSS Portal[4], UNOSAT Flood[5], ESRI Living Atlas[6], COPERNICUS[7], Global Forest Watch[8]. FAO WaPOR[9], as well as all data from the US governmental bodies[10]) or for a nominal fee (such as EUMETSAT[11], where a dongle is approx. 200 Euro and provides access to a variety of useful products such as H-SAF precipitation products[12])

These datasets, when used by trained personnel, can be used for a range of applications, such as estimation of groundwater abstraction, mapping of crop types and irrigated areas, evaluation of land cover change (such as headwater/recharge zone deterioration), saving time and resources on labour-intensive field work. The quality of these datasets continues to improve, however, it is still necessary to cross-check the remote sensing data with on-the-ground measured data whenever possible, for example, precipitation from the global CHIRPS dataset[13] with rainfall gauge data on the ground, to find any systemic errors. Notwithstanding the need for validation, the increasing availability and quality of remote sensing datasets open up doors for water utilities in their operational planning for low effort and cost.

1.2.7 Future Projections

The data described above enables the setup of a water balance model such as in WEAP, reflecting the situation as it is currently. This model is used to account for 'current day' water use and can be used to identify the amount of water that can be used for allocation under present day conditions.

However, to enable water balance and demand modelling to explore different future development scenarios including climate change impacts, in addition to the above data, the following data is needed:

- Information on growth of water use for each sector (e.g. domestic) – this can be based on projected population growth figures or economic expansion activities. This includes information on expected changes in per unit water use within sectors, such as per capita water use due to development, or agricultural water use due to irrigation efficiency.
- Information on the specific impacts of climate change on the hydrological regime – the key information needed is the expected change in precipitation, with monthly adjustment values or exceedance curves, for one or more climate scenarios.

This additional information allows the setup and exploration of the effects of climate change and future development. Different development pathways need to be established (through stakeholder consultation), for example, different levels of expansion of irrigated agriculture. Together with the climate change impacts on the hydrology, a suite of scenarios can be made from these combinations and subsequently entered and run in the model. Comparing the outcomes of these

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[2] Requires training. https://earthengine.google.com/
[3] https://hypeweb.smhi.se/explore-water/geographical-domains/#wwh
[4] https://www.geoportal.org
[5] http://floods.unosat.org/geoportal/catalog/main/home.page
[6] https://livingatlas.arcgis.com/en/browse/#d=2&type=maps&rgnCode=WO with products such as monthly soil moisture, evapotranspiration, precipitation (sourced from NASA) and land cover (sourced from BaseVue)
[7] Such as https://land.copernicus.eu/global/products/lc
[8] https://www.globalforestwatch.org/map/
[9] https://wapor.apps.fao.org/home/WAPOR_2/
[10] Such as: https://www.usgs.gov/products
[11] https://www.eumetsat.int/website/home/index.html
[12] http://hsaf.meteoam.it/Products/ProductsList?type=precipitation
[13] Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 35+ year quasi-global rainfall data set. Spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery, and in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. https://climateserv.servirglobal.net/

scenarios with the current day 'baseline' outcomes, allows for quantification of the different impacts of climate change and development on the availability of water for different water users.

Through the implementation of robust data collection protocols which enable the validation of such models, countries would gain an advantage in understanding the current situation on water quality and quantity, model for future scenarios, and be able to better engage funding for planning, especially in regard to the risks of climate change and integrated water resources management.

CASE STUDY: WATER RESOURCES MODELLING IN GRENADA

The Water Resources Management unit of the Ministry of Agriculture in Grenada runs the water balance model WEAP to assess the impacts of climate change. They perform analysis of occurrence on rainfall data to get long term series and typical years. The model is used to determine safe yield for certain years to assess what can be done with the available supply.

A rough analysis of the climate change impacts shows a continuous drought development which is worsening, but difficult to quantify. Typically, a drought event that occurred once in ten years, now occurs once in 7 years. There is a need to forecast to 2050 and be able to quantify how much more water would be needed than today. However, the data needed for this forecasting is not available. It is identified that the work of CIMH is key to climate outlook forecasting.

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2 APPENDICES

2.1 Data Management Process