INTEGRATED SUSTAINABILITY

Conceptual Design Report

Consultancy to Produce Requisite Design, Studies and Plans – The 3R's for Climate Resilience Wastewater Systems in Barbados (3R Crew Barbados) Preparation Project

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Caribbean Community Climate Change Centre (CCCCC)

Caribbean Community
Climate Change Centre

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Any questions concerning the information, or its interpretation should be directed to Nick St-Georges.

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
3R's	Reduce, Reuse and Recycle
A^2O	Anaerobic/Anoxic/Aerobic
AAF	Average Annual Flow
AD	Anaerobic Digestion
ADWF	Average Dry Weather Flow
AN	Anaerobic
AR	Aerobic
AS	Activated Sludge (Suspended Growth Wastewater Treatment Process)
ASTM	American Society for Testing and Materials
AX	Anoxic
BBD	Barbadian Dollars
BMP	Biomethane Potential
BNR	Biological Nutrient Removal
BOD or BOD_5	5-Day Biochemical Oxygen Demand
BSTP	Bridgetown Sewage Treatment Plant
BTU	British Thermal Units
BTU/lb	British Thermal Units Per Pound
BWA	Barbados Water Authority
BWRO	Brackish Water Reverse Osmosis
CAD	Conventional Anaerobic Digestion
CAS	Conventional Activated Sludge
$CBOD_5$	5-Day Carbonaceous Biochemical Oxygen Demand
CCCCC	Caribbean Community Climate Change Centre
CFU	Colony Forming Units (Membrane Filtration Bacteria Test)
CH_4	Methane
CHP	Combined Heat and Power
CIRS	Center for Interactive Research on Sustainability
CMMS	Computerized Maintenance Management system
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CZMU	Coastal Zone Management Unit
DI	Ductile Iron (Pipe)
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DPR	Direct Potable Reuse (*The use of reclaimed water as a raw water*
EBPR	Enhanced Biological Phosphorus Removal
E. Coli	Escherichia Coli
EC	Electroconductivity
EDC	Endocrine Disruptive Compound

EEZ	Ecological Economic Zoning
EIA	Environmental Impact Assessment
ELPA	Electric Light and Power Act
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
FAO	Food and Agriculture Organization (of the United Nations)
FAT	Full Advanced Treatment
FC	Faecal Coliforms (Indicator Bacteria)
FOG	Fats, Oils and Grease
FTC	Federal Trade Commission
GCF	Green Climate Fund
GHG	Greenhouse Gas
GOB	Government of Barbados
gpd	Gallons per Day
H_2S	Hydrogen Sulfide
HDPE	High Density Polyethylene
HRT	Hydraulic Retention Time
I&I	Inflow and Infiltration
IPR	Indirect Potable Reuse (*The intentional discharge of reclaimed*
ISO	International Organization for Standardization
kW	Kilowatt
kWel	Kilowatt Electric
KWh	Kilowatt Hours
MAFS	Ministry of Agriculture and Food Security
MBBR	Moving Bed Biofilm Reactor
MBBR-MLE	Moving Bed Biofilm Reactor – Modified Ludzack-Ettinger Configuration
MBEMA	Minister of Blue Economy and Maritime Affairs
MBR	Membrane Bioreactor
MBR-UCT	Membrane Bioreactor – University of Capetown Configuration
MEWR	Ministry of Energy and Water Resource
MENB	Ministry of Environment and National Beautification
MGD	Million Gallons per Day
Mg-N/L	Milligrams of Nitrogen per Litre
MIGD	Million Imperial Gallons per Day
MW	Megawatt
MWel	Megawatt Electric
MLD	Million Litres per Day
MLE	Modified Ludzack-Ettinger
MMF	Monthly Maximum Flow
MPN	Most Probable Number (Multiple Tube Fermentation Test)

MTIT	Ministry of Tourism and International Transport
MTWWR	Ministry of Transport, Works, and Water Resources
MoHW	Ministry of Health and Wellness
N	Nitrogen
N_2	Nitrogen gas
NH_3	Ammonia
NH_3 -N	Ammonia Expressed as Nitrogen
NH_4	Ammonium
NH_4-N	Ammonium Expressed as Nitrogen
Nitrate-N	Nitrate Nitrogen (refers to the nitrogen present which is combined in
NO_2	Nitrite
NO_3	Nitrate
NTU	Nephelometric Turbidity Unit
O_2	Oxygen Gas
O&M	Operation and Maintenance
OSH	Occupational Safety and Health
P	Phosphorus
P3	Public Private Partnership
PDWF	Peak Dry Weather Flow
PE	Population Equivalent
pH	Negative Power of the Hydrogen Concentration
PLC	Programmable Logic Controller
PPE	Personal Protection Equipment
ppm	Parts Per Million
PV	Photovoltaic
PVC	Polyvinyl Chloride
PWWF	Peak Wet Weather Flow
Q	Flow
RAS	Return Activated Sludge
RBC	Rotating Biological Contactor
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SBR	Sequential Batch Reactor
SCADA	Supervisory Control and Data Acquisition
SCSTP	South Coast Sewage Treatment Plant
SIDS	Small Island Developing States
SLR	Solids Loading Rate
SND	Simultaneous Nitrification/Denitrification
SNMP	Salt and Nutrient Management Planning
SOP	Standard Operating Procedures
SRT	Solids Retention Time
SS	Suspended Solids

SSA	Sanitation Service Authority
STP	Sewage Treatment Plant
SWPU	Solid Waste Project Unit
TAD	Thermophilic Anaerobic Digestion
TC	Total Coliform (Indicator Bacteria)
TCDPO	Town and Country Development Planning Office
TDS	Total Dissolved Solid
THM	Trihalomethanes (chlorine and organic matter reaction by-product)
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
Total-N or TN	Total Nitrogen
Total-P or TP	Total Phosphorus
TRC	Total Residual Chlorine
TS	Total Solids
TSS	Total Suspended Solids
US	United States
USGS	United States Geological Survey
UCT	University of Capetown Configuration
UF	Ultra-Filtration Membrane
UV	Ultraviolet
VS	Volatile Solids
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge Concentration
WAS-TS	Total Solids Portion of the Waste Activated Sludge Concentration
WAS-VS	Volatile Solids Portion of the Waste Activated Sludge Concentration
WEF	Water Environment Federation
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

Note:

Reclaimed Water or Reuse Water	Wastewater that has been treated so that it can be beneficially reused to satisfy a wide range of water demands that do not require potable water.

EXECUTIVE SUMMARY

The CCCCC, and the BWA, are conducting a study examining how climate change may affect wastewater management services in Barbados, and the potential impacts on the country. Wastewater management is a component of integrated water management, which considers the entire water cycle from water vapour from the ocean that precipitates over land and returns to the ocean both over and under the soil. The returning water is intercepted as surface water runoff and groundwater extraction and is applied to a variety of beneficial uses. The water picks up impurities that impede its further use and classifies it as wastewater.

This document considers how the existing wastewater collection, treatment and effluent management infrastructure may be impacted by climate change and considers climate-resilient alternative upgrade options that can mitigate the anticipated impact on groundwater resources through the production and use of reclaimed water. *The intent is not to recommend any preferred design options in this report, but rather present background information on water reclamation technologies that could be considered.*

Many climate parameters can affect wastewater infrastructure. Variables and parameters affecting wastewater assets include:

Precipitation

- Higher intensity, frequency and duration of precipitation events leading to infrastructure flooding and overflow conditions;
- Increased inflow to sewers;
- Increased likelihood and frequency of sewer flooding, overflows, and spills;
- Increased surface erosion and introduction of sediment to sewers;
- Excessive loading to wastewater sewage treatment works; and
- Surface flooding, due to intense rainfall events, can lower the efficiency and efficacy of onsite wastewater treatment systems, such as soak-away fields.

Wind

- Increased wind loading on infrastructure assets and buildings.

Temperature

- Heat waves leading to reduced water availability and higher sewage contaminant concentrations (less dilution) increased sewer related odour generation and release;
- Increased hydrogen sulphide production (resulting in increased infrastructure damage due to corrosion; and
- Increased environmental impacts of residual contaminants including nutrient impacts due to elevated receiving water temperatures.

Ocean and Geotechnical

- Increased incidents of storm surges affecting wastewater discharge and property flooding; and
- Increased soil saturation impacting geotechnical stability to support tanks and other infrastructure as well as affecting the efficiency of onsite wastewater treatment systems, such as soak-away fields in affected areas.

The approach to this study was to review and analyse available performance and climate data for the wastewater infrastructure, to verify whether there was evidence of climate related effects and develop / evaluate the feasibility of implementing mitigation measures. This report describes the general characteristics of the existing wastewater treatment and disposal technologies used in Barbados for comparison purposes, as well as alternative technologies and their ability to achieve current required wastewater quality standards for effluent discharge and reuse. The preferred technology selection will be discussed in the final deliverable, the Feasibility Study, and will require a sustainability assessment to determine an optimal configuration, taking into consideration social (requiring stakeholder input), financial, environmental and technology factors.

The previous Baseline Study collated and examined the available information for the existing wastewater management systems throughout Barbados, including the existing sewage collection systems, treatment plants and ocean discharge outfalls serving Bridgetown and the South Coast. That study observed there was insufficient wastewater flow and water quality characterization data in which to draw meaningful conclusions regarding the extent of the influence of meteorological events on wastewater flows of constituent characteristics, consequently, limiting the ability to predict the extent to which more extreme climate-change influencing events would impact the wastewater infrastructure.

After completing the Baseline Study, the GOB announced plans to award a project to relocate and upgrade the SCSTP as well as repairing sections of the associated wastewater collection system, to an out-of-country Design-Build team. Consequently, this Conceptual Design focuses primarily on the Bridgetown central wastewater collection and treatment system, along with consideration for the unsewered areas of Barbados currently served by onsite pit latrines, as well as septic tanks and soak-away fields.

Climate change induced conditions, that would be of most concern to the wastewater collection system, are those that would lead to increased inflow due to surface water entry or infiltration due to high groundwater levels. The increase in wastewater flows and hydraulic loading could have a detrimental effect on the ability to collect wastewater due to hydraulic backups and sewage overflows impacting the treatment plant, and/or effluent water quality as well as impacts on the receiving environment. Wastewater flow data obtained by the BWA for the SCSTP for 2019 indicated the relationship between the lowest point in rainfall events (during January, in the dry season) were inversely proportionate to the peak influent flows entering the plant. Similarly, the SCTSP recorded the lowest flows during the peak of the rainy season. Therefore, it appears that rainfall is not the most significant factor in determining wastewater flows within the South Coast sewage collection system. However, a storm event, in early January 2021, recorded wastewater flows at the SCSTP more than 12,000 m^3/d, which the BWA believes was due to a person or persons lifting manhole lids to drain flooded areas.

If climate change leads to more frequent major storms, including hurricanes, with greater intensity, it is reasonable to assume that the treatment plants, and associated infrastructure such as lift stations and power stations, will be negatively impacted more frequently. As recently experienced, in July 2021, when Barbados experienced its first category 1 (with sustained wind speeds between 119-153 km/h) hurricane in over 65 years, the island experienced damage to rooftops and power lines. Although the category 2 hurricane did not cause any structural damage to the treatment plant, operations staff note there were increased flows at the lift stations, but it was impossible to quantify as the flow meter at BSTP has not been functioning for some time. More intense hurricanes are expected to cause major damage to buildings and power loss, and there is a risk that both the BSTP and SCSTP could sustain critical structural damage that impacts their performance.

The BSTP has a limited amount of ground mounted solar panels that could also be impacted by a category 2, or larger, hurricane, and the BSTP is exposed to significant storm surges, associated with major storm events such as hurricanes as it is only 6m above sea level. A review of historical power consumption data for the sewage lift-stations in Bridgetown also provides evidence supporting unusual flow events occurring within the system, but with no direct correlation to wet weather. The information suggests the primary precipitation related impact on the existing sewage collection systems is likely inflow of surface water due to surface flooding near or around manholes that could be addressed through improved surface drainage, and/or locking manhole lids.

A second potential climate change impact on wastewater management is in regard to the relationship between potable water supply and wastewater management. Water Security is an emerging philosophy predicated on assessing the availability and reliability of supply sources (including treated effluent), and disposal zones as critical locations for aquifer recharge. The goal of water security risk analysis is ensuring sustained business operations and taking into consideration stakeholder, regulatory, and corporate drivers. The approach is based on identifying options and developing a strategy around these options to ensure against unanticipated interruptions that may adversely affect a project or activity. In this case, the lens of climate change is a primary focus to align the needs of future infrastructure with a new and dynamic climate and environmental baseline. Barbados is a water scarce country relying on rainfall to recharge groundwater aquifers, to provide the countries primary water source, supplemented by desalination (at the Spring Garden and Hope BWRO that currently provide approximately 25%[1] of the water) water treatment plants. The precarious balance between annual precipitation replenishing groundwater aquifers and groundwater extraction to meet growing water demands could be seriously impacted by climate change, including possible more frequent hurricanes with greater intensity.

Recent (in 2019) drought conditions and dry water well experiences underscore how easily water resources could be seriously impacted by climate change, and how important water

[1] As noted within the Baseline Report

management (including wastewater) is to the economy and public health. Thus, it would be unwise to increase the amount of wastewater that is collected by sewer, and treated, if it is only discharged to ocean, regardless of upgrades to treatment capacity and effluent quality. The current wastewater discharged through ocean outfalls could be put to beneficial use to supply water to meet non-potable water requirements and thereby reduce potable water demands.

With the use of advanced wastewater treatment techniques, the climate proofing of the current physical infrastructure will ensure the wastewater treatment technologies employed by the BWA are climate resilient and serve as an example for other Caribbean countries. It is expected the project will reduce GHG emissions resulting from the proposed renewable energy upgrades noted in this document. The existing central treatment plant upgrades include consideration for harnessing the energy within the wastewater influent and solar energy. This will promote the circular approach to "reduce use, treat, reuse and recycle" wastewater which also contributes to climate change resilience.

Many global water stressed communities have been relying on wastewater as a water source for many decades to address drought conditions and reusing, or recycling, this water for non-potable water applications, and even indirect and direct potable water use. There are an increasing number of communities that treat their wastewater twice, with the second level of treatment being designed to reliably treat to a potable water standard. The treated reuse water is then blended with raw water supplies to be co-treated to produce drinking water. The existing Spring Garden BWRO desalination plant could potentially be used to recycle treated wastewater from an upgraded BSTP to supplement groundwater being used to produce drinking water.

Extending the concept of a central wastewater collection and treatment system to serve all of Barbados and reclaim the wastewater for reuse is considered to be too expensive to be a practical consideration. However, at the time of writing this report, the BWA and the GOB are considering constructing small-scale (cluster) wastewater collection and treatment systems in sensitive groundwater protection zones (Zone A - Exclusion Zones) and treat the wastewater to an acceptable quality for agricultural irrigation.

Onsite wastewater disposal to ground is the most common form of wastewater management in Barbados and is less likely to be impacted by major storm events associated with climate change than the centralized treatment facilities. Increasing rainfall intensity and duration can saturate surface soils, resulting in reduced treatment and increased contaminant contributions to groundwater. The onsite systems have a number of positive attributes including contributing to groundwater resources with little to no energy consumption and minimal capital and operating cost. However, on the negative side, these wastewater disposal systems are believed to negatively impact groundwater quality along the coastline and contribute to nitrogen loading to the ocean.

The most logical and cost-effective approach would be to maintain the status quo for onsite and centralized wastewater management, upgrade the level of treatment for the existing two centralized wastewater treatment systems (i.e. BSTP and SCSP) so that the treated water can be beneficially reused, and to provide cluster wastewater collection and reuse treatment systems for specific decentralized populated areas of Barbados with a high potential to impact ground water quality (such as Zone A locations).

Three reuse water quality upgrade technologies are considered for conversion application to the existing centralized treatment facilities to support a climate resilient wastewater sector through the provision of additional water resources for the public. These three proposed upgrades represent a broad range of biological treatment technologies using either suspended or attached-growth bacteria as well as consideration for energy and nutrient resource recovery. The three centralized treatment process upgrades include: (1) a CAS process with a plug-flow configuration without nutrient recovery capacity, (2) a MBBR-MLE attached-growth process with nitrogen removal capacity, and (3) an MBR-UCT suspended-growth process with both nitrogen and phosphorus removal and recovery capacities. While all three technologies considered can achieve similar effluent qualities for reclaimed water reuse, and energy recovery purposes, the biological nutrient removal capabilities of the MBBR-MLE and MBR-UCT processes make them also amenable to nutrient recovery. Several factors are considered when comparing the treatment technologies and include capital and operating costs, in addition to the economic benefits associated with resource recovery related to water reclamation, renewable energy, nutrient recovery and residuals management, in addition to minimizing GHG emissions.

The recovery of bioenergy and fertilizers at a decentralized onsite treatment plant is impractical (due to lack of quantities), however the solids and nutrients, associated with septage and waste biomass, could be collected from multiple sources and transported to a central facility for energy and nutrient recovery along with organic food wastes.

Considering the current dynamic climate change conditions experienced, it is not only important to propose infrastructure upgrades as discussed, but also consider the ability of BWA operations staff to operate and maintain wastewater infrastructure modifications that are proposed to address climate change. The shift in maintenance focus from emergency breakdown maintenance to preventative maintenance (PM) will be of particular benefit to preparing for and adapting to climate change impacts on both the two centralized collection and treatment systems, as well as extending the life cycle of the equipment and help to reduce breakdown maintenance that can come with a high financial and environmental cost. Recommendations are made to support a maintenance training programme that includes heightened awareness of the impacts of climate change on infrastructure and operational measures to mitigate these impacts. Of particular importance in planning for climate change impacts is establishing a robust operations information database in the form of a CMMS, potentially through a pilot program, to establish a core electronic data collection, operation, and maintenance programme. Recognizing that valuable hard-copy data was destroyed by fire in the past, an electronic CMMS information system will enable important information to be stored and readily accessed for analysis, and will be less susceptible to potential damage from fires or storm events associated with climate change.

In addition to the climate resilience built into the wastewater systems and water sector, this project is expected to deliver positive social, economic, and environmental impacts expected, that should be further identified within the concurrent ESIA and ESMP project (produced by others). For example, the significant construction efforts associated with this project could stimulate the country's economy, if the work is mostly awarded to local consultants and contractors. Other positive economic impacts include potential cost savings to farmers using reclaimed water and reducing the amount of treated wastewater and residual constituents discharged to the ocean.

A risk assessment is also included within this report that considers risks associated with: Climate Risks; Technical Risks; Environmental Risks; Public Health Risks; Baseline Data Risks; Stakeholder Risks; and Institutional Risks. The concept of risk assessment is founded on the principles of identification and management of risks and opportunities over time. The approach used to outline a conceptual risk assessment for this project focuses on the development of a robust identification, evaluation, and mitigation plan to address risks to the availability and reliability of wastewater treatment and supply of valuable by-products. This included treated effluent, recoverable energy and biosolids, as well as liquid waste disposal to meet current and future needs. Several key risks and associated opportunities are identified that may influence the security of wastewater management, including disposal, and water supply in Barbados. A risk identification and evaluation methodology are proposed to qualify and quantify how the risks affect the viability of infrastructure and the community investment manifested therein. Risk levels are calculated based on severity of consequence and likelihood of occurrence. The risk analysis methodology proposed identify current mitigation strategies and qualify the effectiveness of those controls. For risks that remain unacceptable with current controls, additional mitigation measures are identified, and monitored for effectiveness. These risks are also captured in the LogFrame (presented in the Appendix) that was produced as a draft outcome of the Conceptual Report preparation process, taking into consideration stakeholder engagement responses to the concepts and proposed outcomes described in this report.

Gender-sensitive development improvements are also expected from this project and will be further outlined within the Gender Analysis report, that is to be completed separately from this report. Similarly, a Stakeholder Engagement Report has been developed separately that outlines the various stakeholder involvement in the design process related to this project.

Beside the climate resilience built into the wastewater system and water sector, improved health, safety and sanitation, through this project, will be provided in the form of upgraded sanitation practices for the country and through the utilization of safe technologies to promote the movement towards internationally recognized standards for the OSH of workers.

1 BACKGROUND

1.1 Wastewater & Climate Change

The purpose of this report is to consider mitigative measures to address how climate change may affect water and wastewater services in Barbados. More specifically, this report examines the potential impact of climate change, as outlined within the Risk Framework included in Appendix 2, on wastewater management related to the BSTP, and its associated wastewater collection and disposal system and onsite decentralized wastewater management and disposal practices that are used by the majority of families and businesses in Barbados. The overall intent is to develop climate-resilient and sustainable wastewater management and upgrading that take into consideration resource recovery, renewable energy, and greenhouse gas emissions.

Many climate parameters can affect wastewater infrastructure. variables and parameters affecting wastewater assets include:

Precipitation

- Higher intensity, frequency and duration of precipitation events leading to infrastructure flooding and overflow conditions;
- Increased inflow to sewers;
- Increased likelihood and frequency of sewer flooding, overflows and spills;
- Increased surface erosion and introduction of sediment to sewers;
- Excessive loading to wastewater sewage treatment works; and
- Surface flooding, due to intense rainfall events, can lower the efficiency and efficacy of onsite wastewater treatment systems, such as soak-away fields.

Wind

- Increased wind loading on infrastructure assets and buildings.

Temperature

- Heat waves leading to reduced water availability and higher sewage contaminant concentrations (less dilution) increased sewer related odour generation and release;
- Increased hydrogen sulphide production (resulting in increased infrastructure damage due to corrosion; and
- Increased environmental impacts of residual contaminants including nutrient impacts due to elevated receiving water temperatures.

Ocean and Geotechnical

- Increased incidents of storm surges affecting wastewater discharge and property flooding; and
- Increased soil saturation impacting geotechnical stability to support tanks and other infrastructure as well as affecting the efficiency of onsite wastewater treatment systems, such as soak-away fields in affected areas.

Considering the water scarce conditions that exist in Barbados, wastewater management strategies that return or recycle extracted groundwater back to the ground are critical sustainability considerations. Equally important is the potential for reclaimed wastewater to be reused to satisfy water demands that do not require potable (drinkable) water, thereby, reducing the amount of groundwater that needs to be extracted to satisfy those demands.

1.2 Groundwater & Climate Change

As noted in the Baseline Study, Barbados depends primarily on annual rainfall to replenish and recharge groundwater resources that are extracted as a primary potable water source. Even without consideration for recent atmospheric changes and wide climate change swings, rainfall records, as outlined in Section 3.1 of the Baseline Study, show the island is subject to significant periods of drought and other climate events that have caused flooding and damage to infrastructure. This damage to infrastructure has become increasingly critical as the island's population plateaus and tourism increases. Climate change is expected to cause additional fluctuations to the amount of rainfall, as well as impact the intensity and duration of rainfall events. In turn, this will affect groundwater resources and may contribute to flooding and infrastructure damage. Wastewater management strategies can help mitigate impacts to groundwater levels and are directly linked to the overall island water resources and climate change. While the rain cannot be controlled, the way water is protected, managed, recycled, used, and conserved can be controlled to protect groundwater resources.

There is an unquestionably precarious balance between groundwater extraction, required to satisfy water needs on the island, the amount of rainfall required to replenish groundwater extraction, and the constant diffusion and loss of groundwater to the ocean along the island's perimeter shores. Under such conditions, continuing current practices and increasing the amount of wastewater collection and treatment for discharge into the ocean is not recommended, and the management of wastewater is closely linked to island water resources and climate change.

1.3 Conceptual Design Framework

This conceptual design framework is directed at addressing potential impacts of climate change on groundwater resources and low-carbon emission strategies for the country. This includes considerations for reclaiming wastewater to offset groundwater demands, as well as recovering energy and nutrients from the wastewater.

Overall, it is estimated that approximately 85% of the potable water distributed throughout Barbados is returned to the aquifer along the coastline as a result of the use of pit latrines, septic tanks and soak-away fields. However, some of this water is lost along the perimeter shorelines and makes its way into the ocean instead of being returned to the aquifer. In Bridgetown alone, it is estimated that less than five percent (5%) of the properties are connected to the BSTP sewage collection system, with the remainder relying on onsite wastewater management systems, such as pit latrines, septic tanks and soak-away fields, which return the water to the ground. This means only 12% of the population, served by the Bridgetown and South Coast sewage collection system, has its wastewater partially treated prior to discharge into the ocean. If the discharge of wastewater to the ocean continues, without a strategy for aquifer recharge, future expansion to the sewer connection network would result in a further reduction in the volume of water being returned to the ground. Any future plans for water reclamation and reuse, either to reduce groundwater demands or to replenish groundwater resources, will require extensive public education and social awareness programs for such an initiative to be accepted by the general public and other stakeholders. Continued onsite wastewater management practices should also include a review of potential environmental or public health impacts risks.

There are no restrictions regarding the extent to which the existing central wastewater services may be expanded to serve as part, or all of Bridgetown or the South Coast area. However, the high cost of sewer construction is expected to limit future expansion of the collection systems serving these facilities. As such, alternate strategies need to be developed that consider how to adapt wastewater management to address climate change for areas not served by current centralised systems in Barbados. One fact is clear, Barbados is a water stressed country and needs to consider wastewater as a recoverable resource that can be reclaimed and reused to offset drought conditions that are expected to be exacerbated by climate change, rather than continue to discharge the treated effluent into the ocean.

2 WASTEWATER AS A RESOURCE

2.1 Resource Recovery

2.1.1 Wastewater Reclamation & Reuse

Conventionally, wastewater is treated and then discharged to the environment in a manner that "will do no harm". Wastewater is, however, more than 99.8 percent pure water, meaning it has significant value in areas of the world impacted by climate change and drought. Reclaimed water can be used to offset potable water demands with a lower cost than the energy consumption associated with water produced through desalination while increasing the overall availability of potable water in Barbados. It can also be a significant source of recovered nutrients and be a source of renewable energy. The drivers for reuse centre around three categories: 1) reducing the impact of urbanization on diminishing water supplies, 2) increasing the efficiency of resource utilization, and 3) protecting the environment and public health.

Reuse practices are likely to become increasingly common as the world's population continues to become more urbanized and concentrated near coastlines. This is because climate change can create lengthy or intermittent periods of drought, as well as impact wastewater collection systems from extreme precipitation events that overwhelm wastewater collection and treatment infrastructure.

2.1.2 Energy Reduction & Recovery

Water and energy are mutually dependent, with energy production requiring large volumes of water, and water infrastructure operations requiring large amounts of energy. A sustainable water management strategy is one where water resource management meets the needs of present and future generations. Upgrading wastewater treatment facilities to produce reclaimed water that can be reused to satisfy a wide range of water demands that can be met using non-potable water, is less expensive and energy intensive that producing the same volume of water though desalination, as is done at the brackish water reverse osmosis facility at Spring Garden. Further, if the reclaimed wastewater can be applied to meet water demands within the general vicinity of the wastewater treatment plant, the amount of energy required for the transport of the equivalent amount of potable water can be reduced.

2.1.3 Nutrient Recovery

Increased high-intensity and duration rainwater surface runoff, as a result of climate change, can create negative impacts from nutrient release, from fertilizers used on agricultural lands, into coastal waters. This is why nutrient reduction in wastewater effluent discharged to the ocean is becoming increasingly important. By reducing, or eliminating effluent discharges through water reuse, the need for costly nutrient removal treatment processes can be reduced or minimized, subsequently protecting sensitive marine ecosystems.

Aquifer vulnerability mapping was undertaken in 2009 by Burnside (R J Burnside and Associates Ltd, 2009) as part of the review of Barbados' groundwater protection policy. The Vulnerability Assessment used the DRASTIC methodology and concluded that nearly 80% of the area, excluding the Scotland District was either Very High or Highly vulnerable to aquifer contamination. Work by (Lewis, 1987) demonstrated that groundwater flux onto coral reefs on the West Coast varies spatially, fluctuates with the tidal cycle, and is generally higher in the wet season than in the dry season and that groundwater discharge was richer in nitrogen than in phosphorus probably because of the heavy use of nitrogen fertilizers. Wellington (1999) found that levels of nitrogen and phosphorous in the coastal area were twice and three times higher than at the pumping stations farther inland; and there was also a fourfold and fivefold drop in nitrogen and phosphorous, respectively, in the nearshore zone relative to the groundwater above the beach margin. This was taken as an indication that the dense coastal population at the West Coast was adding significant amounts of nutrient to groundwater after it had left the inland pumping stations. Unpublished work by Baird considered groundwater flows and concluded that groundwater fluxes contributed 85% of the offshore nutrient load. However, BAIRD found no nitrate gradient in a west coast transect during the Adaptation Measures to Counter the Effects of Climate Change Project.

2.2 Wastewater Treatment Technologies

2.2.1 Levels of Treatment & Water Quality

Implementing water reuse programs can pose financial, technical, and institutional challenges in comparison to the conventional wastewater management approach of collecting, treating, and discharging wastewater. An extremely wide range of wastewater treatment technologies have been developed over the past 50 years that are capable of treating the water to a high-quality reuse standard and also address contemporary water quality issues related to emerging pathogens and trace organic and inorganic chemicals. As illustrated in Figure A, water treatment technologies offer a ladder of increasing water quality, and the choice of treatment level is dictated by the end application of the reclaimed water, while also taking into consideration social, economic, and environmental sustainability factors. Choosing the right water quality level depends on the intended use, public health and the potential for public contact, and environmental factors. This is also referred to as a recognition of the "Fit for Purpose" framework to determine the most cost-effective level of treatment that is best suited for the intended reuse application(s).

Rural and agricultural Irrigation is likely the oldest and most widely practiced form of water reuse, particularly for non-food crops. Many areas of the USA, for example, have successfully applied secondary treated wastewater to forage crops for over 100 years. Secondary treatment primarily is focused on the removal of biodegradable soluble and particulate constituents, and a relatively low level of treatment is normally required as bacteria in the soil are highly efficient in consuming any residual organic material, and the plants are able to benefit from the nitrogen and phosphorus contained in the wastewater. Unless irrigation with reuse water is practiced in very arid climates with little to no annual precipitation to flush any accumulated salts from the soil, further treatment is most often not required.

Urban reuse applications have a high probability of the reuse water coming into contact with people, and so a higher level of treatment is often required, with the emphasis being on pathogen removal (i.e. viruses, bacteria and parasites). To optimize the level of disinfection achieved the secondary effluent is subjected to tertiary filtration and more stringent disinfection techniques,

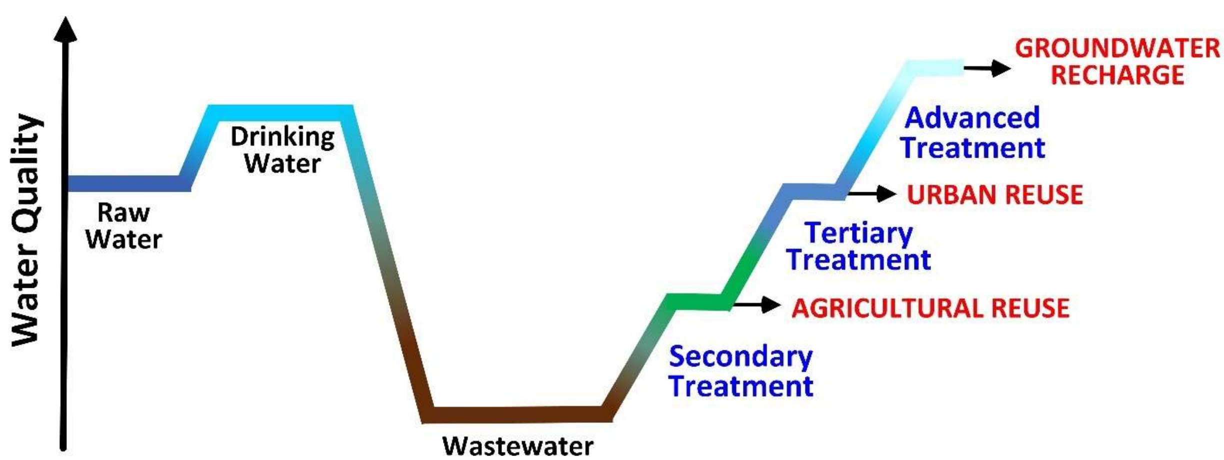

Figure A. Treatment Technologies to Achieve Increased Reuse Water Quality

although a lesser degree of disinfection is often regulatorily permitted if the reuse application is unlikely to come into contact with the public (e.g. irrigation at night only). Urban water reuse practices include toilet and urinal flushing, lawn, and landscape irrigation, building cooling, fire suppression and vehicle and road surface cleaning (as examples). Commonly referred to as non-potable water reuse commonly, urban water reuse is practiced world-wide, particularly in areas impacted by chronic drought conditions. Standards have even been developed to certify package treatment systems to reclaim water for residential and commercial use in Canada, the USA and Australia.

