Baseline Study

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

Contract # 10/2020/GCF3Rs/Barbados/CCCCC

Prepared for:

Caribbean Community Climate Change Centre (CCCCC)

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Report Submission To:	Caribbean Community Climate Change Centre
Legal Company Name:	Caribbean Community Climate Change Centre
Company Address:	Lawrence Nicholas Building Ring Road, P. O. Box 563 Belmopan, BELIZE
Contact Phone Number:	+011.501.600.6342
Contact Email Address:	dcain@caribbeanclimate.bz

Submitted By:	Nick St-Georges
Legal Company Name:	Integrated Sustainability
Company Address:	Franklins House, Lot 47 Bennett's Road St. James, Barbados BB24011
Contact Phone Number:	1.246.823.5300
Contact Email Address:	nick.stgeorges@integratedsustainability.ca

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WATER | WASTE | ENERGY

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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
AC	Asbestos Cement
ADWF	Average Dry Weather Flow
AS	Activated Sludge (Suspended Growth Wastewater Treatment Process)
ASTM	American Society for Testing and Materials
BMP	Biomethane Potential
BMS	Barbados Meteorological Service
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BOD_5	5-Day Biochemical Oxygen Demand
BTSTP	Bridgetown Sewage Treatment Plant
BWA	Barbados Water Authority
BWRO	Brackish Water Reverse Osmosis
CARPHA	The Caribbean Public Health Agency
$CBOD_5$	5-Day Carbonaceous Biochemical Oxygen Demand
CCCCC	Caribbean Community Climate Change Centre
CCREEE	Caribbean Centre for Renewable Energy and Energy Efficiency
CE	Choice Experiment
CFU	Colony Forming Units (Membrane Filtration Bacteria Test)
CH_4	Methane
CHP	Combined Heat and Power
CIMH	Caribbean Institute for Meteorology and Hydrology
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand

Acronym/Abbreviation	Definition
CReWS	Climate Resilience Wastewater System
CREWS	Coral Reef Early Warning System
CWWA	Caribbean Water and Wastewater Association
CZMU	Coastal Zone Management Unit
DBP	Disinfection By-Products
DI	Ductile Iron
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EBPR	Enhanced Biological Phosphorus Removal
E. Coli	Escherichia Coli
EDC	Endocrine Disruptive Compound
EEZ	Ecological Economic Zoning
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
ESIA	Environmental and Social Impact Assessment
FC	Faecal Coliforms (Indicator Bacteria)
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse Gas
GHW	Graeme Hall Wetland
GMST	Global Mean Surface Temperatures
GoB	Government of Barbados
gpd	Gallons per Day
GSC	Garbage and Sewage Contribution
GZP	Groundwater Zoning Policy
H_2S	Hydrogen Sulfide
HSE	Health, Safety & Environmental

Acronym/Abbreviation	Definition
I&I	Inflow and Infiltration
IDB	Inter-American Development Bank
IRWR	Internal Renewable Water Resources
ISO	International Organization for Standardization
KAP	Knowledge, Attitude and Practice
LHV	Lower Heating Value
MAFS	Ministry of Agriculture and Food Security
MBBR	Moving Bed Biofilm Reactor
mbgs	Metres Below Ground Surface
MBR	Membrane Bioreactor
MEWR	Ministry of Energy and Water Resource
MGD	Million Gallons per Day
Mg-N/L	Milligrams of Nitrogen per Litre
MIGD	Million Imperial Gallons per Day
MLD	Million Litres per Day
MLE	Modified Ludzack-Ettinger
MLVSS	Mixed Liquor Volatile Suspended Solids
MMF	Monthly Maximum Flow
MTIT	Ministry of Tourism and International Transport
MTWWR	Ministry of Transport, Works, and Water Resources
MoHW	Ministry of Health and Wellness
MOP	Manual of Practice
MPCA	Marine Pollution Control Act
MPN	Most Probable Number (Multiple Tube Fermentation Bacteria Test)
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium

Acronym/Abbreviation	Definition
NH_4-N	Nitrogen Content of the Ammonium Ion
Nitrate-N	Nitrate Nitrogen (refers to the nitrogen present which is combined in the nitrate ion. This nomenclature is used to differentiate nitrate nitrogen from nitrogen in the form of ammonia (ammonia nitrogen), from nitrogen in the form of nitrite (nitrite nitrogen))
NRW	Non-Revenue Water
NTU	Nephelometric Turbidity Unit
O&M	O&M
O&G	Oil & Grease
P	Phosphorus
PDD	Planning and Development Department (formerly known as the Town and Country Development Planning Office)
PE	Population Equivalent
pH	Potential of Hydrogen
PM	Project Manager (from Consultant)
PPE	Personal Protection Equipment
ppm	Parts Per Million
PTL	Project Team Leader (from 5Cs)
PVC	Polyvinyl Chloride
PWWF	Peak Wet Weather Flow
QMS	Quality Management System
R2RP	Roofs to Reefs Programme
RAS	Return Activated Sludge
RO	Reverse Osmosis
SBR	Sequential Batch Reactor
SCADA	Supervisory Control and Data Acquisition
SCSTP	South Coast Sewage Treatment Plant
SIDS	Small Island Developing States

Acronym/Abbreviation	Definition
SLR	Solids Loading Rate
SOP	Standard Operating Procedures
SOR	Surface Overflow (loading) Rate
SPT	Standard Penetration Test
SRT	Solids Retention Time
SSA	Sanitation Service Authority
SWMM	Stormwater Management Model
SWPU	Solid Waste Project Unit
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
TP	Total Phosphorous
TRC	Total Residual Chlorine
TS	Total Solids
TSS	Total Suspended Solids
US	United States
UV	Ultraviolet
UWI	University of the West Indies
VFD	Variable Frequency Drive
VS	Volatile Solids
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge

Acronym/Abbreviation	Definition
WEF	Water Environment Federation
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This report summarizes the baseline conditions of the wastewater systems in Barbados. It presents assumptions that are to be used in the assessment of options for upgrading and adapting infrastructure to meet climate change impacts. This includes energy and resource recovery opportunities to meet greenhouse gas emission objectives.

The proposed scope of work involved the capture and analysis of available historical flow and raw wastewater water quality data for the BTSTP and SCSTP facilities. Detailed flow monitoring data was to be used in conjunction with information on the number of tourists, season, and precipitation to examine the impact of climate change on wastewater flow and contaminant concentration characteristics. Unfortunately, much of the historical data from the wastewater facilities has been destroyed and there is limited data available. Furthermore, the BWA does not have any laboratory facilities to carry out wastewater contaminant characterization analyses. The lack of laboratory data also means that accurate analysis of the wastewater performance at the existing treatment processes is difficult to determine. This includes the amount of waste materials, in particular screenings and waste biosolids that are generated and being disposed of on the island. It also means there are no records of the septage, being delivered to the BTSTP, from the remaining 85% of the population (including government, hotel and commercial services) that is not connected to either treatment facility, who use septic disposal as part of their means for wastewater management. The flow measurement system for BTSTP has also not been functional for many years. Some summary flow information for the SCSTP was, however, available which, provides some important insights on the effects of tourism and precipitation on flows within the collection system draining to the SCSTP, and can be used to review the SCSTP wastewater collection system.

Without historical information on flow and raw or treated wastewater constituents, it isn't possible to accurately assess the historical operating performance of the treatment facilities or use performance information to present upgrade plans. We have therefore used assumptions and best practices together with the limited information available on wastewater characteristics and the performance capabilities of the existing infrastructure for the comparison of mitigation options and upgrades. In this baseline report we present rationale of assumptions and our strategy to determine reasonable estimates of the wastewater characteristics together with expected treatment system performance which is used to present a basis to assess the potential impacts of climate change. The flow information that is available for the SCSTP is used to confirm resident population flow characteristics, impacts of tourism on wastewater flows. It is also used to conduct a general assessment of the amount of inflow and infiltration that is occurring and taking up sewer and treatment hydraulic capacity. Due to the lack of basic data for the BTSTP, both in terms of influent flow and loading characteristics and equipment performance, we propose to extrapolate the domestic residential flow and loading characteristics generated for the SCSTP collection system and use those wastewater characteristics as the basis for a modelling evaluation. Although wastewater treatment and outfall disposal performance data is not available, we propose the use of modelling software to assess and the potential design capacity of the existing treatment components using drawings and equipment specifications, that are available, as well as site tour and photo information that we have collected since the project's inception. The process

modelling data for the treatment facilities, in conjunction with the estimates of organic loading, primary and waste biomass solids generation, can be used to provide a reasonable estimate of the potential for GHG emissions if this material is not managed appropriately, as well as the nutrient and energy resource recovery that can be achieved.

The greatest challenge that was identified was that the collection systems and the treatment plants are experiencing wide flow and load variations over the year that impede efforts of the operators to attain optimal performance of the treatment systems and are expected to present a significant challenge for the project team to develop an adaptive strategy to mitigate the problem.

Climate change impact considerations includes the importance of water reclamation and reuse in the face of declining precipitation and/or reduced groundwater recharge due to changes in rainfall intensity and duration patterns. Existing evidence of inflow and infiltration that is caused by precipitation influences is used as a basis for expected degradation of wastewater infrastructure, using documented changes for sewers in other locations. The potential effects of storm surges on marine outfall performance and dispersion characteristics are similarly assessed.

Environmental and social impacts are also considered to achieve the best overall development objectives. The GCF, managed by the CCCCC, will be proceeding with a full ESIA project in parallel to this assignment. Environmental and social assessments related to this project will rely on existing literature with the objective to provide key observations and high-level information to the BWA so they can better understand present environmental and social considerations. It is also expected that the parallel project will examine the detailed environmental and social aspects related to this overall project.

A review of current operational and maintenance practices is presented to highlight issues related to the operation of the sewage treatment plants and collection systems. There appears to be a disproportionate number of staff dedicated solely to operational tasks when compared to staffing levels for strictly maintenance aspects. The lack of adequate maintenance staff is a particular concern due to the age and current condition of the equipment that only receives break-down maintenance, as opposed to preventative maintenance through a robust, documented, maintenance management system.

It is also highlighted that the lack of enforceable rules governing discharges to the collection system results in an excessive amount of time and effort required to resolve issues related to FOG and removing rags from the sewage collection system.

Improvements in documentation, procedures, training and the health and safety of field staff, will have cascading positive effects on the current performance of the treatment facilities and lift stations, and the environment.

1 INTRODUCTION

The Government of Barbados, Barbados Water Authority and the Caribbean Community Climate Change Centre have developed a Green Climate Fund project aimed at building climate resilience into the wastewater systems of Barbados. This project concept aims to address challenges facing the wastewater systems and water availability, particularly those caused and exacerbated by climate change.

Integrated Sustainability has been retained by the CCCCC to develop "Requisite Design, Studies and Plans for Climate Resilience Wastewater Systems in Barbados." This project will examine reduce, reuse, and recycle resource-recovery opportunities for wastewater treatment associated by- products including biosolids solids (sludge), methane from biogas and reclaimed treated water from the Bridgetown and South Coast Sewage Treatment Plants.

This Baseline Report establishes the existing conditions, data and other information available for the wastewater treatment facilities, and their collection systems, as well as financial, environmental, public health and public opinion and perception related to water availability and wastewater management practices on the island.

2 OBJECTIVES AND ASSOCIATED OUTCOMES

The overall objectives associated with this consultancy is to conduct and present requisite studies for low-carbon climate-resilient wastewater systems in Barbados necessary to realise funding from the GCF. The aim of this assignment will be to:

1. Conduct a Conceptual Design and Feasibility Study (including a preliminary risk assessment) involving technical, financial, and economic assessments for recommended and approved low-carbon climate resilient wastewater systems in Barbados, including:
    - Identifying climate change adaptation upgrade options to achieve tertiary treated effluent quality for the BTSTP and the SCSTP and the potential for wastewater reuse, energy recovery (such as methane capture), and resource recovery options for primary and secondary biosolids and associated by-products; and
    - Identifying climate resilient design upgrade options for the wastewater collection system.
2. Conduct a Stakeholder Analysis and develop a Stakeholder Engagement and Management Plan; and
3. Conduct a Gender Analysis and develop a Gender Action Plan pertaining to the study subject matter.

INTEGRATED SUSTAINABILITY

3 BACKGROUND

Barbados, the eastern most Caribbean island, has 287,420 residents[1] and has a land area of 431 km^2 (166 miles), with the highest point rising to 323 m near the centre of the island. The bulk of the population lives along the south coast, while the west.

Barbados is the 4th most densely populated country in the Americas, and 15th globally, and it ranks as the 10th most populous island nation in the region[1].

3.1 Climate and Rainfall Data

3.1.1 Climate

Barbados enjoys a tropical oceanic climate with an average daily temperature of 27.2 °C (using the latest 40-year data from the BMS[2]). Average maximum temperatures varies between 28° and 32°C and average minimum between 21° and 26°C though since the mid 1970's an upward trend has been apparent (Figure A). Annual evapotranspiration has been estimated at 1,540 mm.