Advanced water treatment akin to potable water treatment is generally required for reclaimed wastewater that is to be used to recharge a groundwater aquifer that is used as a potable water source, a practice that is referred to as indirect potable water reuse. In fact, most communities practice indirect potable reuse as the streams, lakes, rivers, and aquifers that serve as potable water resources are often subjected to wastewater effluent disposal by another community located up-gradient. In highly populated areas where there is a high degree of groundwater augmentation using reuse water matched by a similarly high groundwater extraction rate, additional levels of treatment may be applied, including treating the reuse water using reverse osmosis (RO) prior to ground injection. The RO treatment also removes micro-contaminants such as residual pharmaceuticals in the wastewater effluent that could travel through the soil to affect potable water extraction.

2.3 Reclaimed Water

2.3.1 Public Education and Acceptance

The use of treated wastewater for non-potable irrigation purposes has been practiced in many parts of the world for over a century. In addition to this, in the past half-century there has been an increasing number of water-stressed communities that have adopted direct potable water reuse, where highly treated wastewater is used as a raw water source for producing potable drinking water. Windhoek, Namibia, has been using reclaimed wastewater to produce potable water since 1968, and there has been a recent increase in interest in the United States (US) in direct potable reuse and associated standards development. Advances in wastewater treatment technologies also enable a range of resources to be recovered from the wastewater, including water, energy, nutrients, and carbon, as illustrated in Figure B.

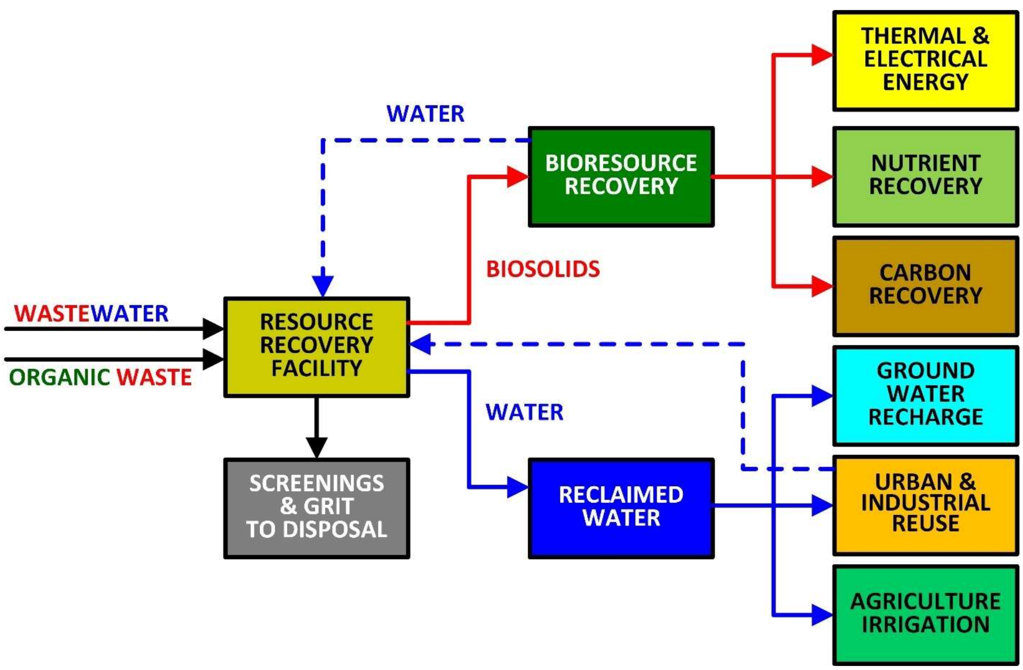

Figure B. Wastewater Resource Recovery Example Alternatives

The majority of reclaimed wastewater is used to meet water demands that do not require the water to be potable, including agricultural and urban irrigation, vehicle and surface washing, and toilet/urinal flushing. Until quite recently the direct treatment of reclaimed wastewater to produce potable water, referred to as direct-potable-reuse, has been uncommon despite the fact the technology to reliably treat the reclaimed water to meet public health standards has existed for over half a century, as exemplified by cities such as Windhoek that has been recycling wastewater into drinking water since 1968. The barrier to direct-potable-reuse is not technology, it is public acceptance. In contrast, indirect-potable-reuse, where treated wastewater is discharged to ground and surface waters to be extracted as a source of potable water, is universally common.

International experience in the US, Australia, Singapore, and Namibia, illustrate that wastewater reclamation and reuse projects are only successful when citizens are genuinely included in the decision-making process. This includes public opinion regarding the water utility or other agencies that promote the reuse project, and early public outreach to build trust in the community, with the dissemination of factual information. By obtaining the support of key stakeholders, they can be later called upon to provide endorsements of water reuse.

The proposed upgrades considered in this project to provide climate change resiliency require extensive stakeholder engagement, which is an opportunity to disseminate information and provide public education. When considering the potential to utilise wastewater for water reuse to build climate resilience, stakeholder engagement and public education about climate change is essential, and the need to manage resources effectively and efficiently.

Australia established an interactive Water Education Program with teachers' manuals for schools that explores the connections between water and the environment. Modified for Barbados, this approach could be used to help convey the relationship between climate change and water management on the island to establish an understanding of the intrinsic, and utility (resource) values of water to society. BWA could develop programs to provide educational support materials for teachers and participates in the delivery of public education programs and associated events that serve to educate students. This increases the general knowledge within the community about water and climate change, so they can make informed decisions, starting with the water cycle and basic facts about water use to protect public safety before addressing water reuse.

2.3.2 Water Reuse Opportunities & Quality

Table A presents a high-level description of the water reuse categories and applications that are typically considered or accepted internationally. The US and Australia have been leaders in advancing standards and regulations for water reclamation and reuse that protect both the environment and public health. Supported by public health risk assessment studies, the specific water quality criteria used for each category may vary slightly between jurisdictions; however, based on the committee work done by the ISO TC282 Water Reuse standards development committee since 2013, there is general consensus regarding acceptable applications and water quality parameter categories. For example, while different jurisdictions may use a different indicator microorganism to assess pathogen risk, such as total or faecal coliforms and E. coli, reuse water applications with unrestricted public access are expected to be at a non-detect level for these indicator organisms.

Table A. Water Reuse Application Categories (US EPA, 2012)

Water Reuse Category		Description
Urban Reuse	Unrestricted Public Access	The use of reclaimed water for non-potable applications in municipal settings where public access is not restricted.
	Restricted Public Access	The use of reclaimed water for non-potable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction.
Agricultural Reuse	Food Crops	The use of reclaimed water to irrigate food crops that are intended for human consumption
	Processed Food Crops and Non-food Crops	The use of reclaimed water to irrigate crops that are either processed before human consumption or not consumed by humans.
Impoundments	Unrestricted Public Access	The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities.
	Restricted Public Access	The use of reclaimed water in an impoundment where body contact is restricted.
Environmental Reuse		The use of reclaimed water to create, enhance, sustain, or augment water bodies including wetlands, aquatic habitats, or stream flow.
Industrial Reuse		The use of reclaimed water in industrial applications and facilities, power production, and extraction of fossil fuels.
Groundwater Recharge / Non-Potable Reuse		The use of reclaimed water to recharge groundwater aquifers that are not used as a potable water source.
Potable Reuse	IPR	Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment.
	DPR	The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a

Water Reuse Category		Description
		water treatment plant, either collocated or remote from the advanced wastewater treatment system.

2.4 Wastewater Resource Recovery

As previously illustrated in Figure B, wastewater and "waste" in general contain valuable resources that can be extracted and recovered for beneficial use with available technology. The figure considers two waste streams entering a resource recovery facility, wastewater, and organic solid waste, both of which contain carbon-energy and nutrient (nitrogen and phosphorus) components that have recycle value. The resource recovery model could be expanded to include other community waste streams, but for the purpose of this document the primary focus is on these two streams, beginning with the reclaimed water stream.

The water reuse categories noted in Table A each have unique water quality requirements that represent the spectrum of what secondary, tertiary, and advanced wastewater treatment technologies can achieve.

2.4.1 Agricultural Water Reuse

Agricultural water reuse reduces demands on fresh water sources and is a means of nutrient management and recovery. It also results in greater crop production reliability due to more constant yields. In contrast, wastewater needs to be adequately treated to be used for agricultural irrigation, especially for food crop irrigation, which is currently not permitted in Barbados due to potential health risks.

Agriculture water demands have been met using secondary treated wastewater for over 100 years with great success, taking primary advantage of the water and nutrient content for seasonal plant growth that characteristically occurs during dry periods with diminished natural precipitation.

US states that regulate the treatment, distribution and reuse of reclaimed wastewater include Arizona, California, Colorado, Florida, New Mexico, Texas, and Washington, among others. The US Federal Energy Management Program published a reclaimed wastewater map that shows water utilities that produce reclaimed wastewater and sell it back to their customers as of 2012[2]. This was done with the intent that Federal agencies can use the map to identify locations in the US that may be good candidates for *purchasing* reclaimed wastewater.

From a global perspective, the use of reclaimed wastewater for agricultural irrigation is considered to be a sustainable practice with regard to both water conservation and nutrient utilization. Most US states have regulations and guidelines in place to permit reuse water to be used for non-food/processing crops as well as permitting reuse water for use in food crop irrigation.

Dissolved salts present in wastewater have the potential to affect the structure and ability of the upper soil layer to retain water and can have negative environmental impact on crops by

[2] https://www.energy.gov/eere/femp/reclaimed-wastewater-map

increasing the soil water pressure and energy requirements for plants to take up water from the soil. There are no inexpensive ways to remove salt from treated wastewater. In arid countries, such as Israel where the main contributor to the salinity in wastewater is the water-softening process used for the meat koshering process, measures have been developed to address salinity and facilitate the ability to reuse the wastewater for irrigation. In climates with high levels of seasonal precipitation, such as Barbados during the wet season (and Walla Walla, Washington), the dissolved salt concentration in wastewater is generally not an issue.

California has a long history of water reuse (Title 22, 1918) and has established themselves as a leader of this practice. They have established a Recycled Water Policy for irrigation applications that does not specify a water quality criterion but instead includes salt and nutrient management planning to help address the potential for recycled water use. This recycled water use impacts groundwater quality and promotes SNMP in basins identified as "priority basins" by the USGS as part of their 2003 study of monitoring and assessing California groundwater. The program components include a predominant element that is consistently applied in all basins, and a secondary element that may be applied in specific basins where local conditions warrant attention and is developed through a stakeholder driven process.

Where irrigation practices may result in salt accumulation in the topsoil, it is possible to address the salt and associated SAR concerns through periodic flushing of the salt to below the root zone using a combination of rainfall and irrigation. Because of this, very few jurisdictions include TDS in their irrigation reuse water quality requirements. None of the states in the US include EC or TDS thresholds in their agricultural water reuse regulations.

The GOB is proposing to use a TDS requirement for irrigation of < 450 mg/L. This value is also referenced within the FAO User's Manual for Irrigation with Treated Wastewater, as summarized in Table B.

The TDS values in Table B can be traced back to a single 8-page Technical Memo published by the University of California Committee of Consultants in 1974 regarding an irrigation study done in California, and subsequently adapted by R.S. Ayers and D.W. Westcot in their report titled "Water Quality for Agriculture" (1985).

Table B. Irrigation TDS Restrictions (FAO, 1985)

Parameter	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
TDS	mg/L	< 450	450 – 2,000	> 2,000

This irrigation table, produced by Ayers and Westcot in 1985, has been repeatedly re-referenced such that it has become a de facto standard used throughout the world, but without regard to the context of the original paper or the *Water Quality for Agriculture* guidance document. Table B indicates that regardless of the nature of the soil or application, a TDS of less than 450 mg/L is inconsequential, and TDS concentrations of up to 2000 mg/L may have a slight to moderate impact on soil that can be managed or addressed. The authors provide this note on the potential use of the values shown in their table:

"The water quality guidelines in Table 1 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgements on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely."

Regarding the assumed site conditions applicable to the values in their table, Ayers and Westcot offer the following advice in the notes to their Table 1 in their document:

*"In a monsoon climate or areas where precipitation is high for part or all of the year, the **guideline restrictions are too severe**. Under the higher rainfall situations, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement."*

In other words, the TDS value used for irrigation should be based on location and site-specific considerations, in particular the ability of rainfall to flush TDS from the soil.

2.4.2 Urban and Industrial Water Reuse

The water quality requirements for reclaimed water used in urban environments for domestic, commercial, or industrial use under circumstances and reuse applications with a high probability of public contact are greater than those required for agricultural irrigation practices and include tertiary treatment. Tertiary treatment can produce a water quality that is safe for unrestricted public contact and typically has a very broad range of non-potable water uses including unrestricted urban irrigation of playgrounds and landscaped areas accessible to the public, toilet and urinal flushing, vehicle, and road surface washing, building cooling, etc. While tertiary treatment can include nutrient removal, it does require tertiary filtration to remove colloidal particles that cause turbidity and can interfere with disinfection efficiencies. Consequently, chemical coagulation and media filtration, or the equivalent, has become the accepted sole technology requirement for urban wastewater reuse treatment requirements. Other requirements based on water quality limits are illustrated in Table C. In general, wastewater reuse quality standards, that meet the criteria noted in Table C, can also be used for agricultural food crops, including food crops consumed raw (ISO, 2015).

Table C. Unrestricted Public Access Urban Reuse Water Quality Standard

Parameter	Units	Reuse Water Quality Criteria
BOD & TSS	mg/L	$\leq$ 10 (average); $\leq$ 15 (Maximum)
Turbidity	NTU	$\leq$ 2 (average); $\leq$ 5 (Maximum)
Indicator Bacteria	CFU/100 mL	< 1 (median); $\leq$14 (Maximum)
pH	-	6 - 9

2.5 Nutrient Recovery

2.5.1 Phosphorus and Nitrogen

Additional treatment beyond secondary is referred to as tertiary treatment and is generally required when discharging wastewater effluent into a receiving environment or an environmental control zone (e.g. groundwater protection Zone A exclusion zone) that can be impacted by either nitrogen or phosphorus. Nitrogen and phosphorus are the primary causes of eutrophication in both fresh and marine waters. In fresh water there are many natural sources of nitrogen as a result of atmospheric nitrogen fixation and organic decay, and phosphorus is generally the limiting nutrient affecting excess plant and algal growth. The opposite is generally true of marine waters where nitrogen is often the limiting nutrient, and excess nitrogen increases algal growth and susceptibility of coral to heat stress. Nitrogen released to the ground can be a public health concern if the concentration of nitrate in groundwater extracted for potable use is too high.

2.5.2 Nitrogen Removal

Biological treatment of wastewater to remove inorganic nitrogen (i.e. ammonia, nitrite or nitrate) involves the sequential transformation of one form of nitrogen into another, with various means of removal, as illustrated in Figure C and Table D.

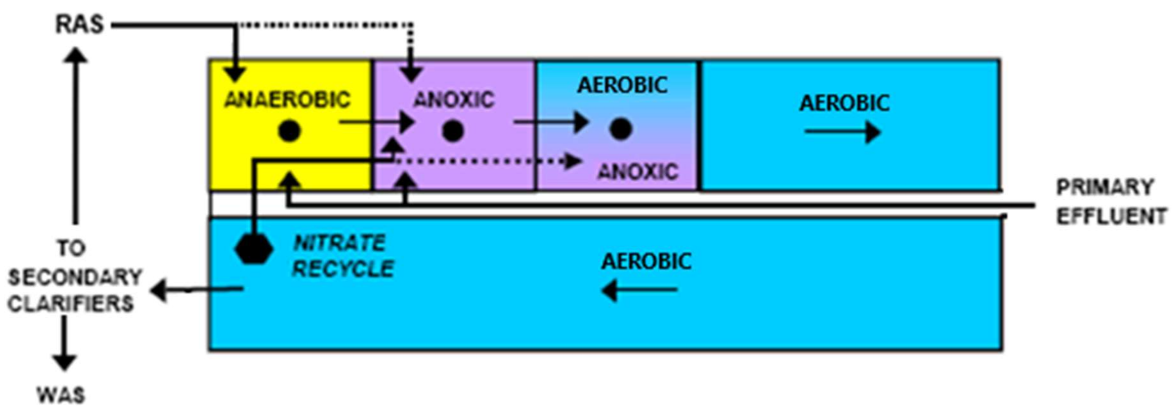

Figure C. Example Biological Nutrient Removal Process

Ammonia is converted into nitrogen gas that is released to the atmosphere in a two-stage process. The first aerobic nitrification stage involves the sequential oxidation of ammonia into nitrite, and then the nitrite into nitrate. The second anoxic denitrification stage involves the conversion of nitrate into nitrite followed by the conversion of nitrite into nitrogen gas.

The ammonia removal process requires a sequence of alternating environmental conditions. Bacteria responsible for nitrification require an environment with oxygen present, whereas bacteria responsible for denitrification require an anaerobic environment without oxygen present as well requiring a source of readily available carbon to serve as an electron donor. From a process perspective, maintaining the proper environment is usually accomplished by recirculating treated nitrified wastewater back to the front of the plant into a tank that has no oxygen source and is fed raw wastewater.

Table D. Nitrogen Removal Mechanisms

NITROGEN FORM	REMOVAL PROCESS	MIN. CONCENTRATION
Ammonia	Nitrification / Anammox	< 0.5 mg-N/L
Nitrite + Nitrate	Denitrification	< 2 mg-N/L
Organic (solids)	Clarification + Filtration	< 1 mg/L (as SS)
Organic (soluble)	Biological Uptake	< 1 mg-N/L
Total Nitrogen	All the Above	< 3 mg-N/L

The nitrogen removal process is complicated further as other biological nitrogen oxidation and reduction pathways have been recently discovered. These discoveries include one species of bacteria that can carry out the full nitrification process, oxidizing ammonia through to nitrate, and another group of bacteria that can utilize ammonia and nitrite present and bypass most of the nitrogen conversion, combining ammonia and nitrite to form nitrogen gas. These biological nitrogen conversion and removal processes are complex and require very specific wastewater characteristics and considerable operator training, skill, and experience to ensure optimal treatment performance.

Alternatively, a post-denitrification process configuration could be used to convert nitrate to nitrogen gas. This requires applying an external source of carbon (such as methanol) to the treated (nitrified) effluent under carefully controlled conditions with minimal, ideally no, dissolved oxygen levels. The need for chemical addition, control, online monitoring, and operator attention makes such systems unsuitable for individual onsite or small decentralized application. Additionally, if excess carbon source is added, the process can also result in failing the effluent BOD_5 criteria.

Although it is possible to reduce the total nitrogen concentration in effluent to less than 3 mg-N/L, this requires a significant degree of operator attention and optimization. A more practical general expectation for individual onsite and small decentralized systems is a total nitrogen effluent concentration of 10 mg-N/L, although the total nitrogen standard that has been set by the Barbados EPD is < 5 mg-N/L.

2.5.3 Biological Phosphorus Removal

Phosphorus can be removed biologically in amounts well in excess of metabolic requirements for bacteria cellular growth. As with biological nitrogen removal, there are several highly specific environmental conditions that must be created within a treatment process to achieve excess biological phosphorus removal as well as recirculation. Biological phosphorus removal is typically accomplished using a suspended growth treatment process and subjecting the bacteria in the process to alternating anaerobic and aerobic environments.

The biological removal of phosphorus is considerably more complex than the conventional activated sludge process that is currently being operated at the BSTP and, similar to nitrogen removal, requires a considerably higher degree of operator skill and experience to ensure optimal treatment performance. As illustrated in Table E, although it is possible to reduce the total phosphorus concentration in effluent to less than 0.2 mg-P/L, this requires a significant degree of process complexity. It also requires a high degree of operator's attention, control sophistication, solids handling capacity, and may require the supplemental addition of chemicals, such as alum, to prevent the biologically captured phosphorus from being released.

Table E. Phosphorus Removal Mechanisms

PHOSPHORUS FORM	REMOVAL PROCESS	MIN. CONCENTRATION
Particulate	Sedimentation & Filtration	< 0.05 mg-P/L
Ortho-Phosphorus (soluble)	Excess Biological Uptake	< 0.2 mg-P/L
Ortho-Phosphorus (soluble)	Chemical Precipitation	< 0.1 mg-P/L

2.5.4 Simultaneous Nitrogen and Phosphorus Removal

The environmental conditions required for nitrogen removal are very similar to those required for biological phosphorus removal; however, the optimal design and operating conditions are different, which means there is a trade-off between the two objectives. The result is a treatment performance, and efficiencies, which typically involve selecting a process configuration that is focussed on optimizing either nitrogen or phosphorus removal or achieving a sub-optimal removal efficiency for both.

If a high degree of removal efficiency is required for both nitrogen and phosphorus, then a combined biological and chemical process design is required using a biological treatment process that is optimized for nitrogen removal and using chemical precipitation for phosphorus removal. The problem chemical phosphorus removal is that it typically adversely impacts the ability to recover and use the phosphorus as a fertilizer. A possible exception that has recently been advocated is the use of magnesium hydroxide. A second problem is the process complexity and control required to maintain optimal conditions, resulting in the need for highly skilled operators.

There are three operating environmental conditions that are incorporated within a tertiary treatment process that determine the degree of nitrogen and phosphorus removal that can be achieved: 1) aerobic; 2) anoxic; and 3) anaerobic.

Aerobic conditions have a high oxygen content, and result in the greatest rate of BOD_5 reduction, and are essential to efficient biological treatment. Generally, oxygen is supplied as part of the atmospheric air that is bubbled into the bioreactor through an aeration device, but in some cases the oxygen can be provided through the use of pure oxygen, or by submerging the bacteria in wastewater and then exposing the bacteria to atmospheric air (such as a Rotating Biological Contactor or Recirculating Biofilter).

Anoxic conditions have no dissolved oxygen present, but generally have other sources of oxygen (electron acceptors) available, such as nitrate. Bacterial growth and BOD_5 reduction are slower under anoxic conditions than under aerobic conditions. The condition can be strategically incorporated into a bioreactor design for the purpose of removing nitrogen, as the nitrate present in solution is converted, by bacteria, to nitrogen gas which is released to the atmosphere.

Anaerobic conditions have no oxygen or nitrate present and are commonly used to extract energy from biosolids by using bacteria that can convert organic compounds into methane gas through anaerobic digestion. It takes much longer under anaerobic conditions for bioreactions to take place than for anoxic or aerobic conditions, so normally anaerobic conditions would be considered undesirable. However, about 50 years ago, it was discovered that certain biochemical processes could be triggered by exposing bacteria to alternating aerobic and anoxic/anaerobic conditions, including the biological removal of phosphorus and the growth-inhibition of undesirable filamentous bacteria (excess filamentous bacteria can adversely affect solids separation processes).

2.5.5 Biological Nutrient Removal Process

There are several BNR process configurations that can be considered and as previously noted, some BNR systems are capable of removing primarily either nitrogen or phosphorus, while others can remove both, but to a lesser degree. The configuration most appropriate for any wastewater treatment depends on the wastewater characteristics, the required effluent nitrogen and phosphorus quality, operator experience and, in the case of a retrofit or upgrade, consideration of the existing treatment process. BNR configurations vary in the number of bioreactors, the number of recirculation pathways, the length of time bacteria remains in the treatment system (i.e. sludge age or solids retention time), the number and type of specific bioreactor environmental conditions and sequences (such as, aerobic, anoxic, and anaerobic), and the hydraulic retention time in each reactor environment.

Some common BNR system configurations that were considered for this project include:

1. Modified Ludzack-EttingerProcess – continuous-flow suspended-growth process with an initial anoxic stage followed by an aerobic stage; optimal for removing total nitrogen;
2. Bardenpho Process (Four-Stage) – continuous-flow suspended-growth process with alternating anoxic/aerobic/anoxic/aerobic stages; optimal for removing total nitrogen; and
3. Modified University of Cape Town – four stage process consisting of an anaerobic first stage, followed by two anoxic stages and an aerobic fourth stage: used to remove both total nitrogen and total phosphorus.

Although the exact configurations of each system differ, to remove total nitrogen, the treatment process configuration must have an aerobic environment for nitrification and an anoxic environment for denitrification. BNR systems designed to remove phosphorus must have at least three environmental components, including an anaerobic reactor zone that is free from oxygen, nitrate and nitrite, an anoxic reactor zone to reduce nitrite and nitrate to remove total nitrogen and ensure the anaerobic zone is free of both nitrite and nitrate, and an aerobic reactor zone for nitrification, and for bacteria to pick up excess phosphorus.

Table F compares the expected nitrogen and phosphorus removal capabilities for the two BNR process configurations that have been selected for this project to evaluate wastewater management upgrading options for the BSTP – noting that site-specific conditions, including historical and predicted future wastewater quality data (which is not available for the BSTP) will greatly influence the performance of each process and therefor the process selected.

Table F. Comparison Between Selected Biological Nutrient Removal Process Configuration Performance

BNR PROCESS	NITROGEN REMOVAL	PHOSPHORUS REMOVAL
MBBR-MLE	Good	None
MBR-UCT	Good	Excellent
Ortho-Phosphorus (soluble)	Chemical Precipitation	< 0.1 mg-P/L

2.5.6 Considerations for Retrofitting an Existing Wastewater Treatment Plant for Biological Nutrient Removal

Retrofitting an existing secondary wastewater treatment plant, like the BSTP, to have BNR capabilities requires several considerations besides influent and effluent characteristics, including the following factors:

- Existing aerated bioreactor basin size, depth, configuration and condition;
- Existing clarifier capacity and mechanical equipment condition;
- Type of existing aeration system and equipment condition;
- Method of sludge management and digestion; and
- Operator skills and training.

Typically, the aeration basin size and configuration dictate which BNR configurations are the most economical and feasible for a retrofit application based on the assumption the existing treatment capacity and tank volumes represent a significant portion of that needed for conversion to a BNR process. For the BSTP this would only apply to upgrading the plant under the Status Quo scenario as the upgraded capacity required to treat all the wastewater that can be collected within Bridgetown, using an expanded sewage collection system, means the new tanks that will be required are significantly larger than that currently available. Consequently, under a fully serviced scenario, the existing tanks could be repurposed for other uses or potentially removed if the tanks are inconsistent with a new process design.

2.5.7 Nutrient (Fertilizer) Recovery

According to the United Nations COMTRADE database on international trade and the World Data Atlas, Barbados imported 830 tonnes of fertilizer (Nitrogen, Phosphorus and Potassium) in 2019, worth more than US$3M. In addition to the material and transportation cost, the GHG emissions associated with that transportation is not insignificant. Because biological nutrient removal processes remove significantly more phosphorus from wastewater than is required for cellular growth, the process presents an opportunity to capture both the phosphorus and ammonia nitrogen as a fertilizer by-product, often in the form of struvite crystals (magnesium-ammonium-phosphate). When the waste bacteria from these processes are digested, high concentrations of phosphorus and ammonia are released from the cells during the dewatering processes and can result in the formation of precipitates that if not harvested would form within the treatment system and cause damage to the process equipment and block pipes. The uncontrolled discharge of high concentrations of nutrients into receiving waters can also cause a serious deterioration in water quality. Consequently, the decision to recover phosphorus can be operationally motivated to protect equipment is a biological nutrient removal process is selected, in addition to the potential economic value of the fertilizer collected.

2.6 Wastewater Energy Recovery

2.6.1 Managing the Energy Content of Wastewater

Opportunities for renewable energy are important considerations for Barbados in the quest for net zero emissions by 2030.

Wastewater contains biodegradable chemically different organic matter of plant or animal origin with specific caloric (energy) values and can be considered a renewable energy resource. This material can be biologically converted into fuel (biogas containing methane) which, in turn, can be converted into electricity and heat in conventional and innovative power machines, such as combined heat and powerplants, gas turbines or fuel cells.

CHP operation requires regular maintenance and high gas quality. In addition to drying the gas, the gas must be de-sulphurised so that the sulphur content is maintained at less than 5 ppm, and ideally less than 1 ppm.

The price-performance power range ratio of CHPs is optimal between approximately 200 kWel and 2 MWel, below which air-supported microturbines could also be used. This may require intensive drying but not necessarily desulphurisation, however, these plants could be significantly more expensive. The same applies to the use of fuel cells, which would also have to be equipped with suitable reformer technology. Such technology is currently being tested but is not yet state of the art.

Electricity can then be fed into the power grid or used in the sewage treatment plant itself. The heat generated in the CHP is used to maintain the operating temperature in the anaerobic digestion system. Heat surpluses can be used to provide hot water in the social rooms within the CHP or sold to businesses in the immediate vicinity. Consideration can also be given to replacing conventional electricity-based air-conditioning systems with adsorptive air-conditioning systems.

Various processes are suitable for converting the energy carriers contained in wastewater into fuels, of which anaerobic digestion is considered the most established and suitable technology. From a process engineering point of view, this technology is the simplest and therefore requires little maintenance. The process control in anaerobic technology can be differentiated according to various categories (mesophilic, thermophilic), such as operating temperature, single or multi-stage, batch and continuous, mixed, or fixed bed or combinations thereof.

To estimate the energy content of wastewater it is first necessary to determine their energy yield of the biodegradable solids. The fuel potential is usually assessed using long-term historical COD values obtained from representative samples and correlated with BPM tests. The COD value reflects the mass of oxygen per unit volume of wastewater required to completely burn the energy carriers in the wastewater. Due to energy conservation, the maximum amount of methane that can be generated through anaerobic digestion of the energy carriers can be estimated, as the amount of oxygen has a strict stoichiometric relationship to the amount of methane. For complete combustion of the methane, a total of 2 moles of oxygen (2*32 g/mol O_2) are required per mole of methane (16 g/mol CH_4). The BMP test gives the amount of the maximum biologically convertible fraction of the energy carrier and should therefore be less than or equal to the COD.

Normally, the TS and VS content of the wastewater are also determined regularly. However, the energy content of the resulting fuels cannot be reliably inferred from these values.

Generating electricity by converting bio-organic substances (such as from wastewater) can contribute to reducing the GHG effect in Barbados. Therefore, electricity generation and feed-in via anaerobic digestion is considered by FTC in the design of feed-in tariffs, so that a long-term source of revenue exists.

Available data can enable very rough estimates to be made for the conversion of the energy from wastewater organic matter into electricity into heat. Assumptions are made that correspond to average consumption and pollution values on an international basis. The data on which these high-level estimates are based are listed in Table G. It Is assumed that during aerobic treatment of wastewater 50% of the energy will be stored in additional activated sludge.