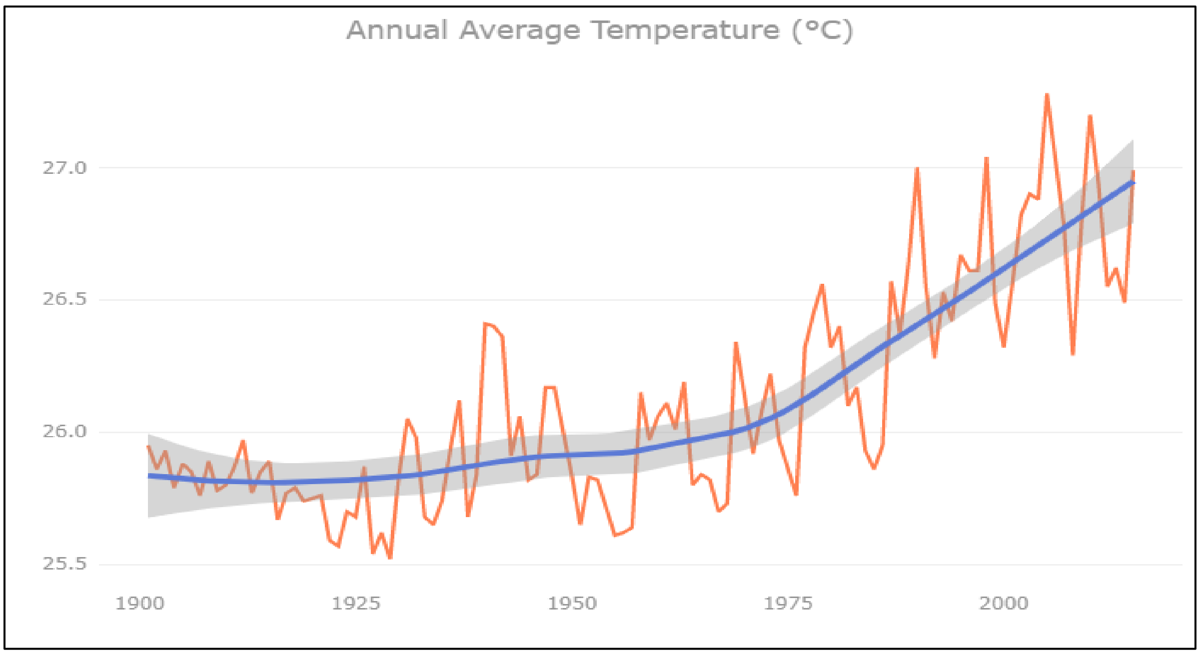

Figure A. Trend in Average Annual Temperatures[3]

Located on the edge of the Atlantic storm zone, Barbados has as dry sub-humid climate with wet and dry seasons, with the wet season coinciding with the Atlantic hurricane season that runs from June until November. As illustrated in Figure B, Barbados has a distinct dry season from December to May.

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[1] World Population Review (Barbados 2020): http://worldpopulationreview.com/countries/barbados-population/

[2] Barbados Meteorological Service, 2020

[3] https://www.jamaalroach.com/2018/10/barbados-is-getting-hotter-in-four-charts/

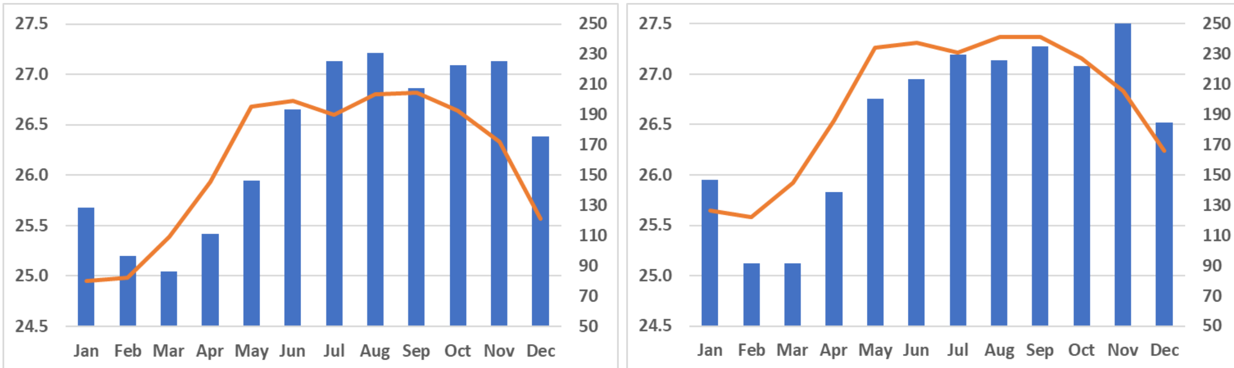


Figure B. Average Monthly Temperature and Rainfall for Barbados for the Periods of 1961-1990 (left graph) and 1991-2016 (right graph)[4]

Barbados, like many SIDS, cannot ignore the potential for climate change to impact its limited existing groundwater resources and the need to engage in adaptive and mitigation strategies. Climate change is expected to have numerous impacts for Barbados including: increased air temperatures; increased sea level impacting erosion, coastal inundation and saline intrusion of coastal fresh water aquifers, and changes in seasonal weather patterns (amount and intensity of rainfall and changes in storm intensity)[5]. Barbados is almost entirely dependent on groundwater supplies that are expected to be threatened by sea level rise resulting in increased salt-water intrusion within freshwater aquifers potentially damaging water infrastructure and soil quality while impacting agriculture and water resources; and by increased frequency and severity of droughts which climate models suggest may intensify in the future in the Caribbean region (Vichot-Llano et al., 2020). The sea-level rise for Barbados is projected at 5 to 10 mm/year and is complicated by vertical crust upheaval due to the tectonic processes, affecting coastal aquifers. (Simpson, et. al, 2009)

Barbados' location along the hurricane belt makes the country vulnerable to associated storm surge and flooding. Although it is rare for Barbados to experience a significant hurricane (larger than a category 3), it is impacted and suffers damage from large storms, including intense rainfall that can cause extreme flooding due to generally limited drainage capacities, as experienced with tropical storm Thomas in 2010. The literature indicates that SIDS already experience significant impacts, and high risks due to tropical cyclones and sea-level rise, and that climate change places SIDS at high risk (Thomas, et. al., 2020).

Climate change modelling (Simpson et. al. 2009) indicates subtropical areas (including the Caribbean) are expected to experience a reduction in mean precipitation as well as more intense and shorter duration rainfall events interspersed with long periods of dry weather. The higher intensity rainfall events are expected to reduce the amount of groundwater recharge that occurs as flood waters are directed to surface drainage courses and the ocean. The literature suggests

[4] *World Bank Climate Change Portal - Dataset produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA) - https://climateknowledgeportal.worldbank.org/country/barbados/climate-data-historical*

[5] Barbados First National Communications to the United Nations Framework Convention on Climate Change (UNFCCC). 2001

that historical damage resulting from climate-related natural disasters in the Caribbean are related to sea surface temperature variations. Modelling suggests that when GMST reach and exceed 1.5 °C above preindustrial levels annual normalised damages may potentially increase to at least US$1.4 billion for a temperature increase of 1.5 °C (Burgess, et al, 2018). Regional climate projections also predict warmer and drier conditions over the eastern Caribbean compared to present in the near future (2020–2049) and far future (2070–2099) with a reduction of consecutive wet days and an increment of consecutive dry days (Vichot-Llano, et al, 2020).

3.1.2 Rainfall Data

Average annual rainfall varies from about 1,000 mm in the north and south-eastern parts of the island to more than 2,000 mm in the central areas. Figure C shows the annual deviation from the long-term average rainfall of 1,270 mm at the GAIA. Rainfall variations are largely influenced by the prevalence of El Niño or La Niña Southern oscillations (see Figure D). La Nina periods tend to produce above average rainfall and create wet conditions, whereas El Nino events create dry conditions. Analysis of the 10-year rainfall at GAIA, provided by the Barbados Meteorological Services, demonstrates that the rainfall has been decreasing since 2010. The Barbados average rainfall distribution for the past 10-years is also illustrated in Figure E. Rainfall distribution across the island indicates a higher average rainfall distribution in the central Parishes of St. George. St. Michael, St. Thomas, and parts of the countryside, namely St. Joseph and St. John.

Of the five consistent rainfall recording stations over the past 10-years, the data indicates 31% of the island's rainfall occurs mainly in St. George, 29% in Christ Church and less than 20% in the remaining parishes.

Also of importance, is the nature of the rainfall, how much falls over what period, and the time between rainfall events. If there is too little rain it evaporates fast, and if there is too much and it runs off as stormwater. Figure C illustrates that the deviations, since approximately 1990, have grown, which supports the statement that climate change has resulted in greater extremes in flooding and drought weather events.