Table G. Assumed Barbados Wastewater Characteristics

	Parameter	Value	Units
A	2019 Barbados Population (1)	287,000	PE
B	2019 Bridgetown Population (1)	112,000	PE
C	2019 Residential Metered Water Consumption (2)	60,400	m^3/d
D	2019 Non-Residential Water Consumption (2)	27,200	m^3/d
E	Ratio Non-Residential/Residential Water Consumption (D / C)	0.45	
F	Estimated Per Capita Residential Wastewater (C / A)	0.210	$m^3/d.PE$
G	Estimated Barbados Population Connected to Sewer (0.15 x A))	43,000	PE
H	Population connected to BSTP (0.12 x B)	13,450	PE
I	Population connected to SCSTP (G – H)	29,550	PE
J	Estimated Bridgetown ADWF (H x F) x (1 + E)	4,100	m^3/d
K	Estimated South Coast ADWF (I x F) x (1 + E)	9,000	m^3/d
L	Biochemical Oxygen Demand (BOD) (3)	232	g/m^3
M	Chemical Oxygen Demand (COD) (3)	655	g/m^3
N	Estimated TOC (L x 1.6)	370	g/m^3
O	Estimated Total Settleable Solids (2)	260	g/m^3
P	Estimate Total Volatile Settleable Solids (O x 0.80)	210	g/m^3
Q	Total Nitrogen (TN) (3)	60	g/m^3

	Parameter	Value	Units
R	Total Phosphorus (TP) [(3)]	6	g/m^3
S	Electric efficiency CHP	40	%
T	Thermal efficiency CHP	55	%

[1] https://worldpopulationreview.com/countries/barbados-population
[2] BWA (2019)
[3] BWA – 2018 SCSTP (January – August) Influent Wastewater Analyses

2.6.2 Wastewater Energy Sources at the Bridgetown Wastewater Treatment Plant

The baseline data assembled for this project, as represented within the Baseline Study, estimates the BSTP currently treats an average dry weather flow of about 5,100 m^3/d, with an associated loading of about 2,000 kg/d of VSS and an estimated anaerobic digestion renewable-energy methane gas production potential of about 550 m^3/d. In addition, the wastewater contains a nutrient recovery potential of approximately 306 kg/d of nitrogen and 31 kg/d of phosphorus.

The process of aerobic biological treatment, as outlined further in Section 5.5, requires both significant energy input and reduces the net energy content of the wastewater due to bacterial respiration, and endogenous decay, resulting in an approximate 50% reduction of the potential energy content in the form of soluble organic matter. The longer the retention time and the longer bacteria are retained within the treatment process, the more the net energy content of the wastewater is reduced and the lower the opportunity to recovery energy.

The existing BSTP is not designed for energy recovery but is designed to biologically stabilize and reduce the quantity of biomass reduced to minimize biomass disposal costs, and then discharge the treated wastewater into the ocean.

2.7 Alternatives to the Current Bridgetown Wastewater Treatment Process

This assignment requires consideration of options to upgrade the wastewater infrastructure in order to mitigate the impacts of climate change while simultaneously considering GHG emissions. The BSTP is a conventional secondary treatment process that uses a considerable amount of energy to treat the existing wastewater at the plant. This results in high energy costs and GHG emissions associated with producing the electricity required by the treatment process.

An alternative approach is to consider technologies that have lower energy requirement and/or technologies that can recover or enable the facility to produce energy such as:

1. Replace aerobic sludge digestion with anaerobic sludge digestion; and
2. Install additional PV panels on available rooftops and available land areas (that do not necessarily have to be within the plant property boundaries).

2.7.1 Replace Aerobic Sludge Digestion with Anaerobic Sludge Digestion

The biosolids, produced by wastewater treatment processes, including organic solids in the raw wastewater and bacteria that are produced by biological treatment, represent a valuable renewable energy resource. Energy recovery from the wastewater treatment process is necessary when considering ever-increasing fuel costs, GHG emissions associated with the combustion of fossil fuels for power generation and increased public awareness regarding the value of renewable energy sources.

Energy management considerations include the use of operational procedures and technologies that can reduce the net energy consumption. They can also recover waste heat and anaerobic digestion to convert organic solids into biogas, consisting primarily of methane and carbon dioxide, the former of which can be collected and combusted for use in process heating, as well as other benefits when coupled with CHP systems.

Biosolids typically contain about 8,000 Btu/lb on a dry weight basis (2.3 kWh/lb) which is similar to the energy content of low-grade coal. Energy can be realized through two pathways: biodegradation (biological conversion of organic matter to methane); and/or thermal conversion (including incineration, gasification, and pyrolysis).

Regarding the wastewater treatment process, anaerobic digestion involves creating an environment with a high concentration of biomass (food) and no oxygen, enabling slow growing methanogenic bacteria to flourish and convert organic solids into biogas. The biological process converts the volatile organic solids to biogas consisting primarily of methane (60-65 percent) and CO_2 (35-40 percent), and the methane can be converted to electricity using onsite power generation equipment (engine generators, turbines, or fuel cells). Residual heat from power generation can also be collected and used to increase the digestion temperature and the overall efficiency of the biological process. If some of the methane generated is used to heat the digester, the resulting thermophilic operating temperatures will result in more rapid digestion and a higher methane yield in comparison to conventional mesophilic anaerobic digestion processes. Further, thermophilic anaerobic digestion is a more rapid digestion process and requires a smaller digester tank, shorter retention times, and has a lower capital cost. The elevated operating temperature also destroys pathogenic microorganisms that may be present in the biosolids.

Biogas production could be further increased by co-digesting the wastewater treatment biosolids with other organic biodegradable feedstocks, such as FOG waste from restaurants and waste food.

One of the primary reasons the capital cost for anaerobic sludge digestion is greater than for aerobic sludge digestion is because anaerobic bacteria have slower metabolisms and grow more slowly than aerobic bacteria; therefore, anaerobic digester tanks reactor sizes are more expensive. Following digestion, anaerobically stabilized biosolids can be land-applied and will have a similar fertilizer value.

The amount of energy that can be recovered through anaerobic digestion depends, in part, on the type of wastewater process that generated the waste biosolids, as some biological wastewater treatment processes produce less biomass than others, resulting in the waste biomass having a lower energy level.

Discussed more in Section 5.8 (and further illustrated in Table U), a CAS process is expected to produce approximately 0.19 kg of VS/m^3 of wastewater treated. If all of Bridgetown was connected to a wastewater collection system, it is estimated the wastewater flow would be approximately 34,100 m^3/d and would produce about 6.5 tonnes (34,100 m^3/d x 0.19 kg.VS/m^3) of

VS/day. The amount of methane that can be produced through anaerobic digestion is about 250 m^3 of methane per tonne of VS, or about 1,625 m^3/d, equivalent to about 16 MWh (based on 10 kWh/m^3 of methane).

A CHP unit with an electrical output of 250 kW could be operated with this and produce around 6.5 MWh of electricity as well as almost 9 MWh of heat per day to improve the rate of anaerobic treatment. It should also be noted the operation of anaerobic digesters and the management and energy recovery from biogas requires highly skilled qualified technical staff.

2.7.2 Install Additional Photovoltaic Panels

The BSTP property boundary, shown in Figure D, covers approximately 34,000 m^2, of which approximately 975 m^2 is currently covered by PV panels. There is also 600 m^2 of existing building roof area that is not covered by PV panels (see buildings situated along the NW corner of the property).

Consideration should be given to install PV modules on appropriate elevated surfaces, such as building rooftops and above bioreactors / clarifiers, as well as open spaces within the property, such as over tanks and building roofs. Shading over the clarifiers would also inhibit algae-growth and improve solids-liquid separation. PV could also be installed off-site within government owned lands, similar to the 4.5 MW of PV that is currently being installed to supplement power for several BWA water pumping stations as part of the WSRN S-Barbados project, managed by the CCCCC and financed by the GCF. The PV panels can be used to off-set plant electrical power costs and/or the electricity generated could be connected into the grid.

Figure D. Bridgetown Sewage Treatment Plant Property Boundary

Another possible alternative is to produce hydrogen gas using the generated electricity, or in conjunction with biogas generation, which is a storable fuel.

3 WASTEWATER TREATMENT RECLAIMED WATER TECHNOLOGY SELECTION

3.1 General

There are a wide range of wastewater treatment technologies that can be considered to produce any reclaimed water quality objective. The selection depends on a range of social, financial, environmental and technological considerations.

3.2 Land Availability

3.2.1 Large Area of Land Requirement

Generally, the greater the amount of land required to implement a technology, the more robust its performance and the simpler it is to operate. A classic example of a large treatment process is a lagoon or wetland system where treatment is carried out through natural biological and physical/chemical processes over a very long period (months to years). Lagoons require little to no operator involvement and are very insensitive to changes or variation in influent wastewater flows or chemical concentrations. Contrarily, there is little to nothing an operator can do to adjust or optimize the lagoon treatment performance.

3.2.2 Small Area of Land Requirement

Limited land availability generally requires the selection a more complex wastewater treatment plant process and equally complex operating requirements. As municipal wastewater treatment is fundamentally based on biological processes, the primary objective for treatment is to maximize the number of bacteria present in the treatment process to do as much of the treatment process as possible in the limited space. This generally means selecting a technology that can house large amounts of bacteria (such as an MBBR) or retain and increase the concentration of suspended bacterial cultures (such as an MBR). The two technologies can achieve a similar level of treatment using the same amount of land, but they have distinctly different operating characteristics. Because the MBBR process is an attached growth process, there is much less an operator can do to optimize the process performance other than to increase or decrease the number of media available for bacterial growth. On the other hand, the suspended growth nature of the MBR process provides a high degree of operational flexibility to adapt to changing wastewater characteristics. Cleaning (anti-fouling) the membranes adds to the operational complexity and increases the energy and chemical cleaning requirements in comparison to the MBBR process. In addition, the MBR process can provide a superior degree of turbidity removal, despite the disadvantage of having a very narrow range of hydraulic flexibility.

3.3 Reuse Water Quality Categories

3.3.1 Agricultural Irrigation and Environment Dispersal (Secondary Treatment)

Reclaimed water quality requirements, for the purpose of irrigating agricultural lands, can be readily achieved using secondary (biological) treatment and modest levels of disinfection if the crop being irrigated is reasonably distanced from urban areas and homes. The Barbados Ministry of Agriculture and Food Safety has determined that in addition to conventional reclaimed wastewater water quality considerations that a requirement for total dissolved solids (TDS) of less than 450 mg/L also be applied for agricultural irrigation water. As the TDS concentration of domestic wastewater is generally greater than 1000 mg/L, the implication is that all reuse water intended for agricultural irrigation will need to be treated with reverse osmosis (RO), resulting in a significant reduction in the quantity of reuse water available for irrigation due to the quantity of brine that is produced and will require disposal.

3.3.2 Urban Unrestricted Public Access Water Reuse (Tertiary Treatment)

In combination with agricultural irrigation applications, urban water use presents a wide range of year-round non-potable water use applications and can have a significant impact on conserving potable groundwater resources. A major drawback, however, is the cost of distributing the reclaimed water into the community for non-potable use. In addition to this, the complete lack of dual plumbing systems to be able to safely distribute and use the reclaimed water within buildings poses another challenge. This can be overcome by considering a decentralized approach to expanding wastewater treatment services in Barbados. Decentralized treatment technologies exist to treat and reclaim wastewater from groups of buildings and even individual homes, thereby significantly reducing or even eliminating the need to construct non-potable water distribution systems. This is similar in concept to the current reclaimed water treatment systems currently deployed by some hotels in the Caribbean, such as Curacao, that reclaim the water and reuse it within the hotel complex or golf course. An urban water reuse strategy could be developed for an optimal combination of decentralized, cluster and centralized water reclamation and reuse applications, with the centralized reclaimed water being transmitted and used for agricultural irrigation or industrial use (such as lower cost of reclaimed water transmission). This would require changes to regulations regarding the acceptable use and distribution of non-potable water, in addition to changes to plumbing and building codes.

3.4 Wastewater Technology Considerations

3.4.1 General

Wastewater treatment essentially mimics natural biological treatment in a manner that maximizes and optimizes the rate of contaminant remediation that would occur in the environment, allowing it to be addressed in a much smaller area that can be controlled. The primary target of municipal wastewater treatment is the biodegradable organic content that, if released to the environment, could overwhelm the natural attenuation capacity, and create unacceptable impacts, including dissolved oxygen depletion within the aquatic environment. This organic material also interferes with the ability to disinfect the water and remove or decrease the health risk associated with pathogenic (disease causing) parasites, bacteria, and viruses.

The second-tier target for municipal wastewater treatment is the removal of nutrients (nitrogen and phosphorus) that are present in high concentrations in wastewater and could promote excess biological growth in aquatic systems, including the proliferation of algae and weeds in fresh water and the destruction of coral in the marine environment. Excess nutrients can also stimulate undesirable changes in the receiving environment ecosystem resulting in, for example, the destruction of coral reefs. Caribbean waters are particularly sensitive to nutrient loading.

While phosphorus can be removed through biological and chemical treatment, nitrogen must be removed biologically through a sequence of treatment conditions involving a wide range of bacteria and environmental growth conditions. As phosphorus is considered to be abundant in the ocean, controlling the amount of nitrogen that is released to the marine environment is important to control excess biological growth and damage to coral reefs.

Municipal wastewater treatment processes are based on establishing optimal growth conditions for bacteria under specific environments conducive to removing organic matter and/or nutrients. Aerobic bio-oxidation respiration is the most rapid means of organic matter reduction which converts the organic matter into a by-product of bacterial cells (biosolids). These biosolids are removed and typically digested to reduce the quantity of biosolids and potentially recover energy and nutrient by-products through a separate biosolids management process.

There are two primary types of biological treatment, classified by the way the bacteria contact with wastewater and are retained within the process: 1) suspended-growth; and 2) attached-growth.

3.4.2 Suspended Growth Processes

Suspended growth wastewater treatment processes involve growing bacteria in a completely mixed tank to prevent them from settling out while they are treating the wastewater. The bacteria is then separated from the treated liquid and recycled back to the bioreactor to build up the bacterial population and maximize the amount of treatment that can be achieved. This type of process that recirculates, or returns bacteria, is called an activated sludge process. Conventional activated sludge processes use gravity clarification to separate the bacteria from the treated effluent, as with the current treatment process at the BSTP. The limitation of this process is related to the effectiveness of the clarification process, as the system reaches a condition or bacterial population that interferes with the clarification efficiency.

Over the past forty years an alternative method to separate the bacteria from the treated effluent has evolved. This is referred to as an MBR. The MBR process eliminates the clarifier and replaces it with a series of membranes that let water through but hold back bacteria. This allows the process to retain more than double the number of bacteria than a conventional activated sludge process and enables the plant size to be reduced while also achieving a highly filtered effluent. Because MBR processes retain more than twice the number of bacteria that conventional activated sludge processes retain, MBR systems typically require twice the amount of electricity or power in comparison to conventional wastewater treatment processes. Overall energy costs for MBR wastewater systems are in the order of US$0.3 kWh/$m^3$, which is about double the expected cost for a conventional activated sludge process (e.g. US$0.15 kWh/$m^3$) such as that in use at the BSTP (Krzeminski et. al., 2012; Fenu et. al, 2010).

While an MBR process typically produces a higher quality effluent than a conventional activated sludge process with respect to biochemical oxygen demand, suspended solids, and turbidity concentrations, it also has a higher capital and operating cost and inherently limits the maximum wastewater flows to the capacity of the membrane filters to filter water.

Considering the ultrafiltration membrane can reject ultra-fine colloidal particles, the head loss across the membrane is high and suction (negative pressure) is required to draw water through the membrane. The rate at which water can be drawn per unit of membrane surface area is referred to as the membrane flux and is the limiting factor in determining the quantity of water that can be filtered.

As water is drawn through the membrane, bacteria and other solids accumulate on the surface, impeding flow or flux, and increasing the head loss through the membrane. This solids accumulation reduces permeability which means greater pressure, or vacuum, is required to maintain the flow rate. To clear the surface of the membrane of solids, and reduce the head loss across the membrane, the pressure across the membranes is reversed, or back pulsed, at regular intervals as shown in Figure E. The membranes require vigorous aeration to keep from fouling and to remove solids from within the group of membranes, which also requires a significant amount of energy.

Permeability, however, is not fully recovered following the back-pulse due to a gradual increase in precipitates that form within the membrane, and eventually the membrane requires chemical cleaning to restore permeability. At small facilities, membranes are cleaned at least every six months using sodium hypochlorite (bleach). The membranes may have to be lifted, inspected, washed, and then placed in the dip tank for 24 hours, and damaged membranes are repaired or tied-off. Alternatively, the membranes may be cleaned in place in the same membrane tank they operate in, depending on the manufacturer. The membranes are also periodically cleaned with citric acid. The high membrane-fouling environment results in low membrane flux rates and the need for large membrane surface areas and a very low peak flow tolerance. Consequently, a large equalization volume is required to maintain uniform membrane flux rates under variable flow conditions, and a large amount of energy is required to provide sufficient air flow past the membranes to keep them clear of solids. The high bacterial concentrations also impact and reduce the oxygen transfer efficiency within the bioreactor, increasing the amount of energy required to maintain required dissolved oxygen conditions.

While chemical cleaning can recover most of the head loss through the membrane, the amount recovered by chemical cleaning gradually reduces because of irreversible fouling. After many cycles, and typically about 7 to 10 years, the irreversible fouling is so great that the membranes need to be replaced.

Membrane bioreactors also require a high degree of preliminary treatment, including fine screening, that removes a substantial amount of untreated organic waste solids that must be disposed of. This is more expensive than the screening required for a more conventional suspended growth treatment process. Membrane systems also require high efficiency pre-treatment, which has historically been an issue at the BSTP, to prevent debris such as plastics, rags, wire, fibrous materials, sand, and grit from entering the bioreactor and getting tangled in the membranes. This material is not only an operational challenge with respect to having to clean the membranes, but the debris and grit can tear and abrade the membranes, damaging them and reducing their life-expectancy. Hollow-fibre membranes are particularly sensitive to damage by the entanglement of the debris. The debris in the fine hollow-fibre membranes can be forced through the membrane when they become entangled and are dragged by the air moving through the membrane. The membranes can also be damaged by attempts to clean the debris from the membranes. Currently, the BSTP has installed new pre-treatment screens that should complement a membraned treatment system, but proper maintenance of the screening equipment will be required to achieve the quality of pre-treatment needed for a membrane treatment system.

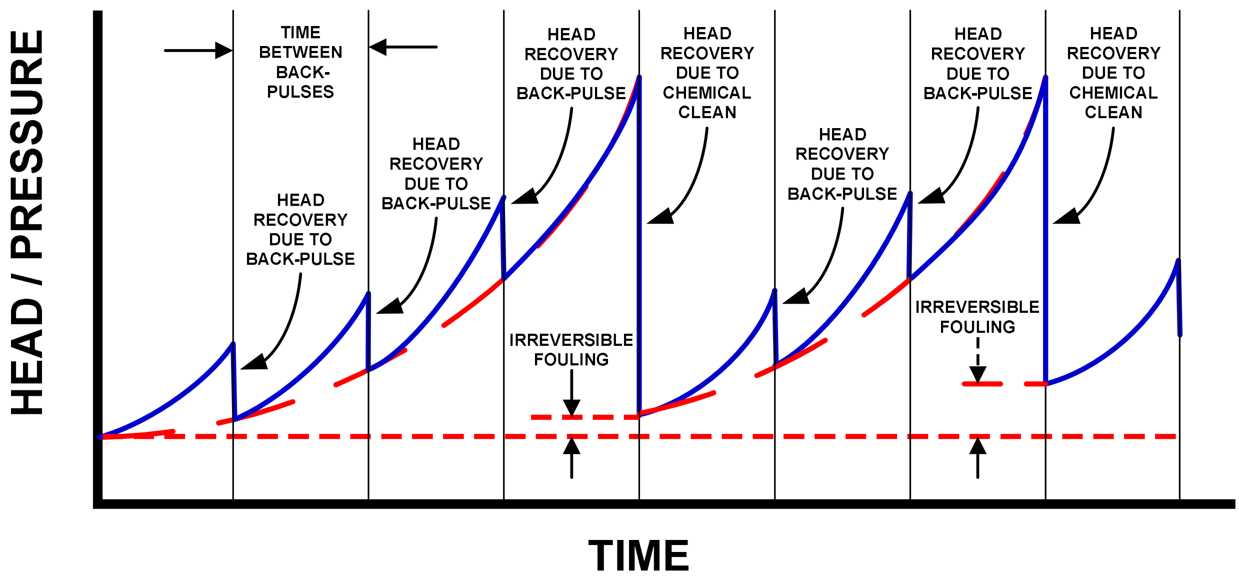

Figure E. Effects of Back Pulsing and Chemical Cleaning on Membrane Flux Recovery and Fouling

3.4.3 Attached Growth Processes

The attached growth process being considered is referred to as an MBBR process. The support media in an MBBR process creates a higher percentage of protected surface area for microorganisms to adhere to and propagate. This feature results in increased levels of overall biomass concentrations inside the reactor and the reduction of the reactor's volume required for the biodegradation of organic matter in the influent. MBBR processes are typically very easy to operate and do not have solids separation problems nor do they have to incorporate membrane technology to achieve a clear effluent. Daily operation is less complicated than for an MBR activated sludge suspended growth process and can be more readily automatically controlled and executed by the operator through a PLC.

Polyethylene carriers, such as the media shown in Figure F, are used to a maximum fill of 60 percent of the reactor volume. The process includes the installation of screens at the discharge end of the bioreactors to prevent the suspended carriers from being washed out of the bioreactor as well as supplying air lances to assist in breaking up media should it become locked. Provision may also be required to be able to add or extract media from the bioreactor tanks to adjust for seasonal loading conditions. It is expected that additional aeration will be required to keep the media mixed than would be required to maintain suspended growth mixing conditions. Accordingly, additional aeration capacity may be required.

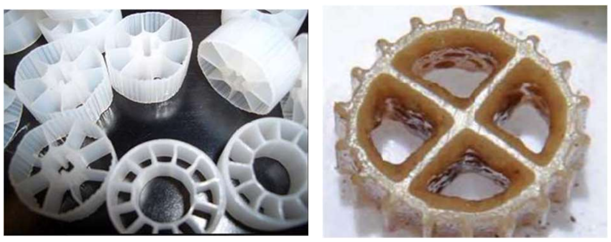

Figure F. Moving Bed Biofilm Reactor Media Examples - New Media (left photo) and with Biofilm Growth (right photo)

3.4.4 Plant-Based (Aesthetics & Education)

The idea that wastewater treatment facilities could look like greenhouses typically captures the imagination of the average person and all the installations described in this section impact waste management.

The photos shown in Figure G, of the Sechelt "Water Resources Centre", demonstrate that conventional ugly-looking sewage treatment plants can be presented in a manner more aesthetically appealing to the public, while meeting stringent reclaimed water standards. The visual appeal is such that the treatment facility receives requests for groups to have receptions in the building's conference area that overlooks the greenhouse area.

The treatment plant achieves a high-quality reclaimed-water standard and includes a number of advanced treatment components including tertiary and activated carbon filtration to remove pharmaceuticals and other micro-contaminants of concern, as well as effluent heat recovery.

In addition to being more acceptable to neighbouring property owners, these systems can have a significant educational impact as the community is visually reminded that chemicals and other materials they may waste, through toilets and sink drains, could have an impact on the plants, which are representative of the environment.

Figure G. Water Resources Centre in Sechelt, British Columbia, Canada

3.5 Process Evaluation Factors

As illustrated in Figure H, the selection of a treatment process begins with determining the level of treatment that is required, with the alternatives of secondary treatment, advanced secondary treatment, tertiary treatment, and advanced tertiary treatment resulting in progressively higher quality effluent and degrees of contaminant removal. Choosing the most appropriate or sustainable technology involves considering many factors including:

1. Land Area Requirement (Large → Small);
2. Operator Skill Level Requirement (Simple → Complex);
3. Technology Adaptability (Low → High);
4. Capital Cost (Low → High);
5. Operating Labour Cost (Low → High);
6. Energy Requirement (Low → High);
7. Process Robustness (Low → High) {ability to accommodate wastewater variability};
8. Water Quality Achieved (Secondary → Advanced); and
9. Water Reuse Applications (Low → High).

The list of factors should be established in consultation with stakeholders, and in consideration of how stakeholders value the technology attributes and ability to meet social, environmental, and financial sustainability objectives.

3.6 Technology Comparison

There are many wastewater treatment processes (see Figure H) that can achieve a high-quality water suitable for unrestricted public access water reuse applications. As presented in the technology comparison table in Appendix 1, each technology has advantages and disadvantages, but a general truism is that technologies that can achieve the same treated wastewater quality are generally commercially priced similarly, as the technology manufacturers are aware of the competition's costs and capabilities.

For the purpose of estimating the size and costs of a central wastewater treatment facility, to achieve reuse water quality suitable for unrestricted public access applications, two secondary treatment technologies have been selected as representative of suspended growth and attached growth technologies, respectively:

1. MBBR process; and
2. MBR process.

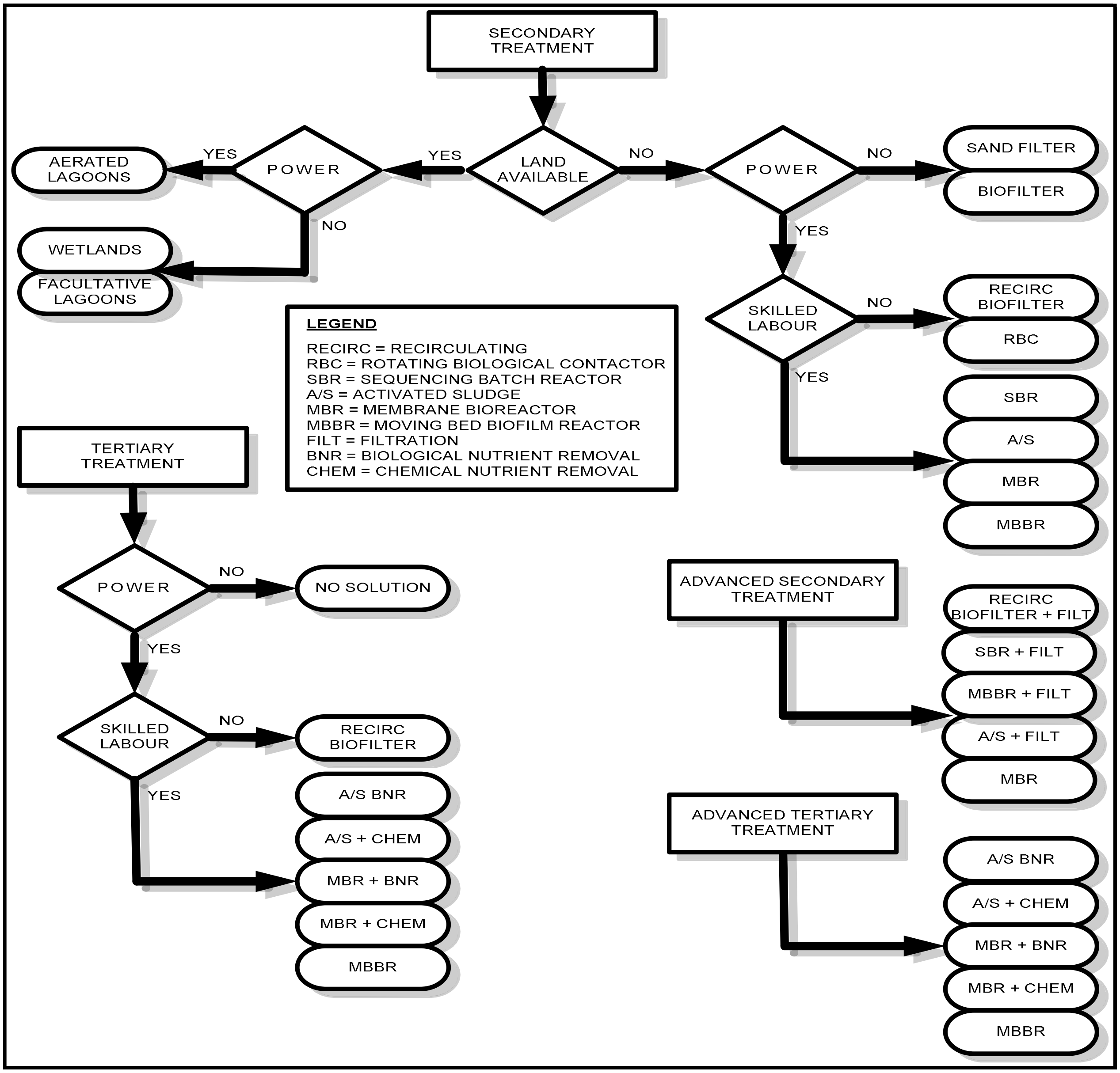

Figure H. Alternative Treatment Technologies

The pros and cons of each are summarized in 0, which include the technologies that were modelled and compared to upgrade the BSTP treatment capacity.

Table H. Wastewater Treatment Process Categories

Process Category	Process Description	Pros & Cons
Fixed Film Growth	MBBR (bacteria attached to floating media);	▪ Less flexible operation ▪ Low operator skill ▪ High energy demands ▪ Greater biosolids generation ▪ Chemical phosphorus removal ▪ Moderate capital cost
Suspended Growth	Conventional Activated Sludge and MBR (bacteria in suspension)	▪ Flexible operation ▪ High operator skill ▪ High energy demands ▪ Chemical or biological phosphorus removal ▪ High capital cost

General Direction of Increasing Cost & Operating Skills

3.7 Central Versus Cluster and Onsite Wastewater Management

An upgraded central wastewater system for the BSTP has the potential to deliver a range of benefits. These include aquifer recharge and increased availability of water resources to households and businesses, while reducing the probability and incidence of water interruptions, improved availability of water for agricultural irrigation and other non-potable water applications. It also has the potential to increase supply of locally sourced renewable power through methane and energy capture and other sources, reduced quantity of untreated sewage discharged into nearby marine environments, increase recovery of wastewater associated resources and reduce incidences of accidental sewage leaks into public spaces.

There is, however, a considerable cost associated with extending the existing sewage collection system currently serving Bridgetown, expanding the treatment capacity of the BSTP, and upgrading the water quality to achieve a high-quality effluent suitable for unrestricted public access reuse.

3.8 Onsite Wastewater Management & Reuse

3.8.1 Sustainability Considerations

Integrated and sustainable water management involves not only making the best use of limited water resources, and the key tenants of sustainability (economic, environmental, and social values), but also the careful selection of appropriate technology combined with public information and education pertaining to methods and community achievements in water conservation.

Onsite decentralized wastewater treatment systems such as pit latrines, septic tanks, and soak-away fields, that are extensively used in Barbados, can be a very sustainable means of wastewater management, assuming they are functioning in a manner that protects the environment and public health. Centralized facilities, like the BSTP and SCSTP, collect wastewater from a broad area, biologically treat the wastewater in a short period of time (hours) using bacteria grown under controlled conditions, and then release the treated wastewater to the environment at a single (ocean outfall) location. All of this is completed at high capital and operating (power) costs. Decentralized onsite wastewater systems like pit latrines, septic tanks and soak-away fields, distribute the wastewater over the same broad collection area and widely distribute it to the soil with the expectation that bacteria will (if functioning properly, see comments in Section 3.8.2) provide the same level of treatment as a wastewater treatment plant, but over a much longer period of time. Because of the wide distribution of onsite systems, the dispersed wastewater is diffused along the perimeter of the island rather than through a single outfall location, with little capital and no operating (power) cost. However, these simple onsite wastewater management systems do not remove nitrogen from the wastewater and contribute to the nitrate content of the groundwater in the area, which is also impacted by agricultural practices.

3.8.2 Sustainability Assumptions

Section 3.8.1 assumes the soil below the soak-away field is unsaturated and allows the wastewater to flow down into the soil (and not surface) and does not contaminate nearby drainage courses and creeks. It takes as little as four feet of unsaturated soil to achieve the equivalent of tertiary wastewater treatment. The phosphorus in the wastewater is typically rapidly removed in unsaturated solids, becoming adsorbed by the soil particles and, if drained through the plant root zone, can be beneficially used by the plants. However, nitrogen can be problematic with onsite systems as nitrogen removal involves two stages of treatment and, generally, only one stage (nitrification) occurs. This results in the wastewater contributing nitrate to the groundwater, and the nitrate will eventually be released to the ocean along the shoreline. The nitrate contributions could also pose a water quality consideration for groundwater potable water consumption.

The greatest climate change risk to onsite wastewater disposal is if rainfall creates conditions that saturate the soil, reducing the ability of the bacteria in the soil to treat the wastewater, and potentially causing the wastewater in the soak-away fields to surface and come into contact with the public. This risk could be characterized and assessed through an investigation of the performance characteristics of onsite systems, with particular consideration for monitoring and assessing the most vulnerable soil types (i.e. poorly draining) along the coast.

3.8.3 Resource Recovery Potential

One of the potential advantages of a centralized wastewater management system, versus decentralized onsite wastewater management systems, is that a centralized plant, and the sewer connected to it, facilitates the collection and recovery of resources associated with the wastewater including the water, bioenergy, and nutrients. However, this does not mean that decentralized management has no opportunity to recover these resources.

As discussed earlier in this report, Barbados is a water scarce country and climate change has a high potential to reduce the amount of precipitation that can replenish limited groundwater resources. Increasingly, wastewater management, in the form of wastewater reclamation and reuse, is becoming a critically important mitigation strategy to address declining water resources in many countries. A centralized wastewater management system would appear to have an advantage over decentralized onsite wastewater systems with respect to treating wastewater to a reliably high-quality level suitable for reuse. The reuse applications could include agricultural, commercial (golf courses) and domestic irrigation, toilet and urinal flushing, vehicle and road surface washing or dust control measures, building cooling systems, or fire suppression systems. Package treatment plants can be purchased for onsite wastewater treatment and can achieve a high-quality treated wastewater standard, meeting international reclaimed water reuse standards, and there are several hotels in Barbados reclaiming wastewater and reusing the water for landscape irrigation.

Assuming the onsite systems are working and do not pose a risk to public health or the environment, the effect of recycling wastewater to the ground through soak-away fields on the net groundwater balance needs to be evaluated; however, it is an important sustainability consideration.

Another potential advantage of centralized wastewater management over decentralized is the ability to recover resources within the wastewater through a centralized treatment process due to the scale of operation. In particular, energy from organic solids, FOG, and other nutrients become recoverable. While the amount of recoverable energy and nutrients may be an issue, septic tanks collect organic solids and FOG, and this material also contains a high proportion of nutrients associated with the organic solids. The material collected in the septic tank is called septage and needs to be periodically removed and treated at a central wastewater treatment plant (like the BSTP) where resource recovery could collectively be carried out.

Only water intended to satisfy drinking and food preparation currently needs to be of a potable water quality standard. Typically, this represents a small portion of domestic water needs; in the order of 15%, or less, of water demands. The bulk of domestic and commercial water uses can be satisfied using water that is not intended for drinking (e.g. toilet/urinal flushing, laundry, bathing/showers, irrigation, vehicle washing, etc.), which can be produced by treating municipal wastewater to a safe non-potable reuse standard and has been practiced in many countries globally for over 30 years including the US, Canada, Australia, Japan, China, Korea, Singapore, and South Africa.

A key cost benefit of onsite systems is there is no need to distribute treated water from a central wastewater treatment facility. For example, a hotel can reclaim the wastewater generated on the property and use it to satisfy non-potable demands on the same property. Similarly, the wastewater from a cluster of homes can be collected and treated, and then distributed for non-potable reuse within the same community, minimizing pipe requirements. This approach is in-line with the recently advertised "Roofs to Reefs Programme" that promotes higher level, than what currently exists with septic tanks and soak-away fields, on-site wastewater treatment. Further, the capital and operating costs for the decentralized water reclamation equipment are borne by the building owners, reducing the overall centralized infrastructure costs to the GOB. This makes consumers more directly responsible for water management and more aware of how their water use and wastewater practices affect the associated decentralized infrastructure. Large cities, including Tokyo and Beijing, have successfully established a decentralized water reclamation policy for large buildings and complexes, reducing centralized potable water demands by up to 50%.

It is expected that an optimal sustainable wastewater management solution that addresses potential climate change precipitation variation impacts, will be a combination of central and onsite wastewater management system.

3.9 Central Energy Recovery

Anaerobic digestion is impractical and not appropriate for onsite system applications. It is best suited for large-scale central facility applications. A central anaerobic digester could be located at the BSTP and could recover energy from biosolids generated by the SCSTP and septage discharges from across the island, while simultaneously co-digesting organic food wastes from homes, hotels, grocers, restaurants, and food processing operations.

3.10 Central Nutrient Recovery

As with anaerobic digestion and energy recovery, nutrient recovery is most cost effectively and sustainably implemented at a large-scale central facility. Digestate can be treated to precipitate nitrogen and phosphorus rich salts for use as fertilizer, and the nutrients in the residual solids left after digestion can serve as a soil amendment when applied to land.

3.10.1 Biosolid Residual Considerations

Changes to existing legislation and guidelines will be required to promote further sustainable farming practices, including reclaimed water reuse for irrigation and the use of sustainable and clean technologies. This will be key to any plans for nutrient recovery, use and the application of digested biosolids residuals for land use.

There is a need to develop legislation in Barbados to include water reclamation and reuse standards, application guidelines and to establish specific policy provisions for wastewater to incorporate integrated onsite/decentralized and centralized infrastructure management. Design standards, improved onsite wastewater treatment and water reclamation designs, identifying appropriate treatment technologies, EIAs and waste management provisions are also important. This also requires improved mechanisms to facilitate collaboration between public health and the environment regarding appropriate water quality standards and monitoring. This includes establishing comprehensive regulatory frameworks that formally establishes water quality criteria for water reuse practices for discharges of domestic wastewater. Consideration should also be given to improve community capacity-building and community/private-sector participation in improving onsite wastewater management. This includes developing communication and educational tools to establish and increase public awareness and promote community involvement in wastewater management.

3.11 New Design Standard

The Ministry of Agriculture and Food Security have determined the TDS concentration of reclaimed wastewater intended for agricultural irrigation applications must be less than 450 mg/L. This decision means that all reclaimed water for agricultural irrigation will need to be treated by reverse osmosis, which will also remove beneficial nutrients from the water.

4 CENTRAL WASTEWATER COLLECTION SYSTEM

4.1 Existing Bridgetown Wastewater Collection System

Although the existing BSTP system was thoroughly described within the Baseline Study, further data collection and analysis on both the treatment and collection system has been conducted since this report was completed. As such, this section will quickly focus on the existing condition of this infrastructure as well as discuss new findings related to recently obtained information from the BWA and our own research.

4.1.1 General Conditions

Figure I illustrates the existing wastewater collection system within Bridgetown, using different colours that represent various sub-collection networks, as outlined by the BWA. The Bridgetown wastewater collection, and treatment system is currently estimated to serve about 2,000 properties within the collection catchment area, representing less than 5 percent of the properties and population in Bridgetown.

It is understood that an additional small collection system (not shown in Figure I, but would be situated at the top of the figure), complete with a lift station (called Garden Land) along Country Road, has been constructed and was added to the Bridgetown sewage collection system. No "as-built" information was available to review.

Most of the force mains, within the wastewater collection system, are made of DI pipe. HDPE and concrete pipes may also have been used, but this is not identifiable from the "as-built" drawings received. The largest gravity line, before the system connects to the BSTP, is 850 mm (34") and the smallest is 100 mm (4").

Estimates were made, regarding the amount/length of pipe required to complete the expansion of the sewer collection system, using the existing system as a basis for the layout. The exact legal limits of the city were not available and so an assumption was made based on publicly available data. Should the Bridgetown sewer system be expanded to the remainder of the city, it is assumed the existing infrastructure will remain as is and that the additional sewage collected will be directed to the existing main trunk line along the coast for transport to the BSTP.

Flooding in the vicinity of sewer manholes is a concern and the BWA have sealed (by welding the manhole lids) some of the manholes within the sewage collection system to lower surface water inflow as well as a measure to inhibit the illegal disposal of solid wastes and FOG into the sewer.

The sewers are also subject to solids deposition, which exacerbates the hydrogen sulphide generation conditions, and BWA operations staff flush the sewer regularly to remove deposited solids. However, the FOG that is discharged to the wastewater collection system is not typically removed by flushing and is a serious operations problem.

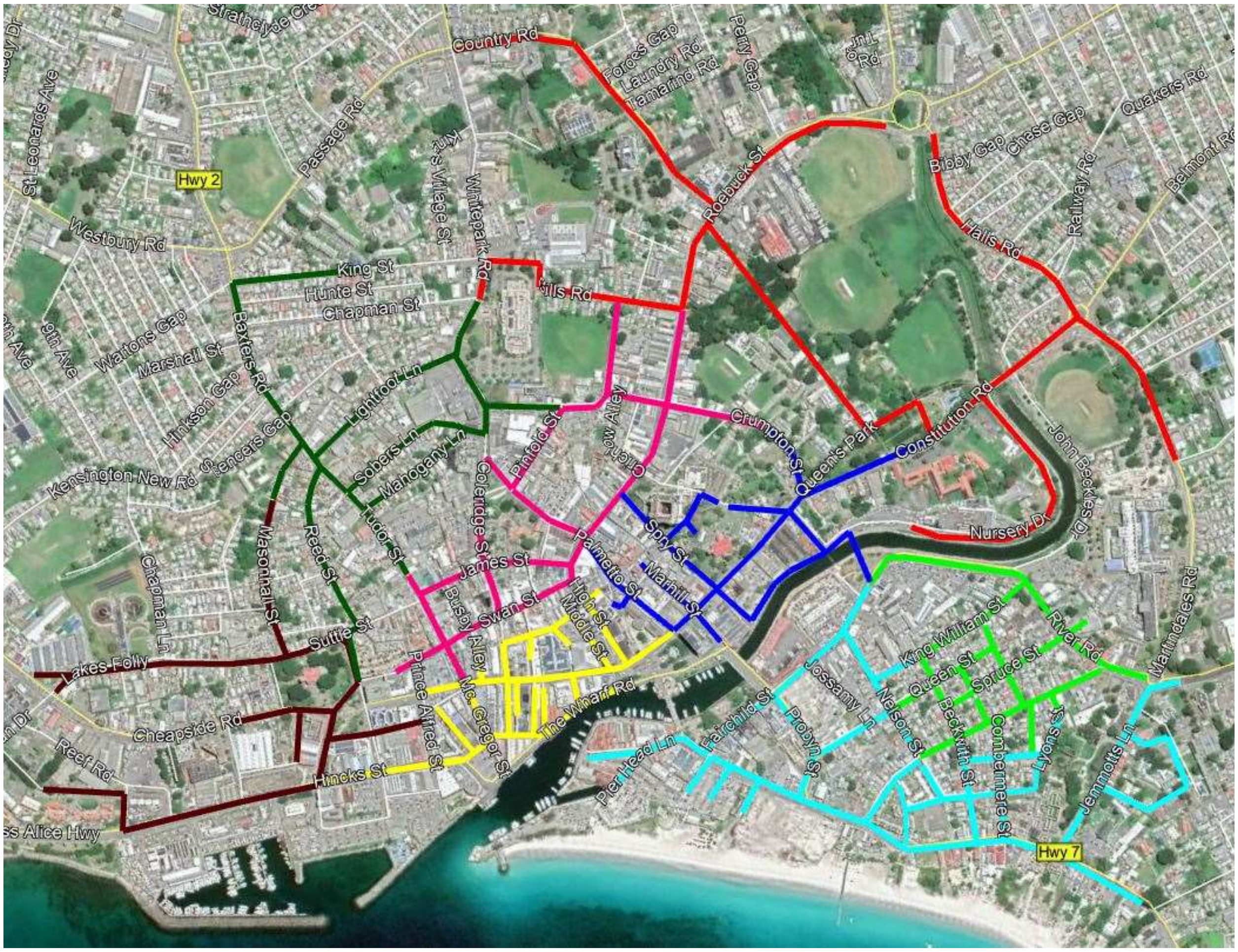

Figure I. Existing Bridgetown Wastewater Collection Areas

4.1.2 Lift Stations and Related Force Mains

The Bridgetown sewage collection system includes four small lift stations and one major lift station (River Road). Most of the lift station force mains are made of ductile iron pipe. Although it is not evident from the "as-built" drawings that are available, following discussions with BWA staff it is our understanding that most of the wastewater collection system is comprised of HDPE and concrete pipes.

Excessive quantities of rags and other debris clog the lift station pumps and manually removing this debris and repairing damage caused by the debris is a chronic operations problem, as is the excessive quantity of FOG that thickly coats all surfaces. Metal components, including steel manhole access rungs, within the wastewater collection network are subject to sulfuric acid corrosion due to hydrogen sulphide generation and release, which is also a serious heath/safety concern, particularly at sewage lift stations where the poisonous gas tends to accumulate. The hydrogen sulphide gas that collects in the lift-stations is also responsible for corrosion problems, exacerbated by sealed manholes that limit proper ventilation in the collection system.

The increased frequency and intensity of storm events, associated with climate change, will negatively impact this infrastructure, while the pre-existing issues related to FOG and rags clogging pumps will act to amplify this issue. Additional flows in the wastewater collection system, associated with inflow and infiltration that are increased due to climate change, were reported by the BWA during the recent category 1 hurricane (Elsa) that passed through Barbados in July of 2021.

4.1.3 Hydraulic Capacity of the Wastewater Collection System

A general review of the as-built drawings indicates the hydraulic capacity of the system should adequately accommodate the 2,000 properties served by the sewer. The largest gravity sewer line (previously mentioned to be 850 mm (34") in diameter) has an approximate hydraulic capacity of 35,000 m^3/day (0.4 m^3/s). However, without flow monitoring data and operations records, it is possible the hydraulic capacity could be inadequate in certain areas due to localized hydraulic conditions, from under-sized pipes, large point-source discharges, or significant stormwater inflow through manholes because of poor surface drainage, which could lead to flooding.

4.1.4 Wastewater Infrastructure Power Consumption

Wastewater power consumption records have a number of uses in considering process upgrades including verifying existing power use to calibrate consumption characteristics for consideration in evaluating upgrade options, providing a basis for estimating variations in flow (in the absence of flow measurement equipment and data, and as a basis for establishing goals for renewable energy production to achieve a net-zero condition.

The BWA provided the study team with utility bills from Barbados Light and Power that illustrate power consumption levels at various facilities from January 2017 to December 2019. This data has been presented graphically in the following figures. There is a correlation between the amount of power used and the amount of wastewater flow at a lift station and the treatment plants. As such, although the graphs represent the amount of power consumed at each facility, they can also graphically represent the amount of flow experienced as well.

Figure J illustrates the variation in power consumption at the BSTP over the past four years. Based on the assumption that power consumption is proportional to the wastewater flow being treated, there is no consistent pattern from year to year that could be used to project future treatment conditions.

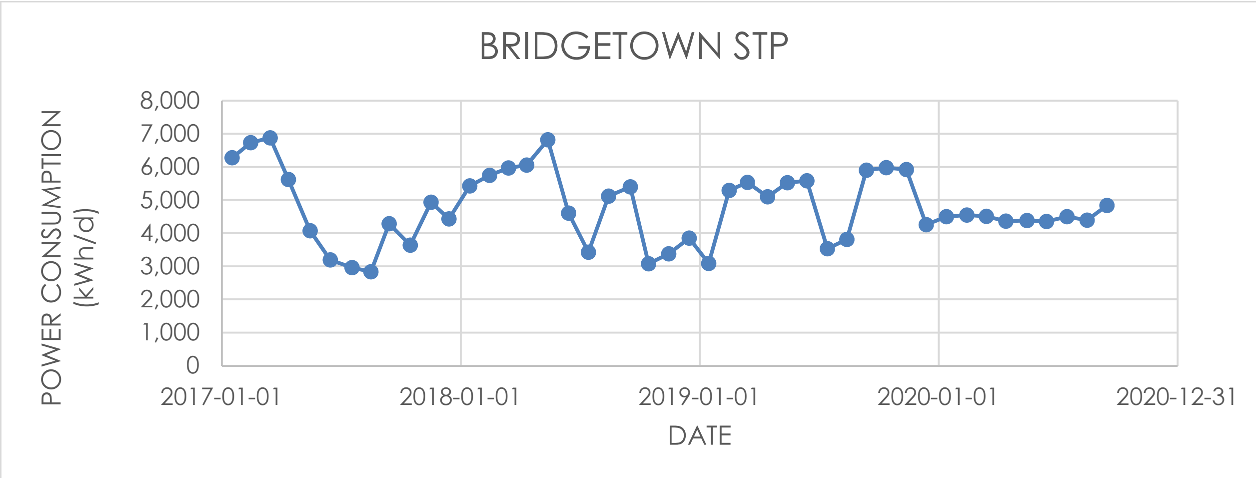

Figure J. Bridgetown Sewage Treatment Plant Power Consumption for 2017 - 2020

The power consumption records for the SCSTP (see Figure K) indicate a significant reduction in the past two years, with consumption levels in 2017 of up to 6,600 kWh/day dropping to an average power consumption over the past two years of around 1,250 kWh/day, and with little month to month variation for over two years. The BWA were not able to provide an explanation for this change and we are unable to speculate on the reason for the reduction.

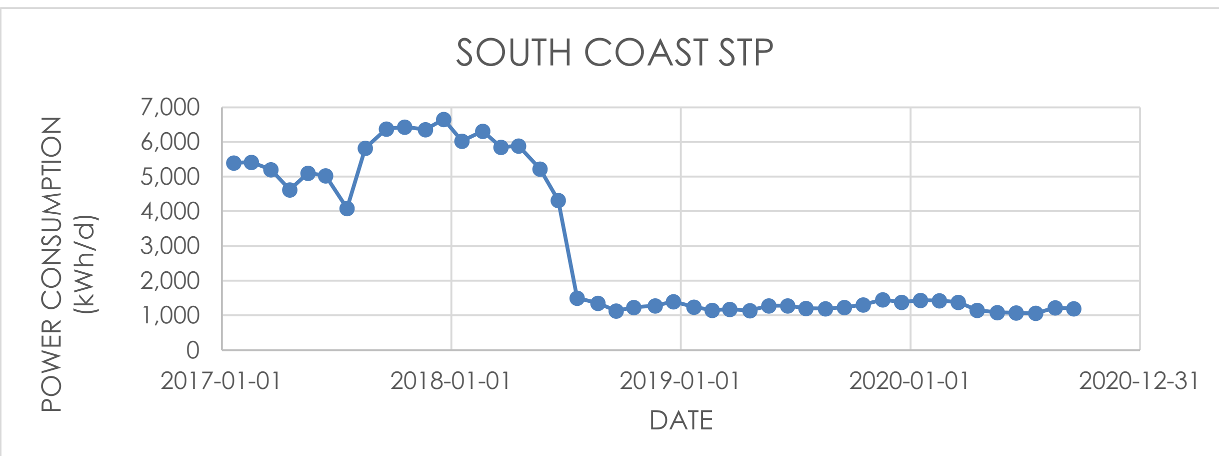

Figure K. South Coast Sewage Treatment Plant Power Consumption for 2017 - 2020

This inconsistent power consumption pattern is also reflected in the power consumption pattern for the lift stations that pump wastewater to the BSTP. Figure L illustrates the power consumption at the River Road lift station for the same four-year period. The power consumption record indicates that 2017 was characterised by monthly wastewater flows variations of over 100 percent, with the highest flows occurring late in the year during wet weather, implying the sewer was affected by rainfall influenced stormwater. However, the virtual absence of a variation in power consumption through 2018, 2019 and 2020 (except one notable spike) would indicate the sewer draining to the pump station is relatively unaffected by precipitation events.

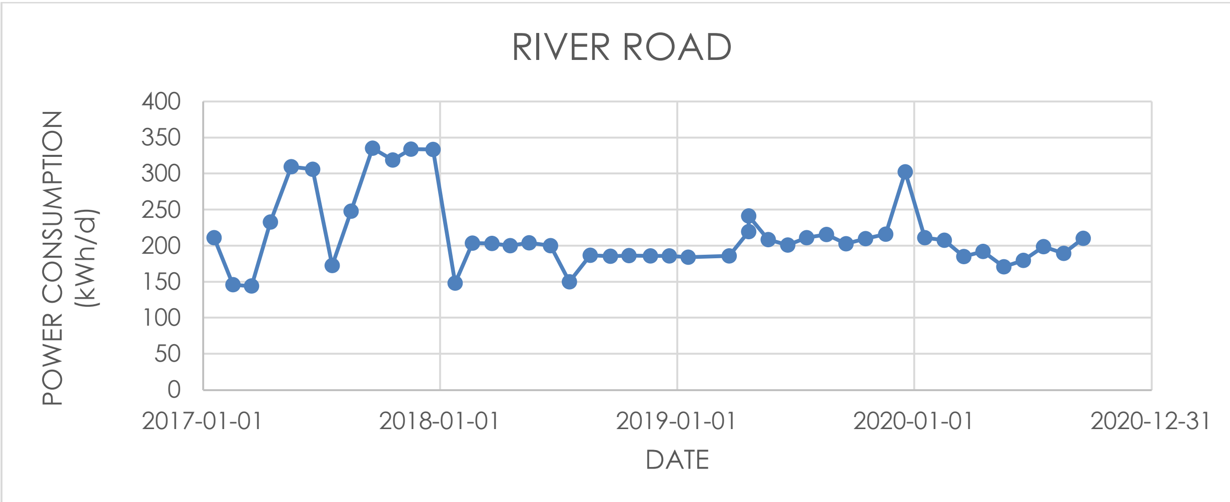

Figure L. River Road Lift Station Power Consumption 2017 – 2020

In contrast, the Hilton Lift Station power consumption record (shown in Figure M) shows virtually no variation in consumption for 2017 through 2019, and then a wide variation through 2020, with a power consumption spike for one month that is more than three times the average power consumption for the previous three years.

The wide variations and discrepant power consumption data underscores the need to gather more data prior to committing to an upgrade path and detailed design.

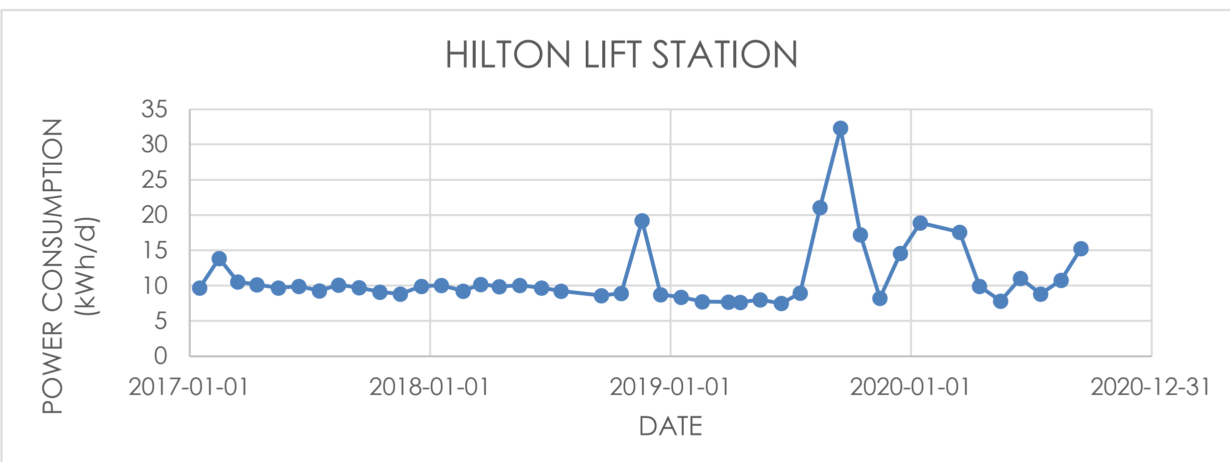

Figure M. Hilton Lift Stations Power Consumption 2017 - 2020

4.2 Bridgetown Wastewater Collection System Upgrade Considerations

In order to maximize the production of reclaimed wastewater to offset potable water demands, including groundwater replenishment, at Bridgetown, it would be necessary to service all of Bridgetown and transfer the collected wastewater to an expanded capacity at the BSTP. Figure N illustrates the conceptual extent of the Bridgetown urban boundary and sub-areas used to carry out a conceptual assessment of the wastewater collection system required to serve all of Bridgetown.

High-level estimates were made regarding the length and diameter of pipe required to complete the expansion of the sewer collection system within Bridgetown, using the existing system as a basis for the layout. The exact legal limits of Bridgetown were not available and so an assumption was made based on publicly available data, as is illustrated within Figure N. Should the Bridgetown sewer system be expanded to the remainder of the city boundary limits, it is assumed that the existing infrastructure would remain as is and that the additional sewage collected would be directed to the main trunk line along the coast that currently transports the sewage to the BSTP. Each collection area was assigned a collection node (shown in Figure O) for the purpose of estimating the cumulative wastewater flows and estimating required pipe diameters. Approximately 23.5 km of sewer pipe, ranging in diameter between 200 mm and 800 mm in diameter, would be required to serve the remainder of Bridgetown that is not currently connected to sewer.

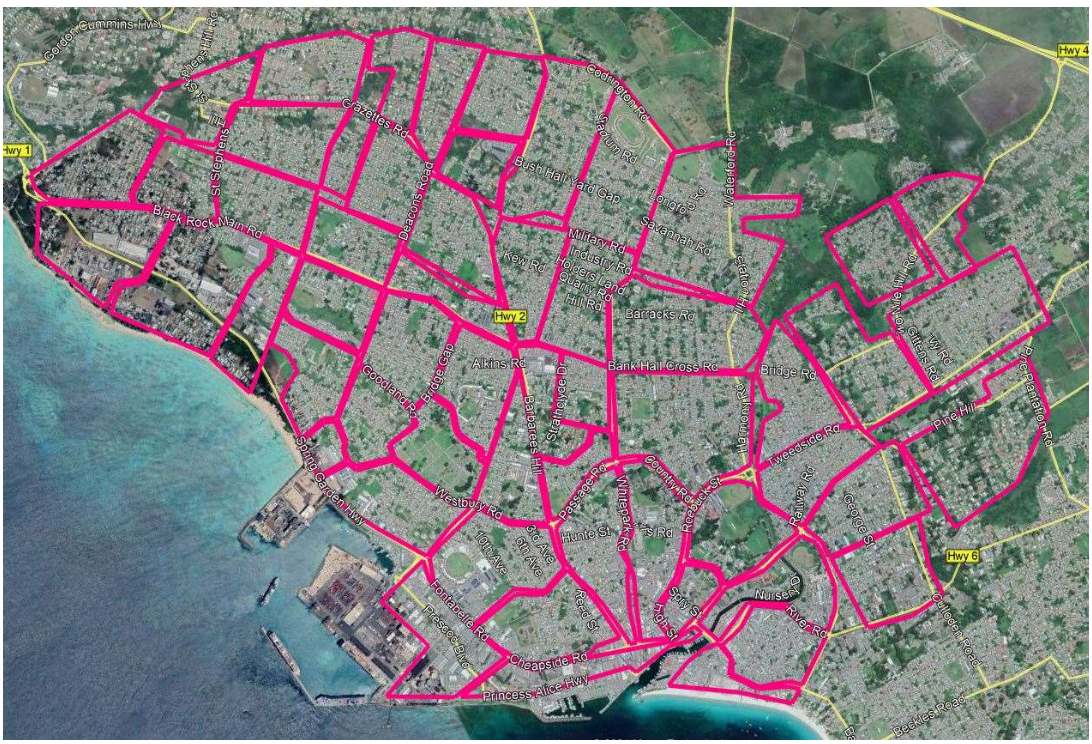

Figure N. Conceptual Bridgetown Extended Wastewater Collection Areas

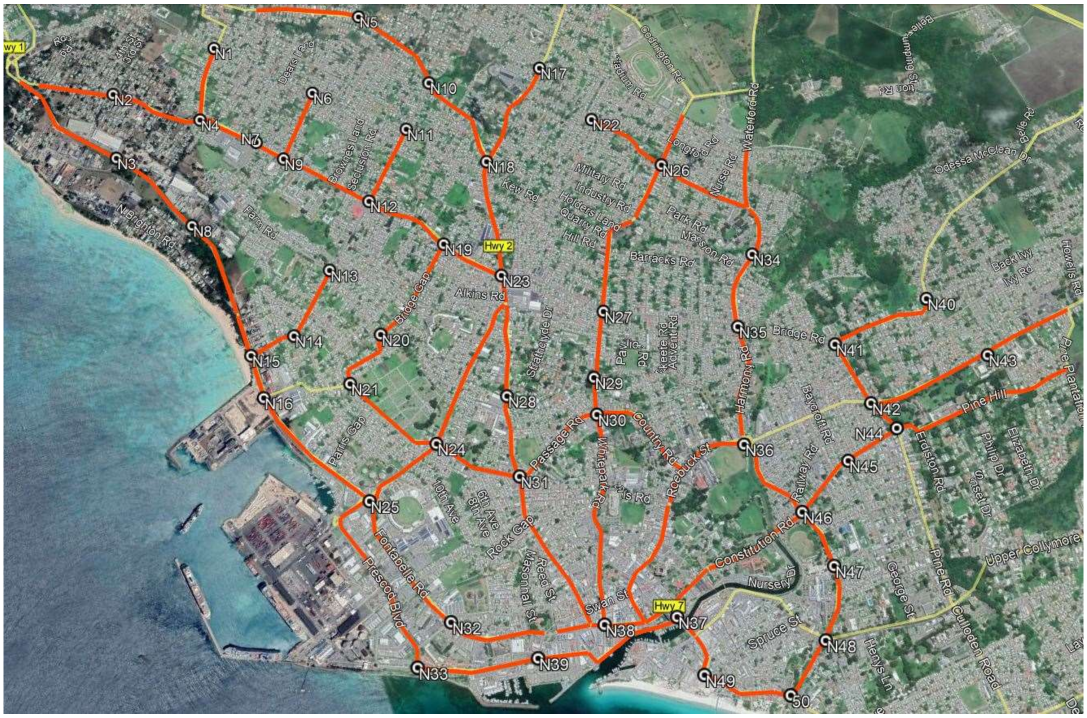

Figure O. Conceptual Sewage Collection System Catchment Nodes and Trunk Lines (Orange)

4.3 Sewer Cost Estimate

For the purpose of providing an order of magnitude cost, assuming a sewer construction cost of US$2,000 per metre of length, the capital cost to provide sewage collection for the remainder of Bridgetown is estimated to be about US$48M.

A more detailed assessment is required to establish a budget value cost estimate to extend the wastewater collection system to the rest of Bridgetown. This detailed cost estimate would need to take into consideration expected construction challenges based on the following:

- Topography;
- Trench depths to accommodate the required pipe slope for gravity collection;
- Shoring or tunnelling requirements;
- Groundwater conditions;
- Lift-station locations and design;
- Pipe materials; and
- Telemetry requirements to coordinate pumping to equalize flows transferred to the BSTP.

4.4 Potential Climate Change Impacts on the Wastewater Collection System

4.4.1 Stormwater Inflow and Groundwater Infiltration

Two areas for consideration related to wastewater collection and climate impacts are with respect to surface flooding causing inflow into manholes, and groundwater infiltrating into the sewer. These considerations have the potential to use up collection and conveyance capacity, dilute wastewater, and hydraulically overload the central treatment plant.

Groundwater infiltration is caused by poor construction practices and can only be controlled during sewer construction. However, BWA staff report that surface flooding during wet weather has resulted in the public lifting sewer manhole covers to rapidly drain flooded areas. This creates high hydraulic loading to the treatment plants. If the surface flooding is not addressed, this situation could easily be exacerbated by climate change increases in precipitation event durations and/or intensity, having a significant impact on sewer costs as well as wastewater treatment capital and operating costs.

The review of limited flow records from the South Coast collection system and lift-station power consumption records do not appear to support the premise that groundwater infiltration is a significant problem with respect to affecting sewer capacity. But it is our understanding that a new flow meter has been ordered and will be installed at the BSTP soon. Additionally, if new data management tools are incorporated (as outlined in section 6), then better O&M practices can be implemented in the future.

4.4.2 Storm Surges and Rising Sea Level

The increase in the number and magnitude of climate change influenced storm events, including hurricanes, that result in storm surges and rising sea levels could impact the ability to discharge wastewater through the marine outfalls as well as result in saltwater entry into the wastewater collection system. This would in turn impact hydraulic capacity and the ability to treat salt contaminated wastewater biologically (i.e impacting the ability to treat and effluent quality). It could also impact the quality of reuse water that is intended for plant irrigation with respect to elevated sodium and chloride content. Storm surges, rising sea levels, and precipitation events that have a higher intensity or longer duration caused by climate change could also result in flooding conditions affecting the BSTP site location.