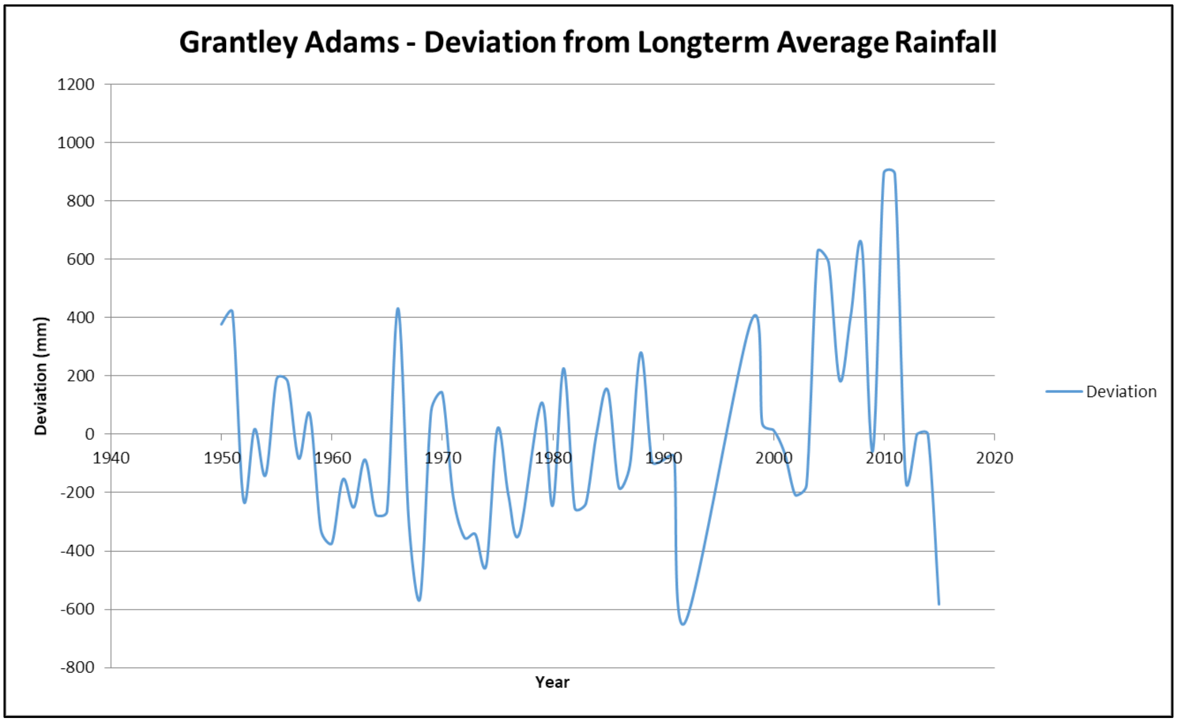


Figure C. **Annual Deviation from Long-Term Average Rainfall at Grantley Adams International Airport 1950-2015**[6]

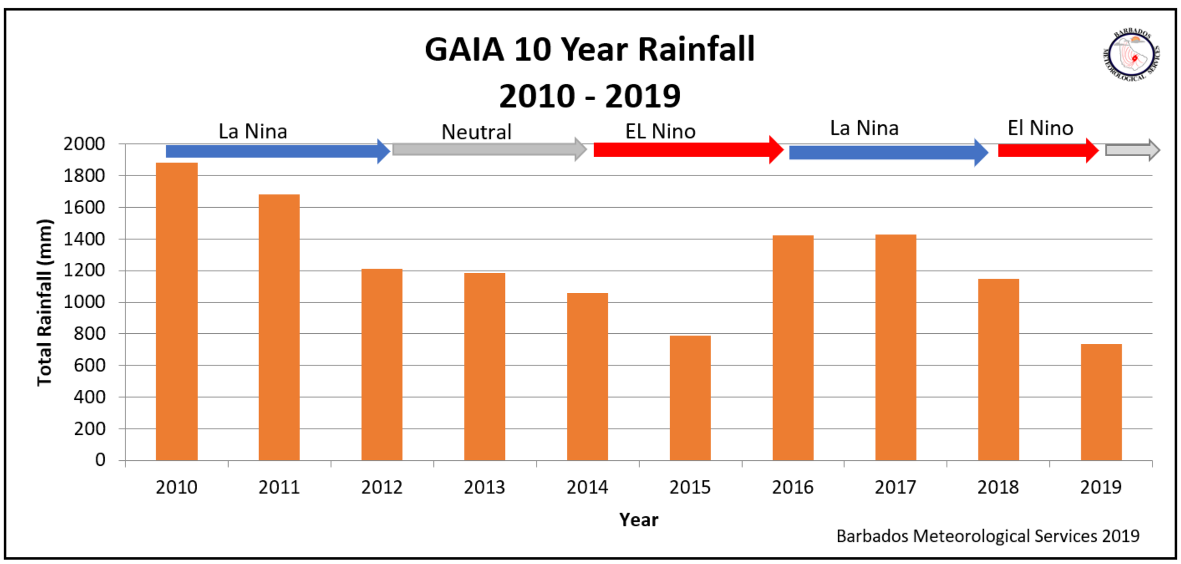


Figure D. **El Nino Southern Oscillation (ENSO) Trend and Effect on Barbados' Rainfall Over the Past Ten Years, Measured at the GAIA**[7]