5 CENTRAL WASTEWATER TREATMENT SYSTEM UPGRADE CONSIDERATIONS

5.1 Wastewater Flow Characteristics

To estimate an existing wastewater treatment facility's treatment capacity, the typical practice is to examine historical wastewater flows and influent/effluent water quality data, and then compare the plant's historical performance with a theoretical prediction based on calculations and/or modelling. The historical data can also be used to calibrate a wastewater treatment model, and then use the calibrated model to predict future treatment plant performance more accurately, as well as evaluate alternative upgrade options as appropriate.

Unfortunately, as noted in the Baseline Study, there was no wastewater flow or influent/effluent water quality data available for the BSTP. Therefore, it was necessary to estimate wastewater flows based on BWA metered water consumption records for the entire island and analyse a limited number of wastewater flow records collected at the SCSTP. While this minimal information may be satisfactory for a conceptual design, and consideration of wastewater management alternatives, the estimated values should be confirmed prior to carrying out a detailed design.

As summarized in Table I, the estimated ADWF for the BSTP is about 4,100 m^3/d, consisting of approximately 2,825 m^3/d residential wastewater flow and 1,280 m^3/d of non-residential wastewater.

The flow of wastewater is not constant throughout the day, with the lowest flows generally occurring in the early morning when most of the population is asleep and businesses are closed, and peak flows typically occurring in the morning when people awake and get ready for the day, as well as around 5 to 6 pm in the evening when people arrive back home. As community populations increase, the difference between the peak daily flows and the average daily flows diminishes. A common method of estimating the Peak Dry Weather Flow (PDWF) is to use the Harmon Formula (see Eq. 1-1 below) as follows:

Harmon's Peaking Factor $= 1 + 14/[4 + \left(\frac{P}{1000}\right)^{0.5}]$ Eq. 1-1

Where, P is the population

PDWF = ADWF x Harmon's Peaking Factor

Based on the current estimated 13,500 people being connected to the Bridgetown sewer, Harmon's Peaking Factor is 2.82, and the PDWF is estimated at 9,300 m^3/d, as shown in Table I.

Table I. Wastewater Flow Estimate

	Population	Flow per Capita	Non-Residential	ADWF	Harmon's Factor	PDWF
UNITS	PE	L/d	m^3/d	m^3/d	(no unit)	m^3/d
	13,500	210	1,275	4,100	2.82	9,300

5.2 Wastewater Quality Characteristics

As there is no historical wastewater quality analysis data available, the wastewater characteristics were estimated based on typical North American wastewater characteristics as shown in Table J.

Table J. Typical Municipal Wastewater Quality Characteristics

Parameter	Concentration
BOD_5	230 mg/L
TKN	50 mg-N/L
TP	6 mg-P/L
TSS	260 mg/L
VSS	210 mg/L

The same raw wastewater quality characteristics were used to assess the current BSTP performance and for the future BSTP upgrade strategies that are described in this report.

5.3 Estimated Wastewater Flows for all of Bridgetown

Connecting all of Bridgetown to the wastewater collection system is a logical consideration or scenario to place in juxtaposition with the relatively unsewered status quo, where it is estimated that 95% of Bridgetown is not connected to the wastewater collection system. Table K summarizes the anticipated wastewater flow characteristics based on an assumed population of 112,000 people, a flow estimate of 210 m^3/d per person (based on current water consumption records), plus a 45% allowance for non-residential wastewater.

Table K. Wastewater Flow Estimate

	Population	Flow per Capita	Non-Residential	ADWF	Harmon's Factor	PWWF
UNITS	PE	L/d	m^3/d	m^3/d		m^3/d
VALUE	112,000	210	10,600	34,100	1.96	56,700

5.4 Effluent Quality Considerations

The previous Baseline Study summarized the required treated wastewater effluent qualities, as outlined within the current EPD requirements and guidelines for the treatment of wastewater for the purpose of direct discharge, tertiary treatment for reuse, and irrigation, respectively. For reference purposes, these standards are summarized in Table L, Table M and Table N .

Table L. EPD Guidelines for Treated Wastewater Effluent Direct Discharge

Parameter	Units	Class 1	Comments (1)
BOD_5	mg/L	≤ 30	
TSS	mg/L	≤ 30	
Total N	mg-N/L	< 20	
NH_4-N	mg-N/L	< 1	
Total P	mg/L	1	
pH	-	6-9	
Faecal streptococci	CFU/100mL	< 35	Geometric mean
Faecal Coliform	CFU/100mL	≤ 200	Geometric mean
Residual Chlorine	ppm	0.1	
Odour & Colour		none	

Note: (1) From EPD (Oct. 2015)

Table M. EPD Tertiary Treatment Guidelines for Reuse

Parameter	Units	Class 1	Comments (1)
BOD_5	mg/L	< 10	
TSS	mg/L	< 10	
Volatile Solids	mg/L	< 10	
Total-N	mg-N/L	$\leq$ 20	
pH	-	6-8	
Total Coliforms	CFU/100mL	<1	
Faecal Coliform	CFU/100mL	<1	
Faecal Streptococci	CFU/100mL	<1	
Residual Chlorine	ppm	> 0.5	(range 0.2 to 1.5)

Note: (1) From EPD (Oct. 2015)

Table N. Barbados Environmental Development Department Treated Wastewater Effluent Requirements for Reuse/Irrigation

Parameter	Units	Recommended Effluent Quality (1)
BOD	mg/L	< 10
TSS	mg/L	< 10
Volatile Solids	mg/L	< 10
Total Nitrogen	mg-N/L	< 5
Faecal Coliforms	Per 100 mL	nil
Total Coliforms	Per 100 mL	nil
Faecal Streptococci	Per 100 mL	nil
Residual Chlorine	ppm	0.5 (range 0.2 to 1.5)
pH	-	6–8

Note: (1) From EPD (Oct. 2015)

Based on the information presented in Table L, Table M, and Table N, for the purpose of assessing process upgrade options, it is concluded that:

1. Ammonia nitrogen and total phosphorus must be reduced to less than 1 mg-N/L, and 1 mg-P/L, respectively, for all discharge and reuse/irrigation options.
2. Total nitrogen needs to be reduced to a maximum of 5 mg-N/L, for all discharge and reuse/irrigation options.
3. BOD_5 and TSS need to be reduced to less than 30 mg/L for direct discharge, and to less than 10 mg/L for reuse applications, including irrigation;

4. Faecal coliform levels need to be reduced to less than 200 CFU/100 mL, and less than 1 CFU/100 mL for direct discharge and reuse, respectively, while there is no limitation for irrigation.
5. Residual chlorine in the effluent needs to be a minimum of 0.1 mg/L for direct discharge, and 0.5 mg/L (0.2 to 1.5 mg/L) for reuse / irrigation.

The maximum total nitrogen standard of 5 mg-N/l has been established in recognition of the impact nitrogen has on the coastal environment. As previously described, the removal nitrogen involves two well-understood biological conversions involving nitrification (ammonia oxidization to nitrate) and denitrification (conversion of nitrate to nitrogen gas). This can be achieved by a conventional activated sludge process, similar to the contact stabilization process currently in operation at the BSTP, along with a recirculation pump and the introduction of an anoxic zone at the head-end of the bioreactor. The stringent nature of the total nitrogen concentration is not difficult to achieve, but it requires a considerable amount of energy to recirculate nitrified wastewater to the head-end of the process and involves recirculation pumping at roughly eight (8) times the influent flow rate. Regardless of the treatment process, it will require, at a minimum, an anoxic and an aerobic bioreactor configuration.

5.5 Treatment Upgrade Options

5.5.1 Estimated Existing Bridgetown Sewage Treatment Plant Capacity and Effluent Quality

As noted in the Baseline Study Report, the current BSTP contact-stabilization activated sludge treatment process is not capable of nitrogen or phosphorus removal, other than that required for cellular growth. Figure P presents a BioWin (simplified) process schematic of the BSTP process, and Table O presents a summary of the modelled BSTP effluent quality performance using BioWin. The modelling results indicate the BSTP process configuration is capable of a high-quality secondary effluent in terms of BOD reduction and expected effluent suspended solids concentrations, but the BSTP process cannot remove nutrients as it is currently operated.

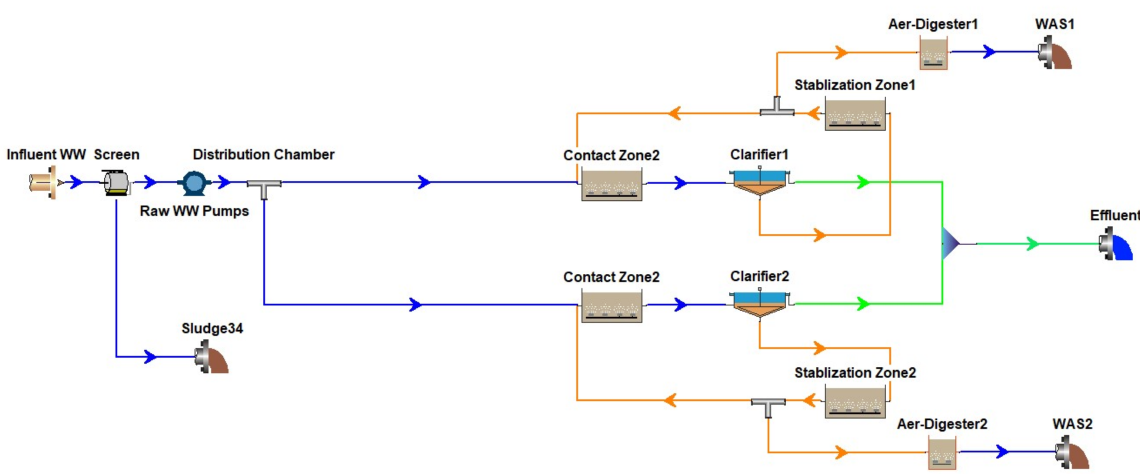

Figure P. Existing Bridgetown Sewage Treatment Plant Process Schematic

The BTSP was designed and built over 40 years ago to achieve secondary effluent quality standards, but there have been considerable advances in treatment technology since. Process upgrading would enable the BSTP to achieve a higher tertiary water quality suitable for reuse to satisfy non-potable water use requirements, such as irrigation, in addition to the potential for energy and nutrient resource recovery, depending on the process configuration selected.

Table O. BioWin Simulated Performance of the Existing Bridgetown Sewage Treatment Plant Treatment Process

AWWF (m^3/d)	PDWF (m^3/d)	BOD_5 (mg/L)	NH3-N (mg/L)	NO-X (mg-N/L)	T-N (mg-N/L)	P-T (mg-P/L)
4,100	9,300	9.9	7.5	22.2	33.3	4.64

5.5.2 Bridgetown Sewage Treatment Plant Upgrade Options Considered

Three treatment processes were considered as potential upgrade options for the existing BSTP, specifically: 1) CAS; 2) MBBR-MLE; and 3) MBR). These technologies provide a reasonable representation, for comparative purposes, of the wide range of process configurations that can achieve a high-quality tertiary effluent suitable for non-potable water uses with a high potential for public contact. Further, each of the technologies considered can take advantage of the existing wastewater treatment plant components by modifying the existing component's use and repurposing the component.

Of the three process configurations, the CAS represents the simplest process configuration to operate and the least expensive to implement (similar in operation to the existing BSTP process), while the MBR-UCT represents technologies that have a high-potential for nutrient removal and/or recovery and a small footprint, but are also more complex and expensive to construct, operate and maintain.

Conventional Activated Sludge Process Upgrade

The CAS process (see Figure Q) represents modifications to the existing contact-stabilization process that would convert the existing BSTP to a plug-flow activated sludge process configuration capable of achieving a higher degree of nitrification than the existing contact-stabilization process is capable of. The upgrade conversion involves modifying the two existing aerobic digester tanks and the two secondary clarifiers into aerated bioreactors that could be added to the two existing aerated contact chamber tanks and the two aerated stabilization chamber tanks to form two parallel process trains capable of complete ammonia nitrification (i.e. total ammonia less than 1 mg-N/L). Two new secondary clarifiers would need to be constructed with a hydraulic capacity for future flows, and the clarified effluent would then flow through tertiary filters. Chemical phosphorus removal can be incorporated into the process by adding aluminium or iron salts before the secondary clarifiers. The addition of anaerobic digesters to recover methane from the waste biosolids can be considered and would stabilize the sludge before off-site disposal. Note that chemical phosphorus removal is not shown in Figure Q.

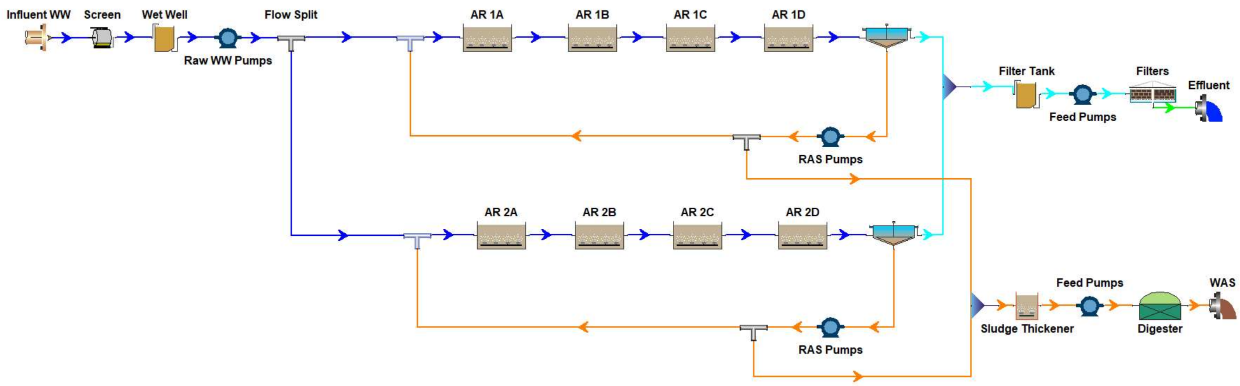

Figure Q. BioWin Schematic of the Existing Process Converted to a CAS Plug-Flow Process

If no sewer expansion is contemplated, the existing contact stabilization could be upgraded with tertiary filters and disinfection added to achieve a water quality suitable for water reuse applications.

Moving Bed Biofilm Reactor – Modified Ludzack-Ettinger Configuration Process Upgrade

The existing BSTP process could also be converted to an MBBR-MLE process configuration (as illustrated in Figure R) to both nitrify the ammonia to nitrate and then denitrify the nitrate to nitrogen gas, which is released to the atmosphere. This conversion could be done by adding MBBR media to all the bioreactors along with modification to retain the media in the tanks. The two existing stabilization chamber tanks could be converted into anoxic reactors, and the two existing secondary clarifiers and the two aerobic digesters could be converted into aerated bioreactors. The existing aeration grids located in the stabilization chambers, contact chambers and aerobic digesters could be decommissioned and replaced with coarse-bubble aeration grid. As for the CAS upgrade, two new secondary clarifiers along with tertiary filters would need to be added to the process to achieve the quired suspended solids and turbidity levels for reuse applications. Chemical phosphorus removal and anaerobic digestion may also be incorporated with this option. Chemical phosphorus removal is not shown in Figure R.

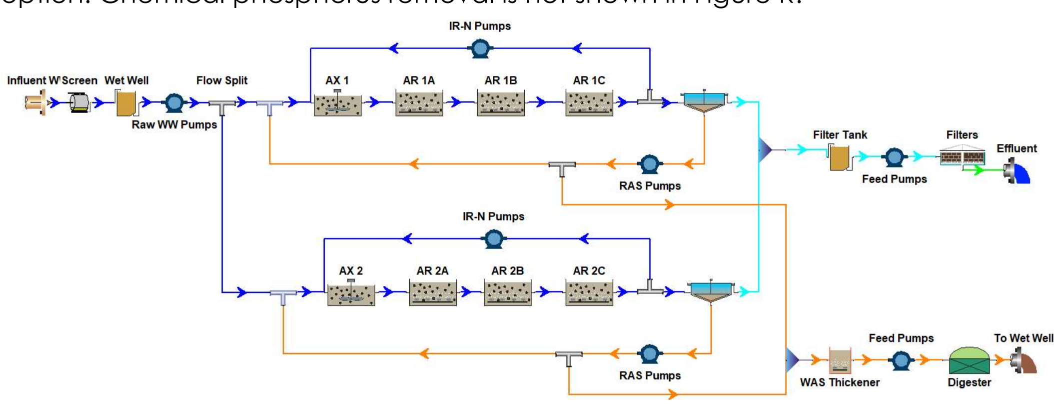

Figure R. Converting Existing Process to Moving Bed Biofilm Reactor – Modified Ludzack-Ettinger Process

Membrane Bioreactor – University of Capetown Configuration Process Upgrade

The MBR-UCT configuration (as illustrated in Figure S) could be capable of providing both biological nitrogen and phosphorus removal. The upgrade involves converting the two existing stabilization chambers into anaerobic process tanks, positioned at the beginning of the process, and adding in impeller tank mixing system. The two existing secondary clarifiers could be converted to anoxic bioreactors and the two existing aerobic digesters would be converted to aerobic bioreactors. A membrane tank would need to be added to enclose the MBR membrane cassettes. Chemical phosphorus removal is not shown in Figure S.

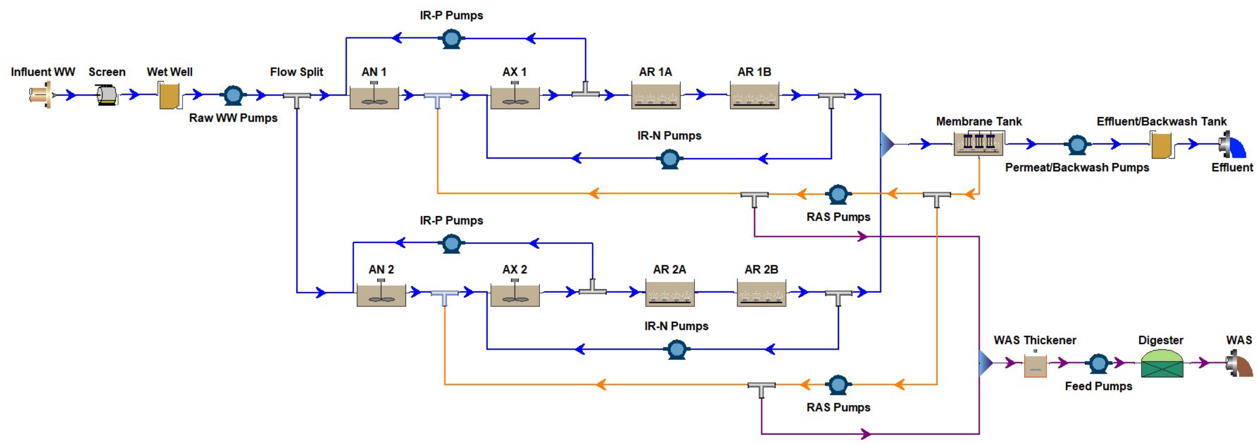

Figure S. Converting Existing Process to Membrane Bioreactor – University of Capetown Configuration Process

Upgrade Options Comparison

0 and Table Q present a comparison of the expected effluent water quality for the three upgrade options based on BioWin modelling. All three options are expected to achieve a tertiary water quality suitable for non-potable water reuse applications, along with nearly complete nitrification. While the T-N concentration indicates a modest degree of total nitrogen removal for the CAS process, a significantly lower T-N concentration is expected to be achieved for the MBBR-MLE and MBR-UCT configurations. Most noteworthy is that while a modest degree of phosphorus removal is achieved for both the CAS and MBBR-MLE configurations, the MBR-UCT configuration is expected to achieve a high degree of biological phosphorus removal (0.2 mg/L) without the use of chemicals, while producing about 6,000 kg/d of waste biosolids, of which 77% is volatile.

Table P. Wastewater Treatment Upgrade Effluent and Capacity Comparison

PROCESS	Q m^3/d	BOD_5 mg/L	NH_3-N mg/L	NO-X mg-N/L	T-N mg/L	P-T mg/L	WAS-TS kg/d	WAS-VS kg/d	VS/TS %
CAS	24,000	5	0.37	25.2	27.8	2.5	5,972	4,572	77
MBBR-MLE	20,000	3.5	0.87	2.3	4.9	2.5	5,536	4,410	80
MBR -UCT	30,000	2	0.61	4.7	7.0	0.2	7,352	5,378	73

Table Q. Wastewater Treatment Upgrade Aeration and Power Comparison

PROCESS	Q m^3/d	Aeration Nm^3/h	AR Power kW	AR Power $kW.d/m^3$
CAS	24,000	12,086	170	7.1
MBBR-MLE	20,000	45,148	637	31.9
MBR -UCT	30,000	32,686	461	15.4

The upgraded MBBR-MLE configuration would have a lower treatment capacity (20,000 m^3/d) than the CAS configuration (24,000 m^3/d) and generate about 5,500 kg/d of waste activated sludge of with an 80% volatile content.

The MBR-UCT configuration upgrade would have the highest treatment capacity (30,000 m^3/d) of the three options and is expected to produce an effluent with the lowest total nitrogen concentration (7 mg-N/L) and lowest total phosphorus concentration (0.2 mg-P/L). Due to the increased load capacity, it also produces the most waste activated sludge (7,400 kg/d) with a lower volatile content of 73% due to having the longest sludge age (SRT).

As the upgrade modifications and associated wastewater treatment capacities are primarily based on modifying the existing infrastructure and tanks, the indicated capacities can be increased beyond that shown by constructing additional tanks.

Table Q compares the aeration and associated power requirements that relate to the cost to operate each technology for the three process configuration upgrades. The power requirements, per 1000 m^3 of wastewater treated, show the CAS process has a significantly lower operating cost that the other two technologies; about one-half the power requirement of the MBR-UCT process and about one-quarter the unit power requirement for the MBBR-MLE process configuration. There is enough land area to accommodate the required new secondary clarifiers for the CAS and MBBR-MLE configurations and the membrane tanks required for the MBR-UCT configuration.

5.6 Treatment Upgrade Options to Increase Capacity and Effluent Quality for the Existing Bridgetown Sewage Treatment Plant

5.6.1 Effluent Quality

Table R illustrates the BioWin modelling results for the three configurations based on collecting and treating all the wastewater generated within Bridgetown to a water quality standard suitable for unrestricted public access non-potable water reuse applications. Each of the three process configurations shown in Table R have the same treatment capacity and will achieve the same reclaimed water quality objective; however, only the MBBR-MLE and MBR-UCT configurations are designed for nutrient removal.

Table R. Wastewater Treatment Technology Effluent Quality Comparison

PROCESS	Q m^3/d	BOD_5 mg/L	NH_3-N mg/L	NO_3-N mg/L	T-N mg/L	T-P mg/L	WAS-TS kg/d	WAS-VS kg/d	VS/TS %
CAS	56,684	5	0.2	25.88	28.6	2.6	13,988	10,602	76
MBBR-MLE	56,684	5	0.5	3.16	6.1	2.9	13,634	10,444	77
MBR-UCT	56,684	1	0.4	4.9	6.5	0.5	13,248	9,586	72

The Biowin model layouts for the three configurations are illustrated in Figure T, Figure U, and Figure V.

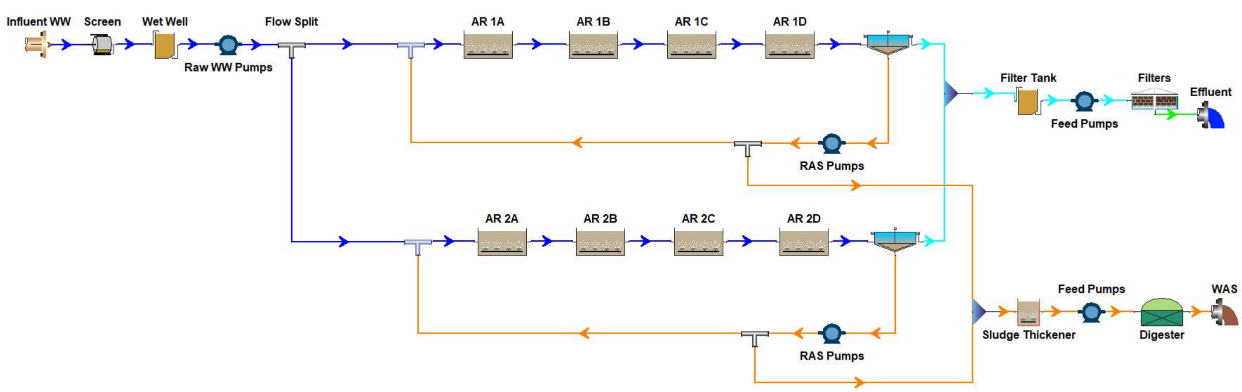

Figure T. BioWin Conventional Activated Sludge Plug Flow Process Schematic with Tertiary Filtration, Anaerobic Digestion and Mechanical Sludge Dewatering. (No Primary Clarification)

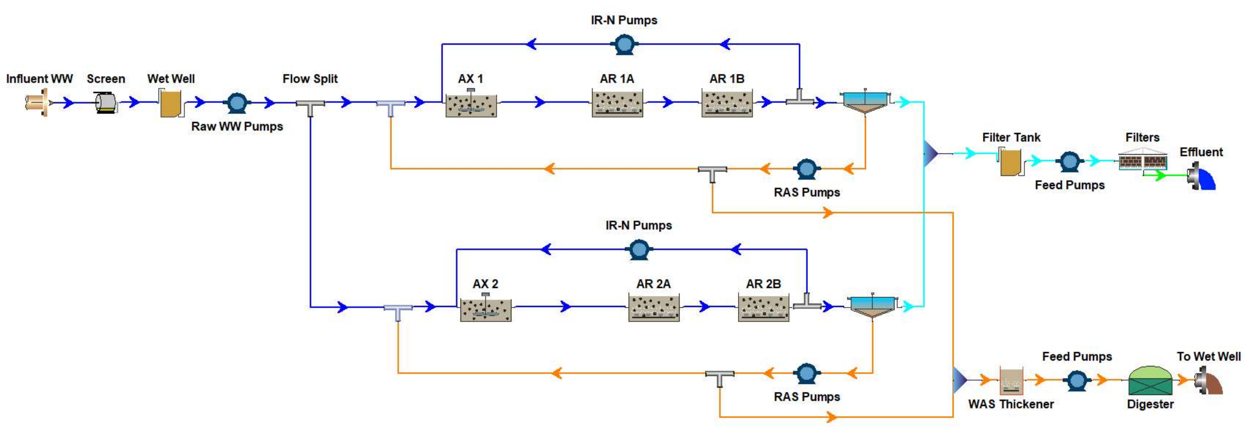

Figure U. BioWin Moving Bed Biofilm Reactor – Modified Ludzack-Ettinger Configuration Process Schematic with Tertiary Filtration, Anaerobic Digestion and Mechanical Sludge Dewatering. (No Primary Clarification)

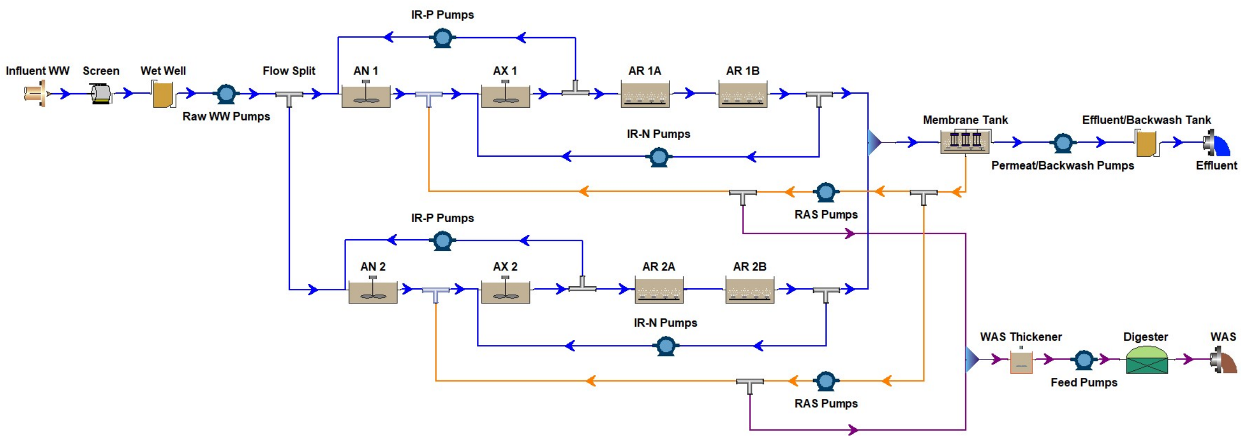

Figure V. BioWin Membrane Bioreactor – University of Capetown Configuration Process Schematic with Tertiary Ultrafiltration, Anaerobic Digestion and Mechanical Sludge Dewatering. (No Primary Clarification)

5.6.2 Upgrade Options - Reactor Sizes

Table S illustrates the relative size of the bioreactor tanks required for each of the three configurations, noting they all have similar total volumes, although the use of the total tankage is considerably different for each configuration.

Table S. Wastewater Technology Reactor Volume Comparison

PROCESS	AN (m^3)	AX (m^3)	AR (m^3)	Clarifier (m^3)	Total Vol (m^3)
CAS	0	0	11,160	4,800	15,960
MBBR-MLE	0	1,200	4,800	2,400	8,400
MBR-UCT	2,400	4,000	7,200	400*	14,000

*For MBR Membrane Cassette Tank

5.6.3 Upgrade Options - Power Consumption

Table T illustrates the aeration, pumping and total energy consumption for the three process configurations. Because biological nutrient removal requires a considerable amount of energy for recirculation pumps, the power requirements for pumping for the MBBR-MLE and MBR-UCT configurations are considerably greater than for the CAS configuration. The MBR-UCT power consumption is almost three (3) times that required for the CAS configuration, the MBBR-MLE power requirements are almost five (5) times greater than the CAS configuration. The impact of power consumption in terms of energy cost and associated GHG emissions, related to power generation if electricity in Barbados is still generated primarily by diesel generators, is a significant and important consideration. The cost of nutrient removal is substantial, and the need for nutrient removal for the reuse applications, largely expected to be irrigation and/or groundwater recharge, needs to be carefully considered.

Table T. Wastewater Treatment Technology Power Consumption Comparison

PROCESS	Aeration Nm^3/h	AR Power kW	Pumping kW	Total kW
CAS	32,504	458	132	590
MBBR-MLE	153,278	2,162	690	2,852
MBR-UCT	57,702	814	892	1,706

5.6.4 Upgrade Options - Overall Comparison & General Notes

Key notes pertaining to the upgraded of the BSTP wastewater quality and capacity to treat all of the Bridgetown wastewater include:

- The flow rates shown in Table R are for one treatment train, and total of two (2) trains will be required to treat the projected wastewater from a design population of 112,000 for Bridgetown, with the total plant capacity of 56,684 m^3/d;
- CAS process was modelled as a plug flow reactor;
- MBBR-MLE configuration reactor sizes are significantly smaller than would be required for a MBBR process alone due to the amount of biomass associated with suspended growth as a result of recirculation;
- MBBR-MLE process clarifier volume shown in the Table S is for the membrane tank;
- The pumping power calculation was based on assuming a pumping head of 8 m and 60% mechanical and electrical efficiencies; and
- The aeration power calculation was based on 4.5 m water column (same as the existing plant), and 70% mechanical and electrical efficiency, and based on the following equation.

$$Pw = \frac{wRT1}{29.7\,ne}[\left(\frac{P2}{P1}\right)^{0.283} - 1]$$

W:		Mass flow of air
R:	8.314	Gas constant
T1:	303	Absolute inlet temperature
P1:	1	Absolute inlet pressure
P2:	1.6	Absolute outlet pressure
n:	0.283	constant for air
k:	1.395	constant for air
e:	0.7	Blower efficiency

5.7 Water Reuse

As previously discussed, wastewater management and water reuse are connected, and it is a critical mitigation measure required to address climate change impacts on water resources in Barbados. Centralized management reuse considerations include ensuring the wastewater is treated to the necessary reclaimed water quality standard either for its most significant applications or its greatest range of non-potable water uses.

Large-scale, or large capacity, reclaimed water reuse applications are typically related to satisfying irrigation demands or indirect potable reuse through groundwater recharge. While agricultural irrigation can often benefit from secondary effluent quality reuse water where there is limited potential for public contact or with food crops, irrigation typically has wide seasonal variations in demand (less is required during the wet season) and other reuse applications generally require a higher reuse water quality standard.

One of the key challenges in making reclaimed water available for a wide range of reuse applications is the cost of distributing (using piping or even trucking) the reclaimed water to those uses. Building applications, such as toilet flushing, require dual plumbing (non-potable plumbing in parallel with potable water plumbing) to be installed at considerable cost.

There is an increasing number of communities globally that now practice indirect potable water reuse as well as direct potable water reuse. The former involves applying or recycling the reclaimed water in a manner that would add to the water resource available for potable water, but in a manner that the water must flow through an environmental buffer to be part of the potable water resource. The latter involves treating the water to a potable water quality, often using reverse osmosis or a similar technology, and then blending it with the raw water being treated to produce drinking water.

The Spring Garden BWRO desalination plant in Bridgetown could potentially be a convenient location to return reclaimed water from the BSTP to the ground in a manner that would increase the availability of potable water supplies. The reclaimed water from the BSTP could be piped or trucked and discharged to the ground in vicinity of the Spring Garden BWRO desalination plant groundwater intake, thereby increasing the availability of groundwater in the area. Another consideration could be to treat the wastewater using RO at the BSTP and then blend it with the groundwater that is extracted for treatment at the Spring Garden BWRO desalination water treatment plant.

5.8 Energy Resource Recovery

The energy potential for all the scenarios evaluated is proportional to the mass of waste and the VS content generated by each of the three treatment process configurations. Process configurations that retain biomass within the treatment process longer will produce less waste biomass as a result of endogenous decay, where bacteria feed on other bacteria and reduce the biodegradable organic (volatile) content of the sludge.

Adjusting for flow, Table U illustrates that the MBR-UCT and the CAS are expected to produce similar amounts of volatile sludge with the same bio-energy generation potential through anaerobic digestion, and the MBR-UCT is expected to produce about one-third more volatile biomass (energy potential) than the other two process configurations.

Table U. Projected Volatile Solids

PROCESS	Total Amount of VS (kg per m^3 of wastewater treated)
CAS	0.19
MBBR-MLE	0.25
MBR-UCT	0.18

The amount of energy generated can also be greatly increased by including primary clarification into the design. The primary clarifier withdraws a large portion of the influent solids, which contains a very high volatile content. Without a primary clarifier, these solids will pass through into the bioreactor where the energy associated with the VS will be consumed by bacteria for metabolic purposes, reducing the overall energy potential. For example, Table V illustrates that with primary treatment is included, the MBR-UCT process is expected to produce 3 times more electricity and heat energy, assuming 40% and 30% conversion recoveries, respectively. For comparative purposes, the conventional activated sludge process currently in use would be expected to produce about half the amount of energy.

Table V. Energy Projections

PROCESS	Total Energy Generated (kW)	Equivalent Electricity Generated (kW)	Equivalent Heat Energy Generated (kW)
MBR-UCT, *without* primary clarification	365	145	110
MBR-UCT, *with* primary clarification included (1)	1070	430	320

Note 1 - Assuming 40% and 30% conversion recoveries between electricity and heat, respectively.

5.9 Nutrient Resource Recovery

When biosolids are digested anaerobically, the cell walls break down releasing nutrients into solution. Once digestion is completed, the digested solids are removed and subjected to dewatering processes that remove a significant proportion of the water, the ammonia and phosphorus released from the biomass during digestion. By adding calcium and/or magnesium salts to the filtrate, or centrate, generated through dewatering, a precipitate can be formed containing both ammonia and phosphorus.

Struvite ($MgNH_4 PO_4 6H_2O$) precipitation is a well-known fertilizer recovery product that can be precipitated if the concentration of phosphorus and ammonia are high enough. This is typically achieved by anaerobically digesting biosolids that are produced by a biological nutrient removal process that is designed for biological (excess) phosphorus removal. Anaerobic digestion results in the release of high concentrations of dissolved phosphorus and ammonia into solution, which is separated from the digested biomass during dewatering. If the water from the dewatering process is not properly managed, struvite can form naturally and uncontrollably within the pipes, and the crystals that form can cause serious operational issues to plant operations, such as pipe blocking, valve malfunction, and pump damage.

Struvite crystals are formed in a controlled manner by adding magnesium and achieving dissolved magnesium, ammonia and phosphorus concentrations that accessed the solubility of struvite, causing the crystal precipitate to form. The crystals are harvested from solution and can be used directly as a fertilizer or blended with other fertilizers to create specific nutrient ratios for different plants and growing cycles. Struvite crystal formation enables nutrients to be recovered as a valuable resource by-product and could be a revenue source.

Some of Struvite recovery technologies include:

1. **Pearl, from Ostara**

   This technology utilizes magnesium to facilitate and accelerate the formation of struvite in a specially designed FBR reactor under controlled pH setting. The formed struvite is crystallized into a granular product in the reactor and is dried and bagged as the commercial product.

2. **Struvia, from Veolia**

   This technology utilizes a continuous stirred reactor with addition of magnesium salt for form struvite under elevated pH, then separates struvite using an integrated lamellar settler. Once separated, struvite is drained to dry in a storage facility before is sent to the packaging unit.

3. **AirPrex, from CNP-Water and Biosolids Corporation**

   This technology also employs fluidized reactor and magnesium to form Struvite, but the reaction is augmented with CO2 air stripping provided with the reactor.

4. **NuReSys**

   This technology employs an aerated reactor that is completed mixed with CO_2 stripping. The technology can form Struvite with or without addition of magnesium salt depending on the applications and the specific site conditions.

The purpose in mentioning the above technologies is to illustrate the commercial viability and availability of technologies that can recover a nutrient product from wastewater. Although, the decision to implement nutrient recovery technology is generally not based on economics, but rather is driven by social considerations and the ability to demonstrate that resources of value can be recovered.

The total amount of wastewater that is generated in Bridgetown represents about 300 kg/d of phosphorus. If a biological phosphorus removal process were implemented, approximately 50% (55 tonnes per year) could be recovered and sold or used commercially, while about 50% would remain in the residual biomass that could benefit the land it was applied to. Diammonium phosphate [$(NH_4)2PO_4$] increased to about US$390 per tonne in 2020. It contains about 24% phosphorus by weight, so in terms of the phosphorus content the value is about US$1,560 per tonne. As a very rough estimate, the value of the phosphorus that could be collected at the BSTP serving all of Bridgetown is about US$86,000 per year. At face value, this does not seem to have a highly significant economic value; however, it also represents a reduction in GHG emissions associated with the need to transport phosphorus to Barbados.

5.10 Renewable Energy Recovery

5.10.1 Energy Options

The electricity supply in Barbados is provided by Barbados Light & Power Company with conventional power plants that use fossil resources, and the price of electricity in Barbados high in comparison to other industrialised countries.

Barbados is pursuing a goal of complete decarbonisation by 2030 and the policy for a climate-neutral Barbados is regulated in the ELPA. It also prescribes feed-in tariffs, which the Fair-Trade Commission readjusts every two years for renewable energy fed into the Barbados electricity grid. The parameters used are described in Table W, 0, and Table Y.

Table W. Alternative Energy Installed Costs for a 20-Year Term

RE	Installed Cost[1] (US$/kW)	Net Capacity Factor	Annual Degradation
Solar			
Up to 10 kW	$3,044	18%	0.5%
Above 10 kW-100 kW	$2,326	18%	0.5%
Above 100 kW-250 kW	$2,097	19%	0.5%
Above 250 kW-500 kW	$1,848	19%	0.5%
Above 500 kW-1 MW	$1,790	20%	0.5%
Wind			
Up to 10 kW	$4,146	25%	0.5%
Above 10 kW-1 MW	$2,856	30%	0.5%
Other Technologies			
Anaerobic Digestion	$8,177	75%	0%
Solid Biomass	$5,370	91%	0%

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Table X. Alternative Energy Operating Costs

Operating Cost Inputs – Year 1 Expenses (subject to inflation)					
RE	**Fixed O&M** (US$/kW- yr)	**Site Lease** (US$/kW- yr)	**Insurance** (US$/mille)	**Project Mgmt** (US$/kW- yr)	**Land Tax**[3] (% of rev.)
Solar					
Up to 10 kW	$50	N/A	2	Incl. in O&M	0%
10 -100 kW	$18	N/A	2[2]	$20	0.95%
100 - 250 kW	$18	N/A	2[2]	$38	0.95%
250 – 500 kW	$18	$13	2[2]	$32	0.95%
500 -1,000 kW	$16	$13	5[2]	$30	0.95%
Wind					
Up to 10 kW	$35	N/A	2	Incl. in O&M	0%
10 -1,000 kW	$35	$13	5[2]	$37	0.95%
Offshore	$120	$13[1]	0.4% of cost	Incl. in O&M	N/A
Other Technologies					
Anaerobic	$300	$13	0.4% of cost	$18	0.95%
Solid Biomass	$238	$13	US$27/kW-	$18	0.95%

1. *Proxy for comparable benefits assumed paid in lieu of a site lease.*
2. *US$2/mille for equipment replacement and US$3/mille for business interruption insurance. Mille = Thousand*
3. *Rate of US$0.15/kWh used as proxy for value of electricity sold to calculate tax.*

Table Y. Feed-In Tariffs

Technology, Size Category	Oct. 1, 2019 – Dec. 31, 2021 FIT 31, 2021 FIT (US$/kWh)	Oct. 1, 2019 – Dec. 31, 2021 FIT 31, 2021 Allocation (MW)
Solar, Up to 10 kW	21.38	5
Solar, Above 10 kW to 100 kW	22.38	
Solar, Above 100 kW to 250 kW	20.88	8
Solar, Above 250 kW to 500 kW	19.13	
Solar, Above 500 kW to 1 MW	18.13	12.7
Land-Based Wind, Above 10 kW to 1 MW	19.88	3
Anaerobic Digestion, Up to 1 MW	22.13	2
Solid Biomass, Up to 1 MW	26.13	2
	Total Allocation	32.7

5.10.1 Harvesting Solar Energy

Barbados has favourable solar radiation conditions due to its location in the tropics. Therefore, the installation of PV for electricity generation and solar thermal energy for hot water production is advantageous.

Recently, the Barbados Light & Power Company deployed 44,496 panels covering 42 acres of land and producing an estimated 10 MW per day into the national grid[3]. Assuming a standard panel has an area of 1.93 m^2 (related to: 77" x 39") per panel, the total area of solar panels is estimated to be 86,200 m^2, that produce approximately 120 Watts/m^2.

The total number of hours of sunlight in Barbados is about 3,030 hours per year (or an average of about 8.3 hours per day). Using a reasonably conservative panel output of 120 W/m^2, about 1.0 kWh/m^2/d (0.12 W/m^2 x 8.3 h/d) can be produced by PV panels mounted over open areas within the BSTP property. Additional PV panels can also be installed off-site and tied to the grid and contribute to the BSTP electrical demands. A further analysis of how this can apply to the BSTP site is discussed in Section 2.7.2.

5.11 Legislation and Policy Reform Considerations

Further to Section 3.6 (regarding Wastewater Governance and the Policy Framework) in the Baseline Study, a legislation and policy review was conducted related to the Barbados wastewater sector and offer the following reform considerations.

The National Environmental Survey (2010), and the Barbados National Assessment Report (2010) have pointed to outdated and inadequate legislation, overlapping and contradictory roles and responsibilities, conflicts of interest and poor enforcement as hampering the efficient and effective management of water resources and, provision of water and wastewater services. At present the BWA is responsible for both the regulation of the country's water resources as well as the delivery of water and wastewater services. The water sector has long recognised that this is a conflict of interest, and the roles should be separate; regulatory functions should not be mixed with service delivery. It has long been acknowledged that the governance of the sector needs an overall to improve its transparency and accountability[4] [5] and the introduction of participatory mechanisms in decision-making. Regulatory roles and requirements are in some cases overlapping and contradictory.

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[3] https://www.blpc.com.bb/

[4] Cashman. (2017). Why isn't IWRM working in the Caribbean? *Water Policy Journal*. DOI: 10.2166/wp.2017.100

[5] Cashman. (2011). 'Our water supply is managed like a Rumshop': Water Governance in Barbados. Social and Environmental Accountability Journal (Special Issue on Water), 31(2) pp: 155-165.

A review of existing policy and legislation related to this project was conducted and reported within Section 3.6 of the Baseline Study report. In addition to the information contained in the Baseline Study report, specific examples of gaps in the legislative and regulatory environment that have been identified through CReW and other projects include:

- Outdated legislation:
  - Three Houses Spring Act (1713) and Porey Spring Act (1864) have contradictions and it has been recommended that they should be either reviewed or repealed.[6]
- Failure to develop and implement legislation as well as resolve conflicting legal provisions:
  - Draft Environmental Management Act;
  - Draft Water Reuse Act and regulations[7]; and
  - Conflict between Groundwater Zoning Policy requirements and the provisions of the Marine Pollution Control Act, chapter 392A, particularly with respect to the coastal strip.
- A lack of a comprehensive regulatory framework, including inter alia;
  - Private sector participation in the provision of wastewater services; [8]
  - Improved effluent discharge standards;
  - Standards for the control of agricultural run-off;
  - Policy provisions and codes of practice regarding wastewater infrastructure and design standards, septic tank design, soak-away, appropriate technology and, EIA and waste management provisions; [9]
  - Performance standards for wastewater services;
  - Although there has been some recent development regarding the Barbados National Standard's Code of Practice CP 16 (Part 1): 1981 UDC 691.1:628.15/.3 August 1981, further updates are required to include provisions for wastewater reuse (reclaimed water) as well as rainwater harvesting in the interest of public health, including revisions to the building code to allow different colour pipe (purple suggested) for the use of reclaimed water within buildings[10]; and
  - Complaints regarding the control of nuisance arising from odours and air quality.
- An absence of national medium-term management master plan:
  - Develop a master plan for the management of the country's water resources and, water and wastewater services that takes into account the National Physical Development Plan and national economic development priorities; and
  - Require the water and wastewater service provider (currently the BWA) to draw up and publish, every 5 years, its asset development and financial management plan.

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[6] CEHI (2008)

[7] CEP TEC Rep 66

[8] IDB (2018) Description of the activities by Ms. Daphne Kellman

[9] Moore, W., Alleyne ,F., Alleyne, Y., Blackman, K., Blenman, C., Carter, S., Cashman, A., Cumberbatch, J., Downes, A., Hoyte, H., Mahon, R., Mamingi, N., McConney, P., Pena, M., Roberts, S., Rogers, T., Sealy, S., Sinckler, T. and A. Singh. 2014. Barbados' Green Economy Scoping Study. Government of Barbados, University of West Indies - Cave Hill Campus, United Nations Environment Programme, 244p.

[10] IDB mission report

- An absence of independent economic and service performance regulation to;
  - Develop, set, and periodically revise tariffs for the abstraction, supply and use of water and, for wastewater services; [11]
  - Require the provision of acceptable standards of service and impose penalties when these are not met; and
  - Require the development and submission of business plans for service provision.

Other challenges include the limited human and financial resources which limit the ability to monitor and enforce compliance with legal and regulatory requirements. Financing the upgrading, improvement and extension of wastewater infrastructure and services is a major challenge given the scale of investment required and the limited capacity constraints. The implementation of innovative financing mechanism will need to consider and empower the involvement of the private sector, including legislative change to allow non-state actors to play a role. Lastly, there needs to be better policy coordination across sectors particularly with respect to economic development planning; tourism and agricultural development planning need to consider water availability and wastewater management issues.

The immediate needs that have been identified and which could form the basis of activities to be undertaken include the development of:

- Water Reuse strategy and programme;
  - Regulations governing reuse and effluent discharge standards; and
  - Identification of uses and markets for treated reclaimed water.
- Strategy and programme for low-income communities addressing water and wastewater services, including;
  - Water conservation;
  - Water reuse; and
  - Decentralised treatment.
- Establish national reclaimed water reuse and plumbing standards including;
  - Codes of Practice;
  - Training and certification; and
  - Registration requirements.

Identifying the legal provisions to support these activities would be a necessary first step to be undertaken to be followed by the drafting of appropriate legislation and/or regulations and their passage and entry into force.

6 OPERATIONAL AND MAINTENANCE CONSIDERATIONS

Regardless of whether a centralized or decentralized wastewater collection and/or treatment system is selected as the preferred design option for this project, the BWA needs to remain committed to improving the operation and maintenance programme. This section builds on

[11] IDB (2018) Description of the activities by Ms. Daphne Kellman

information gathered from the BWA for the Baseline Study and provides detailed recommendations on how to improve the BWA operation and maintenance programme.

The proposed conceptual options involve upgrading the existing BSTP to significantly improve the effluent water quality to a reuse standard as well as consideration for increasing the collection and treatment capacity to serve all of Bridgetown. Although one of the alternative process configurations (CAS) is very similar in nature to the existing BSTP activated sludge characteristics, a greater degree of operator knowledge is required to manage the three technology options than is currently needed (and outlined within the previous Section 5), and improvements to operations and maintenance are required.

6.1 Maintenance Programme

6.1.1 Overview

Over the years, the maintenance focus at BWA has shifted away from PM to emergency breakdown maintenance. PM will extend the life cycle of the equipment and help to reduce breakdown maintenance that can come with a high financial and environmental cost. PM in the plant and distribution system is no different than a person conducting ongoing maintenance on their vehicle. If oil changes and engine check-ups are not performed regularly, it results in more expensive breakdowns that must be fixed, as well as the loss of use for a more extended period of time. The same is true for the wastewater infrastructure, including the treatment and distribution network. Another fall-out from the lack of PM is the attitude of staff. It can result in a lack of pride in the workplace and a laissez faire attitude.

From discussions with BWA staff, the reason for this shift away from a scheduled maintenance programme to one that is purely reactive appears to be a lack of staff resources dedicated to preventative maintenance and available finances for maintenance in general.

The staffing within the BWA Wastewater Division mirrored the staffing of the Operations and Maintenance Section with large numbers of staff assigned as plant operators. A much smaller number of staff are assigned to the maintenance of the plant although the treatment process is largely automated. These operators are not tasked to do any maintenance and there does not appear to be a maintenance schedule, or funds allocated in the budget for such.

The ratio of maintenance staff to those in operations has not changed over time although the maintenance requirements for the plants and collection systems would have increased as equipment becomes worn and degraded. There also appears to be government capital funding issues that result in requests for new parts, often never being receiving to complete the repair/replacement order, leading to further deterioration of existing equipment.

Both these issues need to be examined in conjunction with establishing a strong PM culture within the BWA. To successfully transition away from breakdown maintenance, adequate resources are required. However, these resources do not necessarily have to be new. Much could be accomplished by shifting staff from areas where there are adequate resources to a maintenance focus.

There is also a major problem in getting replacement parts. One reason is because some of the equipment is old, and it is difficult to source parts. To improve this situation, staff are trying to standardise equipment to make it easier to source replacement components and parts. Standardization of equipment also greatly simplifies the number of PM tasks required to be developed when compared to having multiple brands of equipment.

6.1.2 Observations

This report considers undertaking significant upgrades to the BSTP to meet the project objectives. These upgrades will result in an increased level of treatment, equipment sophistication and/or increased treatment capacity that is expected to exacerbate the operations and maintenance problems, unless improvements are made. The following are recommendations for initiating a robust maintenance programme.

To support a maintenance programme the training programme of BWA staff should be reviewed and revised, as necessary. All operational staff should have a basic knowledge of simple trouble shooting of equipment so they can be the first line of investigation into maintenance issues before relying on dedicated maintenance staff. Boundaries will need to be established to ensure that issues requiring expanded knowledge are turned over to maintenance staff so they may be corrected in a safe professional manner and captured into the maintenance program.

Maintenance staff would benefit from having some basic operator training and process knowledge to aid in discussions with operations staff and better understand the importance of equipment maintenance from a treatment performance perspective and potential impacts caused by equipment shutdown.

An example of where this cross training would be beneficial is with the large problem of maintaining pumps. Although new screens have been installed at the plants, BWA staff still perform breakdown maintenance on pumps, though it seems that this might just be de-clogging of the pumps rather than actual mechanical/electrical maintenance. They check the running Amperes on the pumps and use this as an indication that they need to give attention to a pump. It is not clear if records are kept and if so, how, and where. With basic training, clogging could be handled by operational staff up until the point where mechanical/electrical maintenance is required, thus freeing up maintenance staff for more specialized tasks.

Reviews of staffing levels and proposed restructuring plans have been completed in the past. These reports should be revisited, examined, and acted upon from the aspect of shifting resources from operational roles to maintenance ones.

Financial support for a maintenance program could be found and earmarked from the collection of fees for the provision of sewage services, implemented by the new Administration which took office in May 2018. The old system of collection of fees for the provision of sewage services was restricted to the domestic and commercial properties within the entire wastewater collection areas, and only applied to those customers who were attached to the collection system. The new system of levies was applied to all the BWA customers and has resulted in the collection of significantly greater sums. The levy being US$3.88/month/customer (or approximately US$388,000/month or US$4.7 million per annum). This funding has been applied for the purchase and installation of critical pieces of equipment at the two treatment facilities. However, it should be noted that if there is no preventative PM instituted, then these new purchases could become inoperable in a very short period.

With the expansion and replacement of equipment proposed in the coming years, an opportunity exists to revisit and invest the time and resources into developing a robust CMMS. Establishing and populating the CMMS prior to any expansion and upgrades will create a smooth transition of the new equipment into an established system thus allowing the equipment to be entered into the PM cycle from its installation forward.

Although an attempt was previously made to implement a CMMS, the maintenance of the treatment and collection system was done on a breakdown schedule rather than according to the schedule of the equipment manufacturers.

A CMMS, whether developed in-house or from a third party, can be tailored to any degree of complexity, but all systems have the same basic principles and goals. The end goals are to establish and maintain a well-documented PM program to extend the life of the equipment and to keep it functioning at the design level to maintain effluent quality and reduce any environmental impacts or health and safety issues.

Most CMMS programs are scalable in the sense that the same processes are required for a large system as would be required in a much smaller system. Once the structure and hierarchy are developed, additional equipment can be easily added to the system using established BWA templates.

It is for this reason a pilot program is suggested to be carried out within an area of the systems to establish the core programme for a subset of equipment. This can then be expanded by migrating any other existing equipment into the system later once the system is refined.

Future equipment replacement and expansion could be captured into the existing system through requirements written into future contracts to ensure that specifics of the equipment, required PM tasks and scheduling are provided on BWA established templates. This process can be linked to the acceptance of equipment.

Up-to-date, accurate information is required for BWA staff to perform their roles safely and efficiently. Any new upgrades or replacement equipment must be incorporated into existing operations and maintenance manuals and any drawings related to the equipment in a timely fashion.

A strong candidate for piloting a CMMS would be within the operation and maintenance of the collection system and sewage lift stations. Staff in this area do have experience with PM tasks. This area is also a good starting point as the stations basic equipment and components are similar.

At a high level the development of a CMMS would involve the following tasks.

- Establishment of a CMMS team including members from Finance and champions from the front-line maintenance staff;
- Review and selection of third-party software system, or decision to develop in-house if the skill sets exist. Once this is selected the provider should offer staff training to ensure understanding and ability to use effectively;

- BWA senior management and Human Resource support is needed to ensure required resources are available to drive the initiative at all levels in the utility;
- Conduct an inventory of all equipment and specifications using a standardized template. This inventory should focus not only on operational equipment but supporting equipment related to the building envelope and grounds. This must address health and safety related items like eye washes, showers and gas monitoring equipment as well;
- All the data should be entered into the CMMS system including a link from every entity to an owner. This owner would be a staff position such as a supervisor or foreman who would be responsible for the assignment of work related to the entity. It is important to note that this CMMS system often offers an application that can be used on an Operators smart phone or tablet. When introducing a new data collection system, it is important that the new system is easy to use, otherwise most people will not try it and continue to implement it;
- Each entity must then be reviewed to establish what tasks must be scheduled under PM. Any new equipment should be scheduled based on a review of manufacturers guidelines and industry practices. For existing equipment, experience may drive the scheduling;
- For each scheduled task, a documented work instruction or SOP should be developed, with input from field staff, and attached to the entity within the CMMS system. A work instruction, or SOP, should be written using an agreed upon standard template;
- Once tasks have been developed, a scheduled triggering system needs to be created among staff to ensure that when PM is due on a piece of equipment the Supervisor assigned to the equipment is alerted so they may assign the work to a staff member, or other team member;
- Details of the completed tasks must be entered into the CMMS system to create a history of maintenance performed on the equipment that is available to all staff. This history should also include breakdown maintenance;
- Before launching the CMMS, all staff must be educated and trained on the system. Depending on the complexity of the CMMS system chosen, most offer add-on modules that can be used for time and financial tracking as well as parts inventory. This information is often utilized by others outside of the Maintenance department;
- Finally, the system must be periodically audited to ensure PM tasks are being completed and that the tasks themselves are adjusted if required. Often manufacturers suggested maintenance schedules require shortening or lengthening due to actual field performance conditions;

Once a CMMS has been established, and tested for the equipment in the collection systems, it can then be expanded into the treatment plants and other areas using the existing hierarchy and BWA templates developed.

Some of the opportunities for improvements identified in the report are well known to BWA staff but it appears that due to other priorities or funding issues, these have not been enacted.

Although major upgrades are being discussed for the future, the existing equipment and BWA staff would greatly benefit from some initial changes and improvements that would carry over when future upgrades are completed. A functional and supported CMMS is a launching point for establishing a PM culture and the benefits that can result from it.

6.2 Operations Programme

6.2.1 Overview

Considering the amount of treatment equipment that requires monitoring and adjustments, compared to the mechanical work necessary to keep it performing, there appears to be a disproportionately high number of staff performing operational duties versus mechanical duties on a regular basis. This has led to two aspects that impact the effectiveness and efficiency of the wastewater treatment systems; 1. Operational staff not being fully engaged during work; and 2. Maintenance staff postponing preventative maintenance work due to responding to breakdown/emergency maintenance.

6.2.2 Observations

To establish a more balanced workforce and ensure that staffing resources are utilized in the most efficient fashion, daily tasks and resources required to perform them should be re-evaluated. Currently there are an insufficient number of available, documented work instructions related to the operation of the treatment plants and collection systems. This makes it impossible to conduct a time management study for both operational and maintenance staff.

Section 6.1.2 outlines observations, such as work instructions and SOPs, outlining maintenance activities, and requirements to be developed. These should be included in the CMMS. Tracking of preventative and breakdown maintenance activities using the CMMS will provide sufficient data to determine the overall staffing requirements related to maintenance.

A similar exercise must occur with the operational aspects of the wastewater systems. Although the activities of an operational nature are not well suited for utilizing a CMMS to drive daily activities the principles behind such a system are transferable.

Currently operational duties are not well documented in SOPs or up-to-date operations manuals. This lack of documentation and agreed upon service level has resulted in new staff learning their functions from existing staff. This allows opportunities for variation in the performance of operational duties, depending on what is shared and how the existing operators disseminate information to the newer operators.

Traditionally plants and collection systems would have an up-to-date Operation Manual outlining the operational philosophy and tasks required to keep the systems running and operating as designed to meet any internal or external requirements. As full manuals are often only pulled off the shelf to investigate specific issues, work instructions, forms and SOPs are often developed as stand-alone documents to outline specific operational duties. The Operations Manual can reference these procedures by name thus allowing the updating of the SOPs without a full manual revision. Documentation is generally lacking or is outdated. The current Operational Manual is a paper copy that has been photocopied and is dated April 1982. A newer electronic copy should be created that is easier to update and circulate.

Operations manuals, and SOPs, form the foundation upon which sound operational practices are established and implemented. Field staff cannot be held accountable for their operational actions unless they have been provided with clearly documented directions along with the training and resources necessary to carry out these duties.

Once established, management can more accurately review the duties, and the resources required to perform them, to ensure staff resources are adequately provided in the areas required to ensure the systems are operating in a safe, reliable manner and staff are performing as directed.

To update any existing manuals and create new manuals a standard template should be developed based on industry standards including at a minimum, operational, health and safety, environmental, security, data management components and regulatory aspects.

For the establishment of a pilot CMMS, it is suggested the focus be on the lift stations and the collection systems. From there it can be expanded to the treatment plants. A similar process can be adopted for documenting operational procedures and establishing manuals for the lift stations while collecting maintenance information.

BWA staff are aware of safety related issues, such as potential contact with H_2S gas, within the facilities. Despite this, safe operational procedures are not outlined in existing SOPs. The establishment of documented procedures and training on these procedures will clearly lay out the health and safety equipment and measures to be taken that are paramount to performing the duties in a safe reliable manner. These documents also include operational requirements for environmental performance and reporting.

Manuals, drawings, and procedures must be updated in a timely manner when any new equipment, processes or policies are introduced. Updates to these documents can be the responsibility of internal staff or, for larger upgrades, can form part of the project documentation as a deliverable. A formal documentation procedure should be established related to updating and storing documents.

External training opportunities are very limited, and an internal training program is lacking. Once finalized, training should be provided on all SOPs. This training, at the beginning, may be delivered by third party experts, but the training given should have a "train-the-trainer" focus so that the utility can develop a strong, sustainable training culture among staff. Subsequent training of staff would be conducted in-house and preferably in the field by internal staff through hands-on activities and tail gate talks, as opposed to full, or half day classroom training sessions.

It was noted by BWA staff that paper records, containing older flow records at the BSTP, had to be burnt, due to the documents becoming covered in rat excrement (urine mostly). Hence details of operational performance and flow rates (from when the flow meter was operational) were lost. This would not be such an issue if records were saved electronically, rather than using paper copies.

Records and documentation are not readily available within the facilities. These records may be available at the office, but field information is limited and often relies on Operator memory or experiences. Clearly defined procedures will incorporate documentation and record management requirements. The goal is for any staff member who requires operational information to be able to access it electronically for the location it is required. Central electronic databases of the procedures and records, supported by paper copies if necessary, will achieve this goal.

There is a lack of in-house testing for operational parameters to help Operators monitor the performance of the treatment plants. There is no on-site laboratory testing, as the Lab Technician resigned and has not been replaced. All tests are now sent to the Government of Barbados Analytical Laboratories for testing, and even this activity is rarely performed, most likely due to the inconvenience of performing this off-site activity.

To efficiently operate the treatment plants, collection system and ensure regulatory compliance with environmental parameters, BWA staff need clear ranges for acceptable parameters and the ability to test for these operational parameters so adjustments in the treatment plant can be made.

On-site lab testing capabilities, including trained staff, should be available at both treatment plants for basic operational parameters to aid in operational decisions and identify equipment failures. Compliance samples could still be sent to the Government Lab, if necessary.

After addressing the lack of documented procedures, and operations manuals for the current equipment, there will be an established BWA template for use when new technologies, such as wastewater reuse, are contemplated. This will help with the transition process and establishing operational procedures for new equipment in an expediated manner.

Having documented procedures for daily operational tasks will allow management to evaluate the time and resources required for the overall operation of a facility or component. This will then allow management, over time, to ensure adequate staffing exists and, in cases where staffing is either overtaxed or underworked, provide educated decisions regarding shifting workload or redirecting staff to other tasks.

Following a similar process future expansions and technologies may be assessed against operational needs to help determine future staffing levels required to adequately maintain the technology at the established service levels.

7 PRELIMINARY RISK ASSESSMENT AND MATRIX

7.1 Risk Assessment Introduction

The goal of this risk assessment is to identify internal risks, exposure to cumulative effects, and external factors that may affect the availability and reliability of wastewater management for wastewater treatment and sewage collection systems in Barbados, including effluent disposal as a critical element of subsurface aquifer recharge. A focal point for the risk assessment is the framing of risk within the context of climate change. The risk mitigation strategies that will be developed during this project are recommended to minimize the potential for operational disruption and create an adaptable strategy, resilience to changes in baseline conditions, and under the expectation that future conditions will be strongly influenced by climate change.