[6] Source: Adrian Cashman, 2020

[7] Barbados Meteorological Services data, May 5, 2020

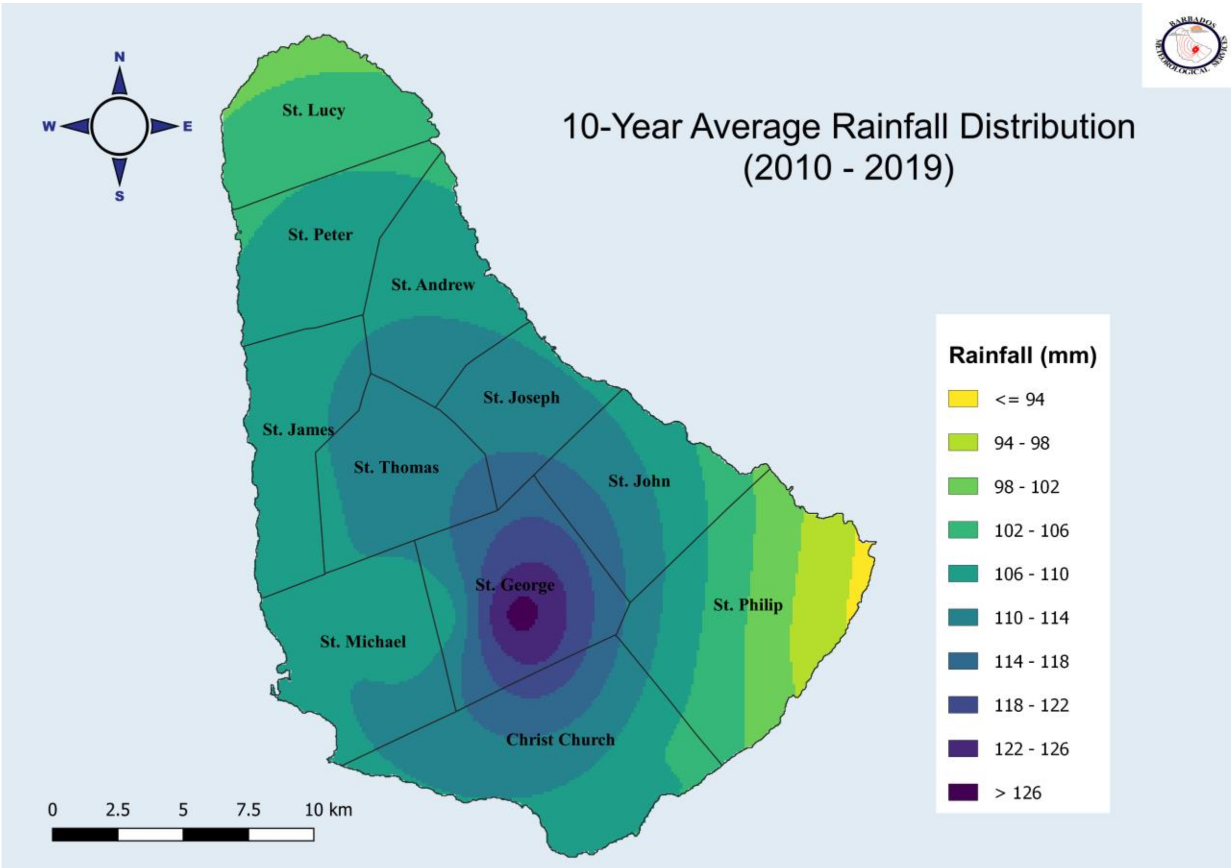


Figure E. Barbados 10-Year Average Rainfall Distribution[10]

The Barbados-based CIMH has reported[8] that there are concerns over long term drought conditions in Barbados. 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.[9]

Flash-flooding has increased in frequency and magnitude, illustrating the impact of climate change on Barbados. For example, in December 2016, Barbados experienced over 6 inches of rainfall in a couple hours, which was only previously observed in 1995, contributing to the failure of the sewerage system.

[8] Barbados News (Mar. 5, 2020): https://www.nationnews.com/nationnews/news/244196/barbados-countries-facing-term-drought

[9] *Simpson et. al. 2009. An Overview of Modelling Climate Change – Impacts on the Caribbean Region with contribution from the Pacific Islands. UNDP. pp. 264. (https://www.bb.undp.org/content/dam/barbados/docs/Publications/UNDP-Modelling-Climate-Change-Full-Report.pdf)*

3.2 Geomorphology and Hydrology

3.2.1 Geomorphology

The terrain is characterised by a series of terraces rising from the west and southern part of the island towards an escarpment on the east. Barbados is made up of two distinct geologies: coralline limestone (86% of the bedrock) and older volcanic deposits (outcropping in the Scotland District). Barbados' soils are mainly residual clay soils.

Vernon and Carol (1966) recognised nine units; the St Lucy Plain, Below First High Cliff, Below Second High Cliff, the St George's Valley, the St Philip Plain, the Upland Plateau above the Second High Cliff and including the St John's Valley, the Christchurch Ridge, the Scotland District and Below Hackleton Cliffs. Geologically, Barbados is made up of two distinct geologies.

1. The Scotland District is made up of extensively folded marls, clays, muds and volcanic deposits associated with the emergence of Barbados as the Caribbean Plate collided with the North Atlantic tectonic Plate.
2. By contrast 86% of the island is made up of coral limestone of varying depth overlying the Scotland District rocks.

The marked terraces (Figure F) are thought to be relic fringing reefs developed as the island rose from the sea. Whilst the primary porosity of the limestone is low to medium, secondary porosity is high, due to weathering and the formation of solution channels by percolating water.

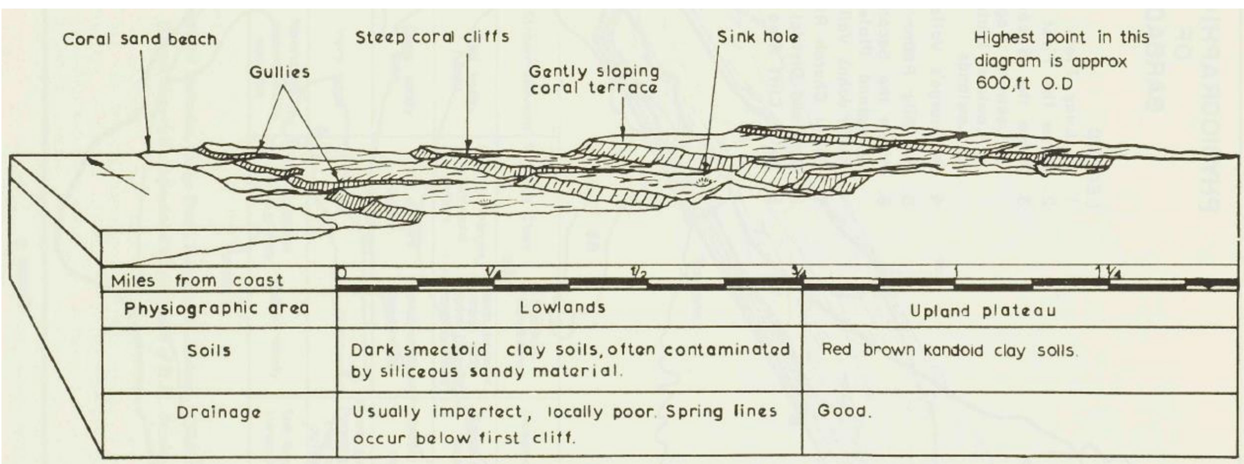


FIGURE 2
Coral Terraces of the Leeward (West) Coast, Barbados
(Crown Copyright, Reproduced by permission of H.M. Stationery Office)

Figure F. Schematic Cross-Section of Barbados Coral Terraces

3.2.2 Hydrology

Sen (1946) distinguished two types of groundwater flows, stream flow and sheet water (see Figure H). Stream flow is associated with the flow of groundwater through the secondary porosity conduits whilst sheet flow occurs diffusely through the limestone forming a freshwater lens over the denser seawater in coastal areas (Figure G).