In the context of this assessment, security is defined as having access to a suitable wastewater collection and treatment infrastructure, capable of supplying sufficient volume and quality of treated effluent to facilitate successful aquifer recharge, while ensuring safe, and sustainable disposal of waste residuals. Reliability, on the other hand, is defined as the assurance that the wastewater collection, treatment, and effluent supply functions will not change significantly with time, with adaptable plans in place to avoid interruptions in critical functions of the infrastructure.

7.2 Risk Assessment Objectives

The concept of risk assessment is founded on the principles of identification and management of risks and opportunities over time. The objectives supporting the goals of this plan include:

- Ensuring access to reliable wastewater collection and treatment infrastructure, with resiliency against climate change impacts;
- Identifying suitable effluent disposal options to ensure continuity of aquifer recharge;
- Ensuring long-term availability and reliability of water sources and effluent disposal/recharge in areas that are not designated as a groundwater protection zone (i.e. Zone A exclusion zones);
- Operating wastewater treatment and effluent injection operations in a manner that acknowledges other activities in the area of influence;
- Using water, managing wastewater, and disposing of related wastes, in a manner that respects community values and is protective of the environment; and
- Managing the process in an adaptive manner, recognizing that uncertainty exists regarding certain factors influencing the sourcing and disposal of water in dynamic climactic conditions.

Availability of a wastewater collection, treatment and effluent management systems does not guarantee the sustainability of future development nor the infrastructure to support future growth. Understanding the reliability of these important factors is key to understanding the potential internal, external, and technology risks over the duration of a project. The intent of this risk assessment is to focus on the long-term availability and reliability of wastewater collection, treatment, residuals disposal and water supply options for Barbados.

7.3 Risk Assessment Approach

The approach used for this risk assessment focuses on the development of a robust identification, evaluation, and mitigation plan to address risks to the availability and reliability of wastewater treatment and the supply of valuable by-products including treated effluent, recoverable energy and biosolids (Figure W).

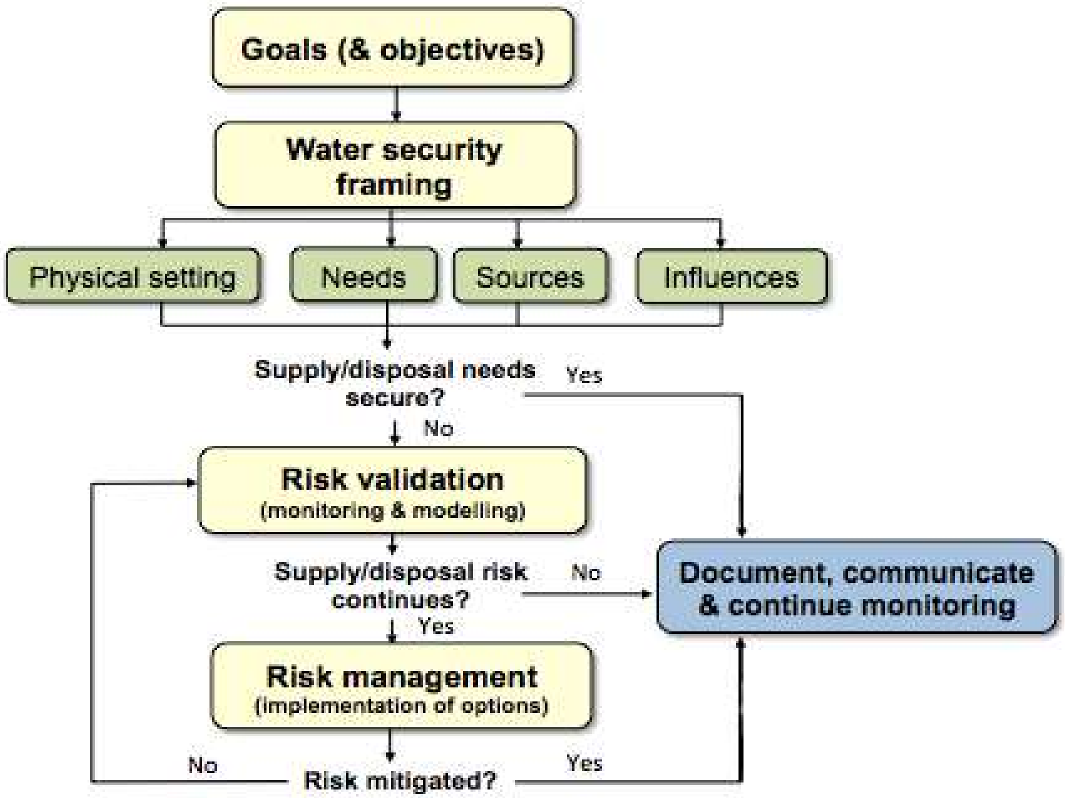

Figure W. Process Flow for Water Security Assessment

The risk assessment is divided into two stages: risk formulation and characterization (Conceptual Phase) and a risk and opportunities analysis component (Feasibility Phase). The risk formulation and characterization are intended to identify, characterize, provide context and professional advice on the current risks to climate resiliency in wastewater systems. The risk and opportunities analysis are intended to affirm the context, determine the likelihood, and expected effects on the economic and technical viability of proposed wastewater management strategies, with potential mitigating solutions to current and future risk valuations. The results from the risk and opportunities assessment will provide strategies to manage through potential risk realizations and provide management approach to address future challenges.

7.4 Assessment Criteria

The following criteria were identified as key project and corporate drivers in determining the risk and opportunities associated with current and potential water source and disposal options for the project.

- Climate resiliency value proposition, such as how does an identified risk or opportunity affect climate resiliency;
- Technical solutions for critical infrastructure functions;

- Wastewater treatment;
- Effluent Supply and Disposal: Security (availability and reliability) of supply and disposal;
- Residuals management and disposal;
- Resource recovery;
- Financial: capital and operational costs;
- Schedule: schedule length for implementation;
- Regulatory: opposition/support, approval requirements, application timing;
- Environment: land disturbance, energy and waste footprints, nutrient management;
- Stakeholders: public perception, stakeholder commitments;
- Treatability: complexity, water quality, beneficial reuse and recycle, chemical consistency, mechanical reliability, treatment requirements to minimize equipment and infrastructure disruptions;
- Commercial: length and complexity of financing terms (i.e. mutually beneficial agreements), relationships;
- Project Management: equipment and infrastructure requirements (such as, collection, treatment and effluent disposal, waste residuals management, energy recovery) and limitations (such as, utilities, electrical, space, technical maturity), constructability; and
- Institutional: political continuity, utility structure, etc.

7.5 Risk Identification

Several key risks and associated opportunities have been identified that may influence the security of wastewater management and water supply and disposal. Each of these are described in the following sections.

Some of the potential environmental and social impacts related to the construction and implementation of this project were mentioned within the Baseline Study. Although environmental and social risks are mentioned in the following sections, they should be further identified within the concurrent ESIA and ESMP project (by others).

7.5.1 Climate Risks

Climate change is expected to exert a significant effect in the hydrologic cycle across the globe. The effects will be dynamic, affecting the amount of rainfall, the intensity and duration of rainfall events, causing both periods of drought as well as flooding and damage to infrastructure. The interactions between wastewater management, aquifer recharge, as well as groundwater extraction and loss of fresh groundwater to the ocean in island nations such as Barbados will become more complex and challenging under a more variable climate. The major risks associated with climate interactions with wastewater and water management include:

- Flooding (related to sea level rise and/or storm surges) could impact the BSTP site, considering it is situated only a few meters above sea level, and/or increase inflow and infiltration, that strain the wastewater collection and treatment infrastructure. Sea-level rise may require extensive re-evaluation to engineering practices and specifications;

- Droughts affecting groundwater availability and promoting more pronounced incursion of salt water into shoreline aquifers. Increased salinity in most of the ground water wells along the coastline; and
- Increase in intensity of storm events, significant damage to infrastructure and required changes to engineering specifications to meet the reliability needs under future conditions.

7.5.2 Technical Risks

The technical risks associated with building and maintaining either centralized or decentralized wastewater collection, treatment and effluent disposal systems are manageable but numerous and vary in cause and effect. Injection of treated effluent has similar technical challenges with respect to infrastructure development, but is also subject to complex subsurface interactions, which may change more rapidly as climate is variable, and may be subject to physical complexities which are difficult to characterize. Climate change will make technical risks harder to manage, and may require careful evaluation of design criteria, engineering safety factors, and construction methods.

Technical risks associated with the proposed infrastructure development options include:

- Design complexity of new wastewater treatment infrastructure to produce effluent of sufficient quality for reinjection;
- Capability for implementation of process management, data collection and analysis systems to adequately manage systems' performance;
- Ability to incorporate reliable nutrient recovery;
- Feasibility of implementing practical energy recovery based on current wastewater composition;
- The footprint of existing BSTP cannot be expanded to accommodate plant upgrading with the options that would be most cost-effective or energy efficient;
- There may be insufficient land area to build new treatment infrastructure and accommodate transition from old to new treatment process;
- Subsurface containment and connectivity to surface receptors;
- Aquifer pressure build-up within a confined aquifer (local, and regional);
- Formation or well plugging (due to incomplete treatment and/or chemical / biological fouling);
- Cumulative effects on water quality from other commercial activities (such as farming).
- Anisotropic injection rates;
- Treated effluent reintroduced to the subsurface may not diffuse in a predictable, radial fashion, but will tend to follow preferred permeability pathways; and

- Reduced availability of water resources, through wastewater recycling and reuse.

7.5.3 Environmental Risks

The environmental risks of expanding wastewater treatment and incorporating significantly higher utilization of treated effluent include both point-source and non-point source-based examples. The environmental risks of centralized collection and treatment versus a decentralized collection, and treatment, are similar in character but different in intensity and extent. Climate change will make the adverse effects of under-managed environmental risks more acute.

The key environmental risks identified include:

- Impacts of wastewater management and water reuse on sensitive surface water, estuarine) and marine environments;
- Management of uncontrolled wastewater release, collection system leaks, infrastructure integrity, monitoring and remediation capacity;
- Management and containment of residuals;
- Control of nutrient loading from treated effluent reuse and biosolids use;
- High nitrogen loads to subsurface and the resulting eutrophication has been identified;
- Environmental risks associated with greenfield construction (as required to accommodate facility expansion); and
- Reliable and complete environmental impact assessment before construction and environmental management plans through construction, operation and closure of facilities is required.

7.5.4 Public Health Risks

All wastewater collection and treatment projects have significant public health risks, which must be identified and managed to protect people. Negative effects due to the presence of pathogens, toxic chemicals and other deleterious compounds in wastewater may be more prevalent and difficult to manage with more widespread use of treated wastewater effluent. Climate change also impacts these public health risks, by exacerbating factors such as expansion of ranges and virulence of disease vectors, and higher risk of failure conditions for critical infrastructure.

The key public health risks identified include:

- Illness from pathogens based on uncontrolled sequestration of wastewater, surface water contamination etc.;
- Uncontrolled releases of water not meeting discharge specifications;
- Potential risks with hydrogen sulphide (H_2S) and other hazardous gases from anaerobic digestion process units if the proper operation, maintenance and the enforcement of safety regulations are not in place;
- Odour issues related to anaerobic digestion that may affect surrounding residential areas; and

- Increased development in the vicinity of the BSTP may impact the operation of the SCSTP.

7.5.5 Baseline Data Risks

Although considerable work has been conducted to date to consolidate and locate baseline data for wastewater generation, collection, and treatment design, as well as performance data, and subsurface hydrogeological data, there is a lack of continuous and reliable information in several areas. This uncertainty regarding existing and boundary conditions translates to risk regarding the suitability and applicability of the proposed upgrades and/or new infrastructure development. Key wastewater characterization and treatment operating datasets are small and incomplete. The lack of continuous hydrogeologic data may hide injectivity concerns, short-circuiting where reclaimed water injected into the ground flows directly to the ocean, presence of negative boundaries associated with thinning aquifers, intervals of limited extent, and/or existence of impermeable barriers.

Baseline data risks identified include:

- Lack of wastewater flow and quality data, requiring extensive assumptions;
- Baseline assumptions on wastewater flows and quality may underestimate the anticipated costs;
- The sewage collection system may have a greater amount of inflow and infiltration than estimated;
- The capacity of the existing sewage collection system may be insufficient to transfer future flows;
- The amount of upgraded wastewater and costs for collection and treatment may be under-estimated;
- The land required for the upgraded plant may be underestimated, and there may be insufficient area available for an upgrade to serve all of Bridgetown;
- The current impact of rainfall on wastewater flows, and capacity to transfer and treat wastewater may be over-estimated;
- Investment in nutrient recovery technology is not justified by the limited value of the recovered nutrients;
- There is no BSTP operating data available to calibrate BioWin modelling used for technical analysis and evaluation;
- The upgrade capacity and associated capital and operating costs could be underestimated;
- The energy and nutrient recovery, and associated benefit, could be over-estimated
- Performance of existing BSTP may be overestimated, and upgrading costs may be underestimated;
- The BSTP is over 40 years old and there is no information available on the existing structural (such as concrete and building components) and equipment condition;

- The salvage and repurposing value of the existing BSTP infrastructure may be over-estimated;
- No information is available on the performance of onsite septic systems;
- Onsite system failures could impact public health and the environment;
- Assumption that existing systems and operational regimes are sustainable and protecting public health and the environment could be incorrect;
- The impact of nutrients and other wastewater components on the shoreline environment is unknown; and
- Limited data is available regarding formation characteristics.

Given the lack of hydro-geotechnical data throughout Barbados, uncertainty regarding the long-term behaviour of performing aquifer recharge is also apparent.

7.5.6 Stakeholder Risks

Stakeholder risks to the project have been identified to characterize the risks to achieving the stakeholder coordination objectives. Stakeholder engagement is critical to developing sufficient public consensus for regional infrastructure projects and ensuring that the social performance is aligned with the community needs. The climate impacts to stakeholder engagement are important and it is important that consultation and engagement is done with a view to incorporate sufficient resiliency and sustainability to ensure that future use of infrastructure provides public utility and return on investment. The key stakeholder risks identified include:

- Attendance to project stakeholder workshops is limited and don't necessarily fully represent the opinions of the many and thus provide only a limited opportunity to gauge government and BWA perspectives on potential water reuse practices;
- There may be insufficient public or agricultural acceptance to support water reclamation and reuse;
- Proposed legislation on reclaimed wastewater for agricultural irrigation is excessively stringent with respect to total dissolved solids content;
- Investment in technologies to remove total dissolved solids is expensive and may limit the amount of water that can be reclaimed;
- Excessive wastewater treatment costs could limit the amount of wastewater that can be reclaimed, limiting the potential benefit of water reuse;
- Technology to remove TSS will only recover from 60 to 75 percent of the water and create a reject stream which could be difficult to dispose and represents water losses;
- Lack of commercial interests to use the heat produced from the cogeneration system powered by the biogas produced from anaerobic digestion;
- Inability to realize maximum economic value for biogas may impact the cost/benefit balance;
- Social (including Farmers, for irrigation use) acceptance risk; and

- Citizens may challenge the value for investment and effectiveness of large capital upgrades, particularly if utility rate structures are significantly affected.

7.5.7 Institutional Risks

Development, upgrade, and long-term operation of extensive public infrastructure projects requires significant institutional coordination and capacity building. Institutional alignment to prepare for the realities of upcoming climate challenges is significant and may require new modes of operating. The institutional risks identified include:

- Lack of capital funding;
- Lack of political continuity (especially between election periods when a different political party takes over);
- Lack of operating and maintenance skills to attain upgraded treatment plant performance and/or meet water quality requirements for reuse;
- Upgraded plant may not be able to meet water quality requirements for reuse applications;
- Inability to meet water quality requirements could jeopardize public health or environment if not closely monitored;
- Shift in global economic situation resulting in difficulties or soaring costs for sourcing some spare parts or materials associated with some specific technologies (MBR, MBBR etc.) to run the plant;
- Upgrading the wastewater treatment to meet water reuse water quality requirements for irrigation purposes will not address water extraction for domestic use;
- Plans to use reclaimed water from both the BSTP and the SCSTP doesn't increase water availability (again, possibly due to a possible short-circuiting effect during the injection process – due to insufficient hydrogeological investigations prior to injecting reclaimed water into the ground) for the BWA, and groundwater continues to be increasingly depleted;
- Reclaimed water does not reduce domestic water consumption (such as reclaimed water is not available for non-potable reuse applications;
- Continued inability to collect adequate water and wastewater utility bills (due to lack of reliable service resulting in unhappy clients not wanting to pay their utility bill), impacts ability to maintain treatment process adequately and reuse water quality;
- Equipment failure due to lack of maintenance;
- Failure to produce reclaimed water to have a significant impact on potable water resources; and
- Time lost discussing options and developing a water management strategy delays the ability to mitigate impacts.

Insufficient time to develop appropriate legislation, construct treatment and reclaimed water distribution infrastructure.

7.6 Risk Characterization, Analysis and Mitigation

7.6.1 Risk Analysis

The following risk identification and evaluation (example is illustrated in Table Z) provides an integrated analysis and characterization process that is required to qualify and quantify how the risks affect viability of the infrastructure and the community investment manifested therein. The analysis makes use of a robust problem formulation framework, characterizing risks by consequence and severity, as shown in Table Z, and Appendix 2. Risk levels are calculated based on severity of consequence and likelihood of occurrence. Risk levels deemed acceptable are documented but may not require additional monitoring or controls.

The risk analysis identifies current mitigation strategies, such as technical controls, operational strategies, behavioural controls, and institutional controls, and qualifies the effectiveness of those controls. For risks that remain unacceptable with current controls, additional mitigation measures are identified, and monitored for effectiveness. The risk trend (unchanging, increasing or decreasing) is monitored until the risk is at an acceptable level.

The characterization, analysis and application of mitigation and monitoring measures can be updated with sensitivity analyses that revise expected frequencies, consequences of adverse effects, as well as the expected effectiveness of controls with changing climate (variability and severity of extremes).

Table Z. Risk Framework and Risk Impact Scales

Risk Assessment Matrix											
	Consequences						Increasing Likelihood				
Impact	Capital	Schedule	Production Performance	Health & Safety	Environment	Reputation & Public Image	A - Almost Certain Expected > =50%	B - Likely Probable 20% to <50%	C - Moderate Conceivable 5% to <20%	D - Unlikely Remote 1% to <5%	E - Rare Improbable <1%
1 Very Low	< $1 M	Delay of 1 month	1 day performance upset	First Aid and / or Medical Aid	Non-reportable spill or release contained within facility or lease	Negative neighbour complaint Negative local stakeholder complaint					
2 Low	$1M to $5M	Delay of 2 months	3 days performance upset	Lost Time Injury / Illness (LTI) < 7 days	Reportable spill or release contained within facility or lease not requiring activation of any remedial measures	Little or no local media coverage Significant delay in consultation completeness					
3 Medium	$5M to $25M	Delay between 3 to 6 months	3 to 7 days performance upset	Lost Time Injury / Illness (LTI) > 7 days	Reportable spill or release not contained within facility or lease and requiring activation of local remedial actions or measures	Local media coverage Statement of concern					
4 High	$25M to $100 M	Delay between 6 months to 1 year	Greater than 1 week performance upset	Single fatality or Permanent Total Disability	Reportable spill or release into a water body or water course requiring activation of external remedial measures Regulatory restriction or Enforcement Action	Negative national or regional publicity Hearing					
5 Very High	$100 M	Delay greater than 1 year	Greater than 1 month performance upset; Complete shut-down	Multiple Fatalities	Reportable spill or release into a water body or water course resulting in severe ecological impact Direct impact on public Prosecution	Negative international publicity Blockade					

7.6.1 Adaptive Management and Regional Planning Initiatives

Utilizing an annual or sub-annual cycle of adaptive management aligned with technical, corporate, institutional, schedule, environmental and climate resiliency objectives can provide a tool to communicate and measure uncertainty and educate stakeholders regarding the timeframes required for implementation and regulatory approval of specific options.

Specific studies to support these opportunities require minimum timeframes to progress, and mid-stage interruption of these timeframes often results in project inefficiencies. At the same time, long durations without internal stakeholder engagement can negatively impact the decision-making process. A clearly demonstrated schedule and adaptive management cycle provides structure as to what support data, studies and other information sources are required by when, and confirms when stakeholder engagement and decision making is required.

The cumulative management of the wastewater treatment and use of effluent as a resource and water source, as opposed to a waste product, are key opportunities for this project to pursue as part of regional climate-readiness and development planning initiatives.

Barbados has investigated numerous options to improve the wastewater treatment and water recovery, with primary focus on either centralized or decentralized strategies. There is also significant opportunity to achieve integration of the benefits from both options, improving the security and reliability of the infrastructure, especially during uncertain times, as is expected with climate-related impacts to hydrological and hydrogeological systems in Barbados.

7.6.2 Risk and Water Security

Water Security is an emerging philosophy predicated on assessing the availability and reliability of supply sources (including treated effluent), and ground dispersal areas as critical locations for aquifer recharge. The goal of water security risk analysis is ensuring sustained business operations and taking into consideration stakeholder, regulatory, and corporate drivers. The approach is based on identifying options and developing a strategy around these options to ensure against unanticipated interruptions that may adversely affect a project or activity. In this case, the lens of climate change is a primary focus to align the needs of future infrastructure with a new and dynamic climate and environmental baseline.

There are many factors that can influence the water security of a public utility, business, or activity, ranging from technical and operational to environmental, social, and regulatory factors. Social acceptance and "willingness to pay" in infrastructure (which will further be investigated within the next deliverable: The Feasibility Study) are now becoming critical drivers for utility-scale water projects. Climate variability exerts a major influence on water availability, with changes to the timing of surface water flow patterns and amounts of precipitation received in the region (based on changes to intensity, duration, and frequency of rainfall events, and competing effects of increased temperature and evapotranspiration) have exerted, and will continue to exert, influences on the water balance that fall outside of human ability to control.

Ensuring containment of discharged effluent within injection intervals, and the viability of those intervals when influenced by cumulative activities, presents a similar challenge to business security. Increased use of key subsurface injection channels could result in cumulative effects from nutrient loading (for example, of nitrogen and phosphorus) ultimately limiting the amount and duration of recharge activities and overall water quality.

8 LOGICAL FRAMEWORK

8.1 Purpose

A Logical Framework, or "LogFrame," conforming to the GCF template, is included as Appendix 3, and an indicative implementation timeline is presented in Appendix 4. The LogFrame is a methodology that has been established to design, monitor, and evaluate international development projects. Constructed typically as a four-by-four table, it describes program activities, short term outputs, medium term outcomes, and long-term goals for a particular project or initiative, to illustrate the logic of how the components and activities will lead to desired outputs which, in time, will achieve desired outcomes and objective goals. It is a method of presenting a neat orderly linear pathway to understand the components and activities that lead to a desired change or objective, presenting a detailed description showing how the program activities will lead to immediate outputs and outcomes and overall goal.

The following sections describe the elements of the LogFrame that has been created as a separate document, based on the information and recommendations presented in this Conceptual Design Report.

8.2 Components

The recommended response to climate change impacts on wastewater management systems in Barbados also considers the direct impacts of climatic events on the wastewater systems (infrastructure) as well as the associated integrated relationship between wastewater management and water availability and scarcity, for which the following five (5) components have been identified:

8.2.1 Component 1 - Reduce the amount of stormwater that enters the Bridgetown and South Coast sewage collection systems.

SITUATION: Information obtained from the BWA indicates both the BSTP and SCSTP collection systems and treatment facilities are currently adversely impacted by extreme flow events that associated with poor stormwater drainage condition that result in flooding over the collection system manholes. The stormwater inflow is often caused by individuals lifting manhole lids to drain the stormwater rapidly to sewer, adversely impacting the collection hydraulics and impeding the treatment facilities performance and impacting treated water quality. Increased rainfall intensity, frequency and/or duration as a result of climate change is expected to worsen the current situation. The impacts of this drainage on the wastewater infrastructure is resolution of surface flooding by draining the water to sewer can damage both the wastewater collection and treatment infrastructure which can be exacerbated rising sea levels, storm surges, increase in frequency and magnitude of tropical storms and high winds.

RISKS & BARRIERS: The main challenges associated with reducing the amount of stormwater inflow into the Bridgetown and South Coast sewage collection systems are as follows:

- Social Risks/Barriers: Members of the public are reported to lift manhole lids to drain flooded areas, and it is anticipated that private property stormwater drainage may also be discharged into the sewer system. The BWA has taken some action by welding manhole lids shut, but this is reported to have resulted in secondary problems related to hydrogen sulphide generation and degradation of the collection system infrastructure. It is likely the public do not understand the negative impact stormwater drainage has on the wastewater infrastructure, and that a public information program could reduce the impacts which are expected to get worse with climate change;
- It is difficult to quantify the potential impact and plan mitigation strategies as there is almost no flow measurement or wastewater quality characterization data available for use in planning and implementing wastewater management climate change adaptation strategies. Without reliable data it is impossible to correlate climate change related events and conditions with wastewater collection and treatment plant performance problems. The limited flow data that exists for the SCSTP sewage collection system, and anecdotal information provided by BWA staff, indicate that both the South Coast and Bridgetown sewage collection and treatment systems are subject to very high seasonal flow variations and peak flows up to an order of magnitude greater than the lowest sewage flows that occur over the year. Although the highest flows seem to occur during dry weather and months associated with peak tourism, and are inversely associated with rain, peak hydraulic flows are also associated with periods of high rainfall and surface flooding which is draining into the sewer through manhole covers. Increasing the availability of operations personnel for laboratory analyses and data management is expected to help develop the necessary data to confirm the impacts and develop strategies to mitigate impacts under climate change conditions;
- Gender Risks/Barriers: None found associated with this Component;
- Financial Risks/Barriers: Cost associated with installing locked manholes, improving surface drainage, and redirecting building plumbing systems away from the sewage collection system. Carrying out a sewage collection system inspection program can be challenging and expensive as it requires a high degree of expertise and experience to install temporary flow measurement equipment in sewers under confined-space-entry conditions and to carry out meaningful interpretation of the resulting data;
- Regulatory Risks/Barriers: There is currently no existing policy in place to deter individuals from directing building drainage and runoff from stormwater into the sewer, nor are there any laws in place to deter the public from lifting manholes;

- Inadequate monitoring and assessment of flow and water quality within the sewage collection system leads to a lack of technical and organizational ability to analyse the impacts of climate change on infrastructure and to develop effective mitigation strategies;
- Improved surface drainage may not be possible in denser urban areas, particularly those located in low land areas, and it may not be possible to collect sufficient data to delineate the sources of high wastewater flows within the sewage collection system; and
- Ecological Risks/Barriers: None found associated with this Component.

BENEFITS: Implementing actions to reduce the potential for stormwater to enter the sewage collection system, and to educate the public as to the impacts the drainage has on the collection and treatment infrastructure and the environment should help to reduce the potential impacts of climate change and will inherently build climate resilience into ongoing operations. Reduced stormwater inflow will decrease operating and capital costs, energy costs, and associated GHG emissions due power generation for sewage collection. Reduced stormwater related drainage to sewer will maximize the capacity for existing wastewater treatment facilities to treat sanitary wastewater and protect public health, as well as improve wastewater treatment operating performance and effluent quality. Improved surface drainage in the vicinity of sewer manholes will improve vehicle safety and reduced risk of property damage due to climate change induced high intensity and duration precipitation events. Investigation into potential illegal sewer connections and sources of high dry-weather sewage flows will benefit treatment performance and increase the ability to treat a greater future population with the same treatment infrastructure. Repaired flow measurement equipment and improved overall record keeping will make more data available with Improved data sets leading to evidence-based decision making for building resilience to climate change.

OBJECTIVES: To increase knowledge within the public of wastewater generation including sources of wastewater and the quantity and quality impacts, as well optimize treatment and minimize energy consumption and associated GHG emissions.

OUTPUTS: Improved operational efficiency and decision-making process for a climate resilient wastewater infrastructure system:

- Reduce Stormwater inflow into the Bridgetown and South Coast sewage collection systems will reduce energy requirements, and associated GHG emissions, to convey (pump) and treat wastewater decreased; and
- Implement decision-making tools and collect data to mitigate potential climate change impacts to the wastewater collection and treatment systems resulting from increased rainfall intensity, duration and frequency and extreme weather conditions (e.g., hurricanes, major tropical storms).

ACTIVITIES:

1. Establish a building drainage inspection program and complete property inspections;
2. Improve surface drainage in the vicinity of wastewater collection system access manholes, lift stations, and treatment plant locations;
3. Implement a sewer flow monitoring program to identify sewer segments with a disproportionate amount of wastewater flow to the incremental number of connections along that segment to mitigate against hydraulic surge impacts and load variations as a result of major storm events.; and
4. Install and/or calibrate flow measurement equipment, and rain-gauging stations at both the Bridgetown and South Coast Sewage Treatment Plants and establish a routine data analysis program to assess correlations between rainfall duration and intensity with wastewater flows and pump station operation as part of an ongoing effort to identify and remove sources of inflow and infiltration to the sewer. Minimizing the amount of stormwater entering the system will reduce energy requirements, and associated GHG emissions.

8.2.2 Component 2 - Component 2 - Treat wastewater to a high-quality reclaimed water standard suitable for reuse applications to reduce potable water demands on climate-change impacted potable groundwater resources and improve water sector resiliency to climate change.

SITUATION: Barbados is almost entirely dependent (approximately 90%) on groundwater supplies, which is directly impacted by the weather and climate. Groundwater supplies are replenished by annual rainfall, through groundwater aquifer recharge, and are impacted by saltwater intrusion (brackish water) as a result of rising sea levels and excess groundwater extraction due to increased frequency and severity of droughts, which climate models suggest may intensify in the future in the Caribbean region (Vichot-Llano et al., 2020) and impact agriculture and water resources. Climate change is expected to worsen these conditions. The Barbados-based CIMH climate change modelling predicts a decline in annual precipitation for 2080-2099 from 10% to 27%. A drop of 27% would be critical for Barbados, which already experiences drought and increasing groundwater salinity. The BWA has reported decreases in groundwater levels at most groundwater wells located across the country. Potable water production has been reduced by as much as 3 million gallons per day during severe drought events that have occurred to date. These restrictions on potable water use have drastic implications for water and food security as well as an economic impact to the island's industries and tourism. Recent trends towards longer periods of drought can significantly impact the water balance resulting in interruptions in water supply, diminishing water supply resources, and increasing strain on current water availability of potable water during drought conditions. Agriculture is also vulnerable to climate change as droughts can cause pre-mature death of livestock and poultry and reduce crop yields (CCCCC, 2019).

Efforts to produce potable water from brackish groundwater along the coast have been effective; however, even this water source has limited availability. Reclaimed wastewater has significant value in application to satisfy water demands that do not require potable water, and reclaimed water can be injected into the ground to replenish groundwater resources in the immediate vicinity of reverse osmosis water treatment facilities, like Spring Gardens, to serve as a means of indirect potable reuse.

RISKS & BARRIERS: The main challenges associated with treating wastewater to a higher quality and re-using this treated water to mitigate against climate-related water resource limitations are as follows.

- Social Risks/Barriers:
    - Although technically feasible, the treatment, reclamation and reuse of wastewater effluent for non-potable water applications to offset potable water demands may not be readily accepted by the public. A willingness to pay study that was initiated as part of this study indicated some acceptance, however, further study is required;
    - Routine wastewater flow measurement, effluent water quality analyses, and have not been carried out for a very long time. ly measuring influent wastewater flows and collecting influent and effluent water samples. In addition, there exists an inability to enforce inadequate influent and effluent wastewater quality testing and reporting;
    - Only a small percentage of Barbadians are currently able to access the BTSTP and SCSTP wastewater collection and treatment facilities; and
    - There is an absence of mechanisms to foster greater stakeholder participation in the design, implementation, monitoring and evaluation of project activities.
- Gender Risks/Barriers: Water shortages as a result of drought conditions, resulting from climate change, can pose great challenges for women who are primarily care givers for children and the elderly (as identified in the Gender Analysis and Gender Action Plan);
- Financial Risks/Barriers: The cost of distributing the reclaimed water into the community for non-potable use may be a major drawback, as dual plumbing systems need to be constructed to safely distribute and use the reclaimed water within buildings. In addition, the O&M costs for tertiary wastewater treatment, and especially specially RO treatment, system can be significant.
- Regulatory Risk/Barriers:
    - Currently there is no adequate policy in place to support and encourage the use of reclaimed water (refer to 3.10.1). The EPD currently restricts the use wastewater effluent for irrigation purposes to only ornamental plants and lawns; and
    - The current indication is the Government would prefer to use all reclaimed water for agricultural irrigation purposes; However, the Ministry of Agriculture has

determined that reuse water for use in agriculture must have a total dissolved solids concentration no greater than 450 mg/L. To achieve this requirement the reuse water musty be treated using reverse osmosis (RO), requiring high pressures and energy use, as well as capital cost.