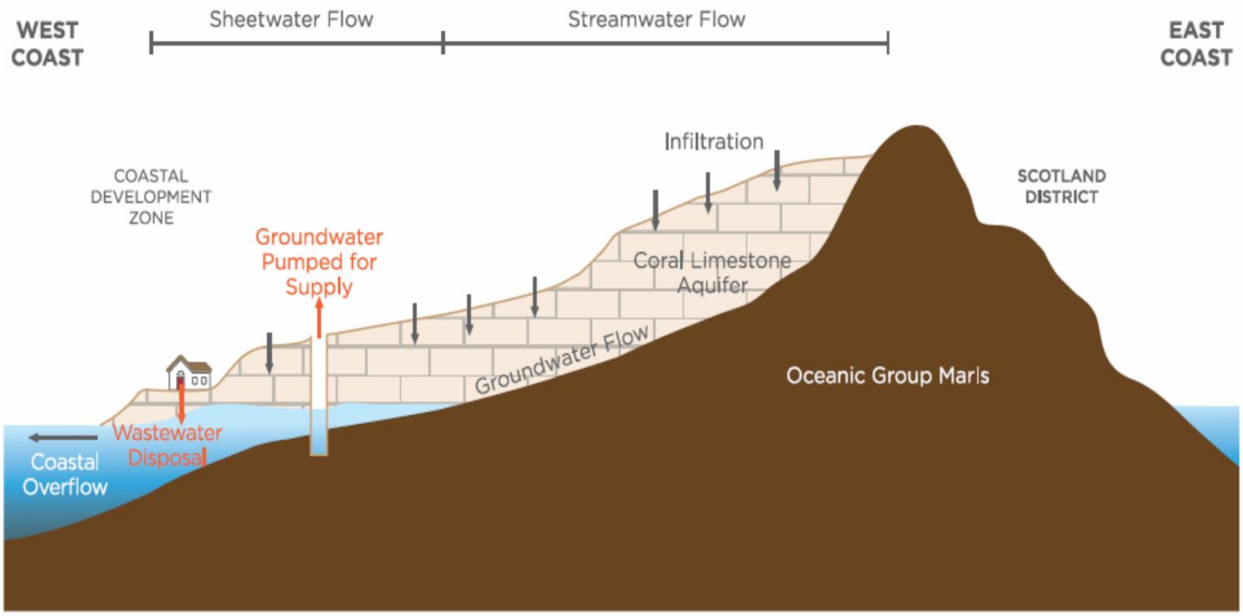


Figure G. Barbados' Groundwater Regimes

Work by Jones and Banner (2003) concluded that recharge occurred through both diffuse and discrete infiltration. Diffuse infiltration is controlled by soil permeability and depth. Soils above the Second-High Cliff tend to be more permeable than those below it. Discrete infiltration is controlled by the presence of karstic features; sinkholes (dolines) and dry valleys also known as gullies. Runoff through the dry valleys only occurs briefly during periods of heavy rainfall. It has been suggested that runoff is generated by rainfall rates exceeding 75–100 mm/day but this is anecdotal. Surface water discharge is very low and has been estimated to be less than 1% of average annual rainfall. High sinkhole densities tend to occur in areas where dry valleys are not well developed and tend to be characterized by low relief. The karst shafts have greater potential as conduits for recharge to the aquifer than the larger sinkholes because they are frequently filled with very low permeability soils that reduce their ability to transmit infiltrating water without ponding and extensive losses to evapotranspiration.

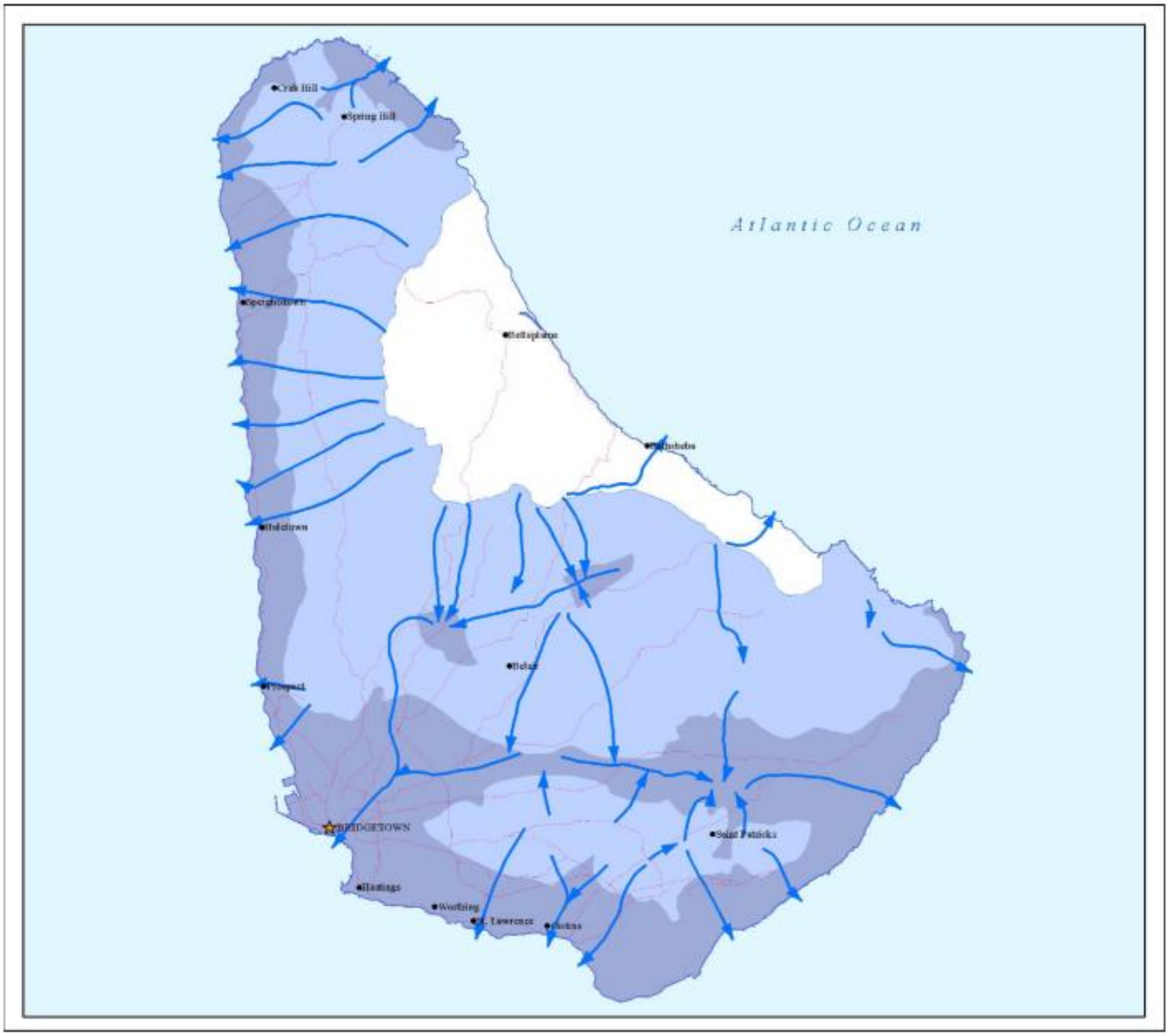


Figure H. Stream Flow, Sheet Water and Groundwater Flow Directions

Based on observations of responses to rainfall in caves, a flow rate response is observed within hours of a large rainfall event followed by a second smaller response weeks or months later. The first flow response is associated with rapid discrete infiltration, while the second response is related to slower diffuse infiltration. Diffuse recharge is most likely to occur where soil infiltration rates are highest (e.g., above the Second-High Cliff).

"The 195 mm rainfall threshold represents minimum conditions that will result in recharge to the aquifer as a result of runoff to karst features. The amount of rainfall that will generate runoff in any specific rainfall event will vary with soil moisture, such that runoff and therefore recharge are more likely to occur when soil moisture is high. Recharge may thus be the product of multiple small rainfall events or a single large rainfall event. Monthly

rainfall less than 195 mm is likely to be taken up by evaporation and transpiration and thus make an insignificant contribution to recharge." (Jones and Banner, 2003)

The variation of recharge over time is therefore related more to the distribution of rainfall throughout a given year than variations in total annual rainfall. Little recharge takes place during El Niño years when wet season rainfall is suppressed, while much more recharge takes place associated with La Niña episodes when peak wet season rainfall is enhanced.

Although Barbados' highly permeable coral limestone geology is conducive to rapid percolation over most of the island, at the eastern end of the island (the Scotland District) the geology consists of impermeable oceanic sediments, such as silty clay, and a large portion of the rainfall is lost through runoff to the ocean.

3.3 Water Supply and Demand

3.3.1 Water Supply

Approximately 85% of the BWA potable water supply comes from groundwater aquifers which, in turn relies on rainfall infiltration as a source of water. As previously noted, variations in rainfall intensity and duration, due to climate change, and recent trends towards longer periods of drought, can significantly impact the water balance. The drought periods can harden the soil surface and make it less permeable, and high intensity rainfall tends to drain rapidly to the ocean, with insufficient time for the surface flow to infiltrate into the aquifer.

The water system is supplied by 22 wells (17 sheet and 5 stream water wells) together with 8 boreholes, all ranging in depth from 34 to 98 metres, and two spring sources. Barbados is classified as being in the top 15 of the world's most water scarce countries (as reported by PAHO, 2012), not so much in relation to the availability of potable water, but in relation to its lack of freshwater resources, with a rating of 210 m^3/person/yr, well below the benchmark of 1,000 m^3/person/yr.

The BWA has reported drastic decreases in groundwater levels at the majority of their groundwater wells located across the country and potable water production has had to be reduced by as much as 3 million gallons per day during some of the severe drought events that have occurred. The reduced aquifer levels also result in increased saltwater intrusion and higher brackish water (or brine) levels have been recorded in most of the water wells along the coastline, making them inoperable without treatment to remove the dissolved solids. Treatment of the brackish water through a reverse osmosis water treatment plant is expensive due to the high operational energy costs.

Estimates of Barbados' aquifer yield have varied over time. Tullstrom (1964) calculated the safe yield of the aquifers to be 49.46 Mm^3 per year, based on an average annual rainfall of 1,500 mm. Another report (Stanley Associates, 1978) estimated that under drought conditions, of 1,016 mm rainfall amounts, the safe abstraction should be 54.28 Mm^3. A 1996 (Klohn-Crippen Consultants Ltd, 1996) study, using an average annual rainfall of 1,424 mm arrived at an estimate of 73.95 Mm^3.

However, as previously stated, climate change conditions appear to be reducing this volume. To address the reduction in volume and the increasing saline nature of the water, the BWA commissioned their inland BWRO desalination plant in 2016, located north of Bridgetown. The water produced by this facility varies with need. The plant was upgraded in 2019 to produce up to 15.0 Mm^3/yr and, in addition to untreated well water, BWA could potentially withdraw up to 92 Mm^3 of water per year from the aquifer.

3.3.2 Water Demand

As summarized in Table A, the BWA estimates that 51.9 Mm^3 of water was extracted from groundwater sources in 2019 and distributed through the water distribution system. Of that BWA reports that 19,981 Mm^3 (38%) was unaccounted for; representing non-revenue water losses associated with water leakage, un-metered utility hydrant and standpipe water uses, inaccurate flow meters, and unauthorized water system connections.

Agricultural irrigation accounts for the largest water use in Barbados. The BWA estimate the agricultural water use in 2019 to be 10,590 Mm^3, representing 20% of the total amount of groundwater extracted from the aquifer in 2019. The exact amount of water extracted is unknown as most of the water for agricultural irrigation use is obtained from un-metered private wells.

Table A. Water Production and Consumption (BWA 2019)

Description	Volume (Mm^3)	Percentage (%)
Production into the Distribution System	**51.939**	
Total sales (Revenue water)	31.958	100.0
Domestic	*22.044*	69.0
Central Government	*1.714*	5.3
Commercial	*6.477*	20.2
Statutory Government Bodies	*0.284*	0.9
Hotels	*1.406*	4.5
Port	*0.032*	0.1
Estimated NRW Losses	**19.981**	**38% of production**
Estimated Agricultural Water Use	**10.590**	**20% over the current production**

However, the estimated NRW loss illustrated in Table A does not include the estimated NRW losses associated with the Spring Garden BWRO. If the entire water system, including the BWRO, system is included, it is estimated that the total NRW is closer to 50%[10].

3.4 Wastewater Management - Areas Not Connected to the BTSTP or SCSTP

3.4.1 Areas not Connected to the BTSTP or SCSTP

Only 10-15% of the urban population is connected to the BTSTP and the SCSTP sewage collection system along the south coast of Barbados, although 99% have access to improved sanitation in

[10] As per personal communication with Mr. Charles Marville, retired Manager of the BWA Engineering Department

both urban and rural areas (Nurse, Cashman, & Mwansa, 2012). The remaining areas of Barbados, that do not connect into the BTSTP or SCSTP use a variety of septic tank and soak away fields (typically for residential and/or small commercial businesses), or deep well injection (typically for larger commercial and industrial businesses).

Hotels and other tourist accommodations along the west coast are required to have their own wastewater treatment facilities – typically consisting of private-sector third-party operated package treatment plants – which discharge the liquid effluent from the plants into coastal wells. These package plants have capacities ranging from 13m^3/day - 170 m^3/day. Twenty-seven package plants exist in various hotels and, 70% of them meet the Marine Pollution Control effluent discharge standards, although there are concerns regarding nitrate levels and chlorine residuals in the treated effluent produced by the plants.

The increase in residential developments over the last several years, especially within inland areas, and the wastewaters generated by them, the discharges of industrial effluent (with varying degrees of treatment) and the impact of agricultural activity have all raised concerns over their impact on groundwater quality, that connects to the coastal marine environment. There is in place a water quality monitoring system with production and monitoring wells being sampled and tested every two weeks. To date, the measured levels of parameters of interest, such as nitrates have remained below WHO limits. However, elevated levels of nitrates in certain production wells have raised concerns over the quality of water. Investigations into nitrate vulnerable areas have also indicated that groundwater in St. Michael, St. George, Christ Church, parts of St. James and to a lesser extent other parishes could be at risk from a combination of agricultural and human activities (Yusef-Leon & Cashman, 2010).

As previously noted, septage from septic tanks is collected by tanker truck and discharged at the BTSTP. It is anticipated that under the proposed changes to the GZP, it will no longer be permitted to dispose wastewater directly into septic tanks and soak away fields and some form of treatment will be required. The level of treatment will depend on the nature of the wastewater generated, as well as the location of the property (proximity to the ocean or BWA groundwater intake), location relative to sensitive marine ecosystems and the potential impact to groundwater (see groundwater protection zoning policies in Section 3.6.2).

3.4.2 Coordination Opportunity - Roofs to Reefs Programme

The Barbados Government have started to address issues related to increased resilience of freshwater supply and storage by implementing programmes such as the R2RP. The R2RP is a holistic, integrated public investment programme founded on principles of sustainable development and climate change resilience for Barbados. The current R2RP looks to replace current residential septic tank and soak away fields with a more sophisticated on-site treatment system that will lower the level of nitrogen released after treatment. This program is still currently under development.

Some of the R2RP objectives include:

- to make low- and middle-income homes more resilient to extreme weather events as well as possible loss of the electricity grid and potable water distribution systems;

- to increase freshwater storage capacity and water use efficiency;
- to reduce carbon emissions through the deployment of distributed renewable energy generation;
- to decrease land-based sources of marine pollution;
- to implement more sustainable land (and marine space) use practices;
- to make critical utility, water and sanitation and road infrastructure climate resilient; and
- to restore the reduced coral reef ecosystem services particularly on the west and south coasts of the island.