- Technological Risks/Barriers: None. Several treatment technologies were considered (refer to Section 3.4) and ultimately, the BWA has expressed a preference in the CAS treatment type. There is little risk associated with this CAS technology as the BWA is already operating the existing BSTP using this technology; and
- Ecological Risks/Barriers: The continued discharge of partially treated (primary and secondary treatment) effluent into the ocean negatively impacts the marine environment (eg. nutrient loading can be detrimental to coral reefs and the near shore environment (W.F. Baird, 2019)). Elevated levels of nitrates in certain production wells that sample water discharged into the ocean have raised concerns over the quality of water.

BENEFITS: The ability to use reclaimed wastewater to satisfy water demands that do not require potable water will free potable water for other uses and protect against the impact of climate change on the groundwater supply. This will increase potable water security by eliminating potable water demands for applications that can use non-potable reclaimed water, as well as increase groundwater supply by using the reclaimed water to replenish aquifers and creating a greater amount of potable water and increasing water security though indirect potable reuse. By adding reclaimed water to the existing aquifer, it will be possible to increase the supply of water and generate better economic activities among the more vulnerable persons like women and LGBTQIA (Lesbian, Gay, Bisexual, Transgender, Queer and/or Questioning, Intersex, and Asexual and/or Ally). Improved water conservation measures to reduce water demands, develop alternative water supplies, and encourage decentralized water reclamation and reuse practices through government policy and regulation development. In addition to irrigation use reclaimed water can be used to augment groundwater resources as an indirect means of producing potable water (Indirect Potable Reuse – IPR) and reduce the dependence on current water supplies that are heavily variable and impacted by climate change. The application of reclaimed water to agricultural for irrigation will also make agriculture more resilient to the impacts of climate change. If TDS reduction by RO is not required, there are potential cost savings (US$) to farmers by using treated reclaimed water that contains nutrients (high carbon, phosphorus and/or nitrogen content), potentially reducing fertilizer requirements as well as an improving the water source reliability. The discharge of partially treated effluent into the ocean should be minimized by upgrading the WWTP's to tertiary treatment, and beyond (RO). The RO reject discharged to the environment would contain a high concentration of salts and nutrient that can adversely impact the environment.

OBJECTIVES: To build resilience into Barbados' wastewater management systems, which results in increased water availability, production, distribution, and access, thereby improving the community's resilience, health and wellbeing, and water and food security. The increased food security should also lead to increased employment in the agriculture sector as well as reduced food importation cost and dependence. Produce a treated wastewater effluent quality so that it can be reused for agricultural purposes, reducing stress on diminishing groundwater resources and potable water supplies as a result of climate change. Reclaimed water can be used for stream and habitat augmentation to support natural riparian and aquatic habitats and provide water courses for birds and other riparian species (CCCCC, 2019).

OUTPUTS: Improved water security/availability by providing additional storage of reclaimed water to augment non-potable water in aquifers, for future reuse and reduced vulnerability and exposure to climate risks (e.g., ecosystem impacts, saltwater intrusion in coastal aquifers, control or prevent ground subsidence).

- The Bridgetown and South Coast Sewage Treatment Plants upgraded to treat wastewater to a tertiary water-quality standard suitable for water reuse applications and reverse osmosis technology to remove total dissolved solids to meet agricultural irrigation requirements;
- Onsite decentralized package treatment plants or cluster treatment facilities can be constructed within Zone A groundwater extraction locations that have been identified as highly susceptible to climate-related water supply shortages and the contamination of wastewater on groundwater sources;
- Current wastewater discharged through ocean outfalls redirected by installing interception locations along the west coast corridor to intercept and collect brackish water for further treatment and beneficial use to supply reclaimed wastewater;
- Reclaimed water piped to most appropriate end user for irrigation purposes to promote treated water reuse;
- In-house water flow and quality analyses (laboratory testing and flow easement system) implemented;
- Computerized Maintenance Management System (CMMS) implemented and use of climate information in decision-making;
- Wastewater reclaimed and reused to supplement non-potable uses; and
- Waste activated sludge stabilised and utilised as a source of nitrogen and phosphorus for landscaping, turf management, land reclamation and soil cover.

ACTIVITIES:

1. Upgrade the Bridgetown and South Coast Sewage Treatment Plants to treat wastewater to a tertiary reuse water-quality standard suitable for non-potable water reuse applications;
2. Implement reverse osmosis treatment to reduce total dissolved solids concentrations for agricultural irrigation use, as required;
3. Install onsite decentralized package treatment plants or cluster treatment facilities serving approximately 18 Zone A locations that have been identified as highly

susceptible to climate-related water supply shortages and the contamination of wastewater on groundwater sources;

4. Eliminate the current practice of discharging treated wastewater to the ocean environment discharged through outfalls, and intercept and collect brackish water for further treatment and beneficial use to supply reclaimed wastewater;
5. Install a central pipeline to transport reclaimed water to areas in most need of non-potable water including irrigation purposes to promote treated water reuse;
6. Implement CMMS to inform decision making and climate resilient building in the Wastewater Sector;
7. Routinely measure (using CMMS) influent wastewater flow and collect influent and effluent water samples for physical, chemical and biological water quality analyses and use the data to inform operations control strategies that optimize operations and reduce energy consumption and GHG emissions. Capacity building, with respect to operator training and improved operations management, will improve the efficient use of this wastewater infrastructure, which is needed when the system is being stressed by various climate change impacts discussed to date;
8. Apply tertiary treated reuse water to meet the water demands of applications that do not require potable water sources such as: agricultural, landscaping and turf irrigation; groundwater augmentation; toilet/urinal flushing; and street/vehicle washing; and
9. Provide stabilized waste activated sludge as a source of nitrogen and phosphorus to be used for landscaping, turf management, land reclamation and soil cover by third party (potential private sector or P3 opportunity).

8.2.3 Component 3 - Component 3 - Implement Measures for Renewable Energy Opportunities and Improved Energy Efficiencies for Wastewater Treatment to Achieve Zero Emissions.

SITUATION: Centralized wastewater management relies on expensive high-emission electricity supplied from conventional power plants that use fossil resources. The Barbados National Energy Policy (BNEP) sets a goal of achieving 100% renewable energy and carbon neutrality by 2030 including: the provision of reliable, safe, affordable, sustainable, modern and climate friendly energy services to all residents and visitors; zero domestic consumption of fossil fuels economy wide; export of all hydrocarbons produced both on land and offshore; maximising local participation (individual and corporate) in distributed renewable energy (RE) generation and storage (democratisation of energy); and creating a regional centre of excellence in RE research and development (https://energy.gov.bb/publications/barbados-national-energy-policy-bnep/). Upgrading the SCSTP and BSTP can be done in such a way as to produce waste biosolids with high potential for bioenergy recovery through anaerobic co-digestion with other organic solid waste, and power consumption can be offset through the deployment of large solar panel arrays at the treatment plant sites. The existing BTSTP facility can generate approximately 17,200 CO_2e of direct GHG emissions from the treatment process (at an average flow of 4,100 m^3/day) to approximately 238,000 CO_2e (at an average flow of 56,700 m^3/day).

The wastewater management facilities are also susceptible to disruption and public health risk as a result of power outages due to climate change influenced exposure to an increasing number of high energy weather events (e.g., hurricanes). Wastewater treatment plants also generate a significant amount of waste biosolids (sewage sludge) that is transported to disposal sites resulting in truck fuel-associated emissions. In addition, the wastewater collection and treatment systems are extremely susceptible to disruption as a result of power outages due to climate exposure (e.g., hurricanes)

RISKS & BARRIERS:

The main challenges associated with implementing measures to include renewable energy and improve energy efficiency are as follows.

- Social Risks/Barriers: None found associated with this Component;
- Gender Risks/Barriers: None found associated with this Component;
- Financial Risks/Barriers:
  - The costs associated with investing in proposed solar infrastructure could be high, especially if battery storage is deemed to be necessary. If ground-mounted solar is preferred, land would need to be allocated by the government;
  - Switching to natural gas generators, that emit less GHG than diesel generators, will also be costly. Supporting the private sector to develop a biogas facility could require allocating land to a facility; and
  - The establishment of an anaerobic digester to convert waste biosolids from the two treatment facilities to methane is unlikely to be economically justifiable.
- Regulatory Risks/Barriers: Some new legislation is required to support the renewable energy sector to develop, including signing Power Purchase Agreements. As anaerobic digestion applied solely to waste biosolids produced at the SCSTP and BSTP is unlikely to generate enough methane to be sustainable, co-digestion with other high energy organic solid waste would be required;
- Technological Risks/Barriers: Solar PV is a mature technology, therefore there is little risk associated with it, however, the panels will need to be removed and safely stored during major storm events such as hurricanes. It is also not yet known what exact technology will be chosen by the private sector to develop a biogas facility; and
- Ecological Risks/Barriers: Regarding the biogas facility, collecting methane and other related gases may pose an explosion concern. As such, an explosion development radius may need to be considered. Odour control is also another factor that needs to be considered when choosing a land location to house this facility.

Opportunities for renewable energy will likely depend on the ability to collect and process waste sludge from both the SCSTP and BSTP facilities as well as other organic wastes produced in Barbados and use it as a resource for energy recovery through anaerobic digestion (AD). As AD energy recovery is not currently carried out in Barbados there may not initially be adequate operator experience, or industry buy-in as an alternative to existing methods of organic waste treatment and disposal.

BENEFITS: Potential opportunity to recover the energy from the biomass produced by the wastewater treatment plant process to assist the country in meeting its objective of being 100 percent carbon negative by 2030. Biogas may be used directly as a fuel for domestic, commercial, or industrial application, to power an engine-generator to generate electricity with another form of energy, such as steam or hot water (co-generation), or as a hydrogen source for fuel cell application. The proposed treatment process aims to achieve zero energy consumption which would reduce the overall carbon footprint. Considerations for the harnessing of energy from the primary solids and waste secondary biomass is also incorporated into this project. This will also create a self-sufficient energy generation system that minimizes power disruptions.

OBJECTIVES: Reduce GHG emissions, increase self-sufficiency, contribute to the electricity grid and to contribute to the frequency stabilisation of the electricity grid and act as a power shortfall filler (increase supply of locally sourced renewable energy that allows for a long-term source of revenue through the FTC feed-in tariffs program).

OUTPUTS:

- Climate change resilience and impact mitigation by harnessing energy from wastewater biomass and solar energy and creating a self-sufficient system that reduces emissions. Contribute to the frequency stabilisation of the electricity grid and acts as a power shortfall filler (increase supply of locally sourced renewable energy that allows for a long-term source of revenue through the FTC feed-in tariffs program):Retrofitted existing system to generate energy and increase energy efficiency within the wastewater collection and treatment systems; and
- Renewable energy incorporated and water collection and treatment system upgraded to reduce or eliminate GHG emissions.

ACTIVITIES:

1. Activity 3.1.1: Conduct a preliminary assessment to inform implementation of wastewater treatment process technology that collects high volatile primary solids, fats, oils and grease (FOG) and has low energy requirements and minimal aerobic secondary biomass stabilization (endogenous decay) to maximize the volatile content of organic solids that are collected during the treatment process and made available for anaerobic conversion to biogas and maximize energy recovery efficiency in the form of methane and associated energy generation;
2. Activity 3.1.2: Implement anaerobic digestion to convert volatile organic solids residuals produced by the Bridgetown and South Coast Sewage Treatment Plants into methane gas for energy recovery and reduced GHG emissions, with

consideration for co-generation in conjunction with other volatile organic solid waste produced on Barbados;

3. Activity 3.1.3: Implement sludge dewatering technology at the Bridgetown STP to reduce energy costs associated with waste biosolids treatment as well as GHG and CO2 emissions associated with the volume of waste biosolids that will be transport offsite either to a regional energy recovery facility or disposal;
4. Activity 3.1.4: Install automated controls to improve treatment component energy efficiency including adding a dissolved oxygen control system consisting of Dissolved Oxygen (DO) sensors and control feedback to the Bridgetown bioreactor blowers;
5. Activity 3.2.1: Install grid-tied Photovoltaic (PV) Renewable Energy Systems, Category 1 hurricane resistant solar panels, up to 4 MW;
6. Activity 3.2.2: Install natural gas turbines for emergency power generation after power outages due to major storm events (hurricanes); and
7. Activity 3.2.3: Install combined heat and power (CHP) plants, gas turbines or fuel cells to convert fuel (biogas containing methane) into electricity and heat.

8.2.4 Component 4 - Component 4 - Policy, Capacity Building and Development Planning to Reduce Climate Change Risks (Water and Wastewater Sector, Private Sector Training, Education, Gender).

SITUATION: Capacity building in the water and wastewater sector, as well as more effective regulatory frameworks, policies, and mechanisms to properly and adequately manage water is required to build resiliency into the water sector against climate change. Discharge standards and ambient marine water quality guidelines have remained in draft form as the requisite legislation is yet to be prepared to bring the standards into force. The National Water Reuse Policy document (2018) recognizes this problem. Three reports have been prepared by the EPD that help address the impact of climate change on wastewater management and its relationship to water availability, namely the Water Augmentation Project Concept Paper, draft Water Reuse Act, and draft Water Reuse Regulations (2006) that recommend the possible administrative and legal framework along with proposed standards to regulate the use of reclaimed water. However, the legislation has yet to be brought into law. There is also a need for operator and technologist training to support centralized, cluster and onsite wastewater management strategies to address climate change impacts.

RISKS & BARRIERS:

The main challenges associated with policy, capacity building and development planning to reduce climate change risks are as follows.

- Social Risks/Barriers:
  - Generally, it is expected that the Government agencies and regulatory body (BWA) accept the non-potable use of reclaimed water, therefore there should be little risk of acceptance; and

  - BWA operators will not have experience with operating and maintaining a water reclamation facility or the distribution of reuse water.
- Gender Risks/Barriers:
  - An absence of an enabling gender policy for smooth implementation of the wastewater project (as identified in the Gender Analysis and Gender Action Plan report);
  - Financial Risks/Barriers: As outlined in the Stakeholder Engagement report, there are minimal costs (relative to the capital and O&M costs) associated with developing policy and implementing new internal BWA operational procedures to support the reuse of reclaimed water as described in this report; and
  - To date, there are very few women in technical roles. For example, as identified in the Gender Analysis and Gender Action Plan report, BWA has an equal number of men and women serving as senior managers, although more women hold administrative roles as managers versus technical roles.
- Regulatory Risks/Barriers:
  - As discussed in the previous Components, various new legislation is required to support the reuse of reclaimed water. Although the EPDs proposed draft effluent standards table, listing prohibited concentrations in 2004, includes discharge standards and ambient marine water quality guidelines, the standards and guidelines have remained in draft and the requisite legislation is yet to be brought into law. This may indicate a lack of support for reuse among policy makers; and
  - Changing or updating government legislation/policy often takes a prolonged period of time to draft and implement and one could argue that the effects of climate change are occurring faster than the policy makers are considering changes to legislation.
- Technological Risks/Barriers: There is a lack of water treatment professionals and technical expertise to proactively manage climate change impacts; and
- Ecological Risks/Barriers: None found associated with this Component.

BENEFITS: Support from policy makers to enable change in the form of upgrading and implementing of National Water Reuse Policy and better national planning with respect to wastewater management and water conservation and reuse. Preventative maintenance will extend the life cycle of the equipment and help to reduce breakdown maintenance that can come with a high financial and environmental cost. Improved awareness and buy-in from the public, direct beneficiaries (such as the agricultural sector) and stakeholders (including the BWA) will ensure support from management and ensure that the right personnel attend workshops. This will help to champion the climate change agenda within the water sector. Staff will be trained in operating and managing the new technology and technical specifications and aware of their impact on water quality and quantity (availability).

OBJECTIVES: To provide a standard and formal guidance to regulate and promote the use of reclaimed water and obtain greater by-in from stakeholders. To build capacity and re-train BWA staff to conduct preventive maintenance and adopt climate-risk related adaptation strategies to increase the wastewater collection and treatment systems resiliency.

OUTPUTS:

Building capacity and increasing climate adaptation policy and knowledge to manage climate-related risks and perform mitigation measures integrated into planning for the Water and Wastewater Sector:

- New legislation framework developed to enable Wastewater Reuse;
- The capabilities of water technical personnel is improved with the aim of becoming more efficient;
- Climate change adaptation planning strengthened for wastewater reuse; and
- Climate Change considerations mainstreamed into the SOP and Operational Manual of the Wastewater Systems.

ACTIVITIES:

1. Draft new legislative framework to address wastewater effluent quality and re-use requirements and enable appropriate water reuse systems and applications;
2. Develop educational materials and a mechanism that builds staff and local capacity for climate resilient decisions and climate proofing its existing infrastructures, considering stakeholder and gender, sustainability, and risk reduction and safety;
3. Provide theoretical and practical training related to the installation, operation, maintenance and monitoring of photovoltaic systems, biological treatment technology and techniques, water collection and treatment systems;
4. Update SOP and Operational Manual with operational duties and responsibilities documentation specific to climate change adaptation and preventative maintenance; and
5. Provide theoretical and practical training related to climate adaptive and preventative maintenance and re-assign appropriate roles and responsibilities.

8.2.5 Component 5 - Wastewater Management and Water Conservation Education for Consumers to Adapt to Climate Change Risks (Barbadian Communities and Visitors, School, Community-Based Training, Education, and Gender).

SITUATION: Limited capacity and poor sensitisation/awareness regarding integrated water management (conservation and demand-side management) and the reuse of treated wastewater for non-potable water applications. While technically feasible, technologically robust and applied in many water-stressed areas of the world, DPR of reclaimed water is generally not culturally acceptable in most countries.

RISKS & BARRIERS:

The main challenges associated with wastewater management and public conservation re-education for water users are as follows.

- Social Risks/Barriers:
    - There may also be a lack of awareness or unwillingness of the public, including visitors (tourists) to change current behaviour to better manage and conserve water or accept proposed water reuse practices. This includes both irrigation and aquifer recharge. IDPR may be culturally unacceptable and may lead to negative social perception and lack of acceptance, despite science-based evidence demonstrating a high-level of water quality. Lengthy public engagement and education programs may be necessary to eventually obtain public buy-in. There is limited awareness among the general public regarding integrated water management (conservation and demand-side management); and
    - Given the cross-cutting nature of climate change the involvement of all stakeholders is required; however, there is limited capacity and trained personnel to assist with stakeholder communications and education programs, especially as it relates to climate change, for the community and businesses.
- Gender Risks/Barriers: The BWA appears to lack the human resource, institutional and information capacity to identify the causes of vulnerability among women and other vulnerable groups;
- Financial Risks/Barriers: As outlined in the Stakeholder Engagement report, there are minimal costs (relative to the capital and O&M costs) associated with developing policy and public engagement exercises;
- Regulatory Risks/Barriers:
    - As discussed in the previous Components, various new legislation is required to support the reuse of reclaimed water; and
    - High degree of transparency is required; however, there may be capacity constraints and an inability of the BWA to routinely and consistently publish flow and water quality results on their website.

- Institutional Risks/Barriers: Weak enforcement mechanisms for source contamination could also pose a risk for being able to maintain a high water-quality suitable for reuse and incentives for conservation and re-use may not be sufficient to sway public to take water conservation efforts seriously;
- Technological Risks/Barriers: None found associated with this Component; and
- Ecological Risks/Barriers: None found associated with this Component.

BENEFITS: Stakeholders need to be aware of the impact they can have on wastewater quality and quantity (availability) and on the quality of water produced for reuse. It is important that service announcements and educational materials be effective in conveying the importance of water protection, conservation, re-use and better management to the overall public. Ensure right personnel attend workshop and consultations to champion the climate change agenda within the water sector. Risk and negative social perceptions associated with the reuse of treated wastewater may be alleviated with education, stakeholder engagement, and quality control procedures that include analytical testing of treated wastewater prior to reuse, to demonstrate the quality of the reclaimed water to the public (and health officials) if necessary.

OBJECTIVES: To promote and demonstrate actions that encourage all water users to conserve and efficiently use water resources.

OUTPUTS: Improved water conservation and reuse awareness and buy-in from all water users with enhanced awareness of gender-sensitive responses to climate change impacts related to wastewater and water management:

- Public awareness campaign implemented; and
- Public implementation of Climate Change Adaptation Planning strengthened.

ACTIVITIES:

1. Provide education resources for the community and businesses regarding reuse water quality and quantity (availability) and the importance of water reuse activities to increase the available water supply;
2. Create a Public Awareness Campaign for community and visitors (tourists) through workshops, videos, community town hall meetings, and consultations on Direct Impacts on Ecosystem and Ecotourism. Share lessons learnt to spur greater public and entrepreneurial involvement;
3. Construct a visitor centre at the wastewater plant to educate on the benefits on water reuse;
4. Promote and encourage the public to utilise DPR and IPR and take action to mitigate and adapt to climate variability and change. Conduct outreach programmes in schools, community-based organizations, and stakeholders' groups across customer class;
5. Implement a BWA website page dedicated to transparent measures of reporting of discharged effluent on existing website;

6. Develop and implement an incentive programme to encourage conservation, recycle, re-use;
7. Create a Public Service Announcement, with educational materials to all water users that addresses best practices for efficient water use, conservation, and reuse; and
8. Encourage existing private sector decentralized onsite and cluster wastewater systems to also adopt water reclamation technologies.

9 CLOSURE

Integrated Sustainability would like to thank the Caribbean Community Climate Change Centre for the opportunity to work on this project and for your support. We trust that this report meets your needs and expectations. If you have any questions, please contact the undersigned at any time.

Sincerely,

Integrated Sustainability

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Appendix 1 – Design Technology Comparison

INTEGRATED SUSTAINABILITY

Appendix 2 – Risk Framework

INTEGRATED SUSTAINABILITY

Appendix 3 – Log Frame

Appendix 4 – Indicative Implementation Timeline

INTEGRATED SUSTAINABILITY

Implementation Timetable

COMPONENTS/OUTPUTS	2022				2023				2024				2025				2030				2035				2040				2050			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Component 1: Reduce the amount of stormwater that enters the Bridgetown and South Coast sewage collection systems.																																
Output 1.1: Reduced stormwater entry and drainage to the Bridgetown and South Coast sewage collection systems																																
Activity 1.1.1: Establish a building inspection program to eliminate stormwater discharges to the sewage collection system.																																
Activity 1.1.2: Improve surface drainage in the vicinity of wastewater collection system access manholes, lift stations, and treatment plant locations.																																
Output 1.2: Implement decision-making tools to mitigate potential climate change risks to the wastewater treatment and collection system infrastructure as a result of extreme weather conditions (e.g., hurricanes, major tropical storms)																																
Activity 1.2.1: Implement a sewer flow monitoring program to identify sewer segments with a disproportionate amount of wastewater flow to the incremental number of connections along that segment to mitigate against hydraulic surge impacts and load variations as a result of major storm events.																																
Activity 1.2.2: Install and/or calibrate flow measurement equipment, and rain-gauging stations at both the Bridgetown and South Coast Sewage Treatment Plants, and establish a routine data analysis program to assess correlations between rainfall duration and intensity with wastewater flows and pump station operation as part of an ongoing effort to identify and remove sources of inflow and infiltration to the sewer. Minimizing the amount of stormwater entering the system will reduce energy requirements, and associated GHG emissions.																																
Component 2: Treat wastewater to a high-quality reclaimed water standard suitable for reuse applications to reduce potable water demands on climate-change impacted potable groundwater resources and improve water sector resiliency to climate change.																																
Output 2.1 : Upgrade the water quality produced by the Bridgetown and South Coast Sewage Treatment Plants to a tertiary water-quality standard suitable for non-potable reuse applications and apply reverse osmosis treatment to reduce total dissolved solids to meet Ministry of Agriculture and Food Safety agricultural irrigation requirements.																																
Activity 2.1.1: Upgrade the Bridgetown and South Coast Sewage Treatment Plants to treat wastewater to a tertiary water-quality standard suitable for water reuse applications including reverse osmosis treatment to meet Ministry of Agricultural and Food Safety total dissolved solids requirments for agricultural irrigation use.																																
Activity 2.2.1: Install onsite decentralized package treatment plants or cluster treatment facilities and service Zone A locations that have been identified as highly susceptible to climate-related water supply shortages and groundwater contamination from onsite wastewater disposal practices.																																
Activity 2.3.1: Redirect current wastewater discharged through ocean outfalls by installing interception locations along the west coast corridor to intercept and collect brackish water for further treatment and beneficial use to supply reclaimed wastewater.																																
Activity 2.4.1: Construct a pipeline to transport reclaimed water for agricultural irrigation purposes.																																
Output 2.5: Establish laboratories at the Bridgetown and South Coast wastewater treatment plants to carry out water quality analyses and re-establish flow measurement equipment.																																
Activity 2.5.1: Routinely measure influent wastewater flow (by installing a new flow meter at the treatment plant) and collect influent and effluent water samples for on-site chemical and biological water quality analyses and use the data to inform operations control strategies that optimize operations and reduce energy consumption and GHG emissions. This will require reinstating the on-site laboratory and hiring a laboratory technician.																																
Activity 2.5.2: Identify and enforce (currently) inadequate influent and effluent wastewater quality testing and reporting, in order to meet the MAFS irrigation water standard for TDS (<450 mg/L).																																
Activity 2.6.1: Implement Computerized Maintenance Management System (CMMS) to inform decision making and climate resilience in the wastewater sector.																																
Output 2.7: Wastewater reclaimed and reused to supplement non-potable uses																																
Activity 2.7.1: Upgrade the existing wasterwater treatment processes to produce tertiary treated wastewater suitable for non-potable reuse applications including agricultural, landscaping and turf irrigation and Indirect Potable Reuse (IPR) through groundwater augmentation.																																
Output 2.8: Waste activated sludge stabilised and utilised as a source of nitrogen and phosphorus to reduce the need for importing fertilizer for landscaping, turf management, land reclamation and covering.																																
Activity 2.8.1: Provide stabilised waste activated sludge as a source of nitrogen and phosphorusfor use in landscaping, turf management, land reclamation and soil cover by third-party (potential private sector or P3 opportunity)																																
Component 3: Implement Measures for Renewable Energy Opportunities and Improved Energy Efficiencies for Wastewater Treatment to Achieve Zero Emissions.																																
Output 3.1: Retrofitted existing system to generate energy and increase energy efficiency within the wastewater collection and treatment systems.																																
Activity 3.1.1: Select wastewater treatment process upgrade technologies that maximize the waste biosolids volatile content, collect fats, oils and grease (FOG) and has low energy requirements. Such a process would involve minimal aerobic secondary biomass stabilization to maximize the volatile content of waste biosolids available for anaerobic digestion and energy recovery through methane formation and associated energy generation.																																

Activity 3.1.2: Implement anaerobic digestion to convert volatile organic solids residuals produced by the Bridgetown and South Coast Sewage Treatment Plants into methane gas for energy recovery and reduced GHG emissions, with consideration for co-generation in conjunction with other volatile organic solid waste produced on Barbados.																																
Activity 3.1.3: Implement sludge dewatering technologies at the upgraded Bridgetown and South Coast STP to reduce energy costs as well as GHG and CO2 emissions associated with the transport of waste biosolids to an offsite energy recovery facility or to disposal.																																
Activity 3.1.4: Install automated controls to improve treatment component energy efficiency including adding a dissolved oxygen control system for the Bridgetown and South Coast STPs.																																
Output 3.2: Establish wastewater renewable energy and water recovery capabilities to reduce or eliminate GHG emissions.																																
Activity 3.2.1: Install grid-tied Photovoltaic (PV) Renewable Energy Systems, Category 1 hurricane resistant solar panels, up to 4 MW.																																
Activity 3.2.2: Install natural gas turbines for emergency power generation after power outages due to major storm events (hurricanes).																																
Activity 3.2.3: Install combined heat and power (CHP) plants, gas turbines or fuel cells to convert fuel (biogas containing methane) into electricity and heat.																																
Component 4: Policy, Capacity Building and Development Planning to Reduce Climate Change Risks (Water and Wastewater Sector, Private Sector Training, Education, Gender)																																
Output 4.1: New legislation framework developed to enable wastewater reuse applications.																																
Activity 4.1.1: Draft new legislative framework to address wastewater effluent quality and re-use requirements and enable appropriate water reuse systems and applications.																																
Output 4.2: The capabilities of Water Technical Personnel Improved with the Aim of Becoming More Efficient and Implementation of Climate Change Adaptation Planning Strengthened for Wastewater Use																																
Activity 4.2.1: Develop educational materials to enable climate resilient decisions and climate proofing its existing infrastructures, considering stakeholder and gender, sustainability, and risk reduction and safety.																																
Activity 4.2.2: Provide theoretical and practical training related to the installation, operation, maintenance and monitoring of photovoltaic systems to support wastewater collection and treatment systems.																																
Output 4.3: Climate Change considerations mainstreamed into the SOP and Operational Manual of the Wastewater Systems																																
Activity 4.3.1: Update Standard Operating Procedures (SOP) and Operational Manual with operational duties and responsibilities documentation specific to climate change adaptation and preventative maintenance.																																
Activity 4.3.2: Provide theoretical and practical training related to climate adaptive and preventative maintenance and re-assign appropriate roles and responsibilities.																																
Component 5: Wastewater Management and Water Conservation Education for Consumers to Adapt to Climate Change Risks (Barbadian Communities and Visitors, School, Community-Based Training, Education, and Gender).																																
Output 5.1 Public Awareness Campaign Implemented.																																
Activity 5.1.1: Develop educational and communications resources for community and businesses on their wastewater practices that impact water quality and quantity, and the importance of water reuse activities to increase the surrounding community's water supply: direct potable reuse (DPR) and indirect potable reuse (IPR).																																
Activity 5.1.2: Create a Public Awareness Campaign for community and visitors (tourists) through workshops, videos, community town hall meetings, and consultations on Direct Impacts on Ecosystem and Ecotourism. Share lessons learnt to spur greater public and entrepreneurial involvement.																																
Activity 5.1.3: Construct a visitor centre at the wastewater plant to educate on the benefits on water reuse.																																
Output 5.2: Public Implementation of Climate Change Adaptation Planning Strengthened.																																
Activity 5.2.1: Promote and encourage the public to accept IPR and take action to mitigate, and adapt to climate variability and change. Conduct outreach programmes in schools, community-based organizations, and stakeholders groups across customer class.																																
Activity 5.2.2: Implement a BWA website page dedicated to transparent measures of reporting of discharged effluent on existing website.																																
Activity 5.2.3: Develop and implement an incentive programme to encourage conservation, recycle, re-use.																																
Activity 5.2.4: Create a Public Service Announcement, with educational materials to all water users that addresses best practices for efficient water use, conservation, and reuse.																																
Activity 5.2.5: Encourage existing private sector decentralized onsite and cluster wastewater systems to also adopt water reclamation technologies.																																
Project Monitoring*		Inception Report			APR				APR		Interim Evaluation		APR				APR		Interim Evaluation		APR		Interim Evaluation		APR		Interim Evaluation		APR		Interim Evaluation	

APR = Annual Performance Report

*In addition to this monitoring requirements, the Funded Activity is also subject to financial reporting per the AMA/FAA, such as Unaudited/Audited Financial Statements, Financial information reports, and other reports as defined in the FAA.