The R2RP provides the overarching framework that allows the integrated approach to addressing activities under all of the key sectors as a response to the impacts of Climate Change that affect all sectors (see Figure I).

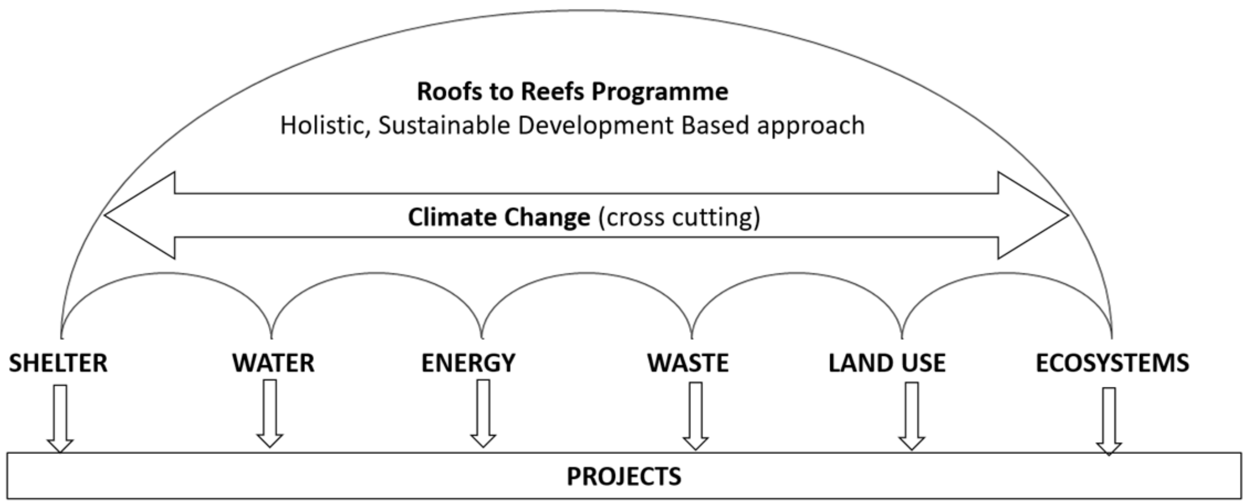


Figure I. R2RP Structure[11]

A breakdown of the R2RP areas include:

- **Shelter** - possible housing structural upgrades (to possibly withstand up to Cat 4 hurricanes) to better accommodate rooftop solar installations, and eradicating pit latrines;
- **Water** - rainwater collection systems, improved stormwater collection to both improve water storage capacity and groundwater recharge rates, potable water storage improvements (including integration of the Personal Tank Programme, organized through the BWA), and better (in comparison to the existing septic tank and soak away field) residential wastewater treatment systems;
- **Energy** – solar PV, including battery storage, and other renewable energy considerations;

[11] Ricardo Marshall presentation on the R2RP, 2020

- **Waste** – improved waste collection, and wastewater treatment with a particular emphasis on nutrient removal/recovery (closing the nitrogen loop) to better protect vital coastal reefs;
- **Land Use** - including use of the EEZ and terrestrial agriculture; and
- **Ecosystems** - gully and wetland ecosystems and terrestrial biodiversity, coral reefs and other marine ecosystems and marine biodiversity.

The draft 2017 Barbados Physical Development Plan includes a vision for the sustainable growth and development of Barbados, including a framework to facilitate and guide public and private investments. The 2017 PDP is to be amended for 2020. The connection between the PDP and R2RP can be explained as; the PDP focuses on the policy and planning framework to assist the R2RP as a public investment programme vehicle.

By implementing better residential wastewater treatment systems, the R2RP should improve groundwater quality which is currently being affected by septic tank and soak away fields.

3.5 Institutional Framework

3.5.1 Wastewater Management

Wastewater management in Barbados is regulated primarily by the BWA who provides oversight for wastewater management and monitors and tests these against international standards. Other authorities involved include the EPD, the MoHW and the PDD (formerly known as Town and Country Development Planning Office). All development projects that involve wastewater treatment and disposal must submit their proposed wastewater designs for approval to these authorities before breaking ground.

The management of solid waste in Barbados is the primary responsibility of three major agencies:

1. The EPD;
2. The SSA; and
3. The SWPU.

The SSA works in collaboration with the SWPU at the SWPU's home-composting workshops and encourages recycling where it is available. The SSA handles liquid waste including blood and grease. These are managed at a separate disposal site including other non-sewage waste, such as effluent from the paint industry, which is disposed of at the Mangrove landfill.

The SSA has also established a committee for the prevention of illegal dumping in Barbados. This committee comprises representatives from the SSA, SWPU and the MoHW. The aim is to educate communities across the island about the problems associated with illegal dumping, and in effect, discourage such practices. The committee goes into communities and hosts town hall meetings to promote clean-up events, as well as to educate persons on the benefits of sustainable waste management practices.

3.5.2 Overall Stakeholder Mapping

The main Stakeholders involved in the wastewater and solid waste management have been discussed in the above section. A more extensive Stakeholder mapping exercise (Appendix 1) has, been prepared that delineates the following various Stakeholders that could potentially play a key role in this project:

- Government Agencies
- Private Sector Agencies
- Other Public Agencies
- NGOs

3.6 Wastewater Governance and the Policy Framework

3.6.1 Wastewater Guidelines and Policies

Although the BWA is tasked with the primary responsibility to manage wastewater in Barbados, other authorities involved also include the EPD, the MoH and the PDD. The PDD's activities promote the reduction of coastal pollution. For example, the pollution regulation states that no outfall should be built that allows wastewater to enter coastal waters directly, without at least primary level treatment (which is screening only).

There is a long list of policy and legislation relevant to wastewater management in Barbados. This has been summarized in a table within Appendix 2 for reference. Some of the key policy frameworks in this summary are discussed in the following paragraphs.

Prompted by coral decline related to coastal water pollution from sewage, Barbados policymakers constructed a central sewerage system on the south coast which is to be later replicated on the west coast. Moreover, Barbados has adopted an incentive approach, using market instruments to achieve sustainable tourism practices. The Tourism Development Act (2002), states that an operator who incurs expenditure in improving the wastewater disposal system be allowed a tax credit of 20% of the capital cost of fittings, pipes and pumps used in the improvement of the wastewater system.

Water resource protection in Barbados is achieved using the "*Revised Policy of Private Sewerage and Wastewater Disposal Systems*." The BWA, EPD and PDD hold the primary responsibility for its enforcement. However, an inter-ministerial policy has been adopted to administer and enforce the policy. The revised policy seeks to control any development or liquid waste disposal system that could be injurious to the national water resources.

Whilst the regulation of effluent discharges and monitoring of groundwater quality are administered primarily by EPD, quantitative aspects and particularly the intersection with groundwater resources are the remit of the BWA, under the 1980 BWA Act. Furthermore, the CZMU has responsibility for the marine environment through the Marine Pollution Control Act (1998) and the Marine Pollution Control (discharges) Regulations (2010). There is a grey area regarding the overlap of the respective remits of EPD and CZMU. It has been acknowledged that the governance arrangements regulating groundwater and water resources in general need revision and inter alia strengthening of enforcement capabilities.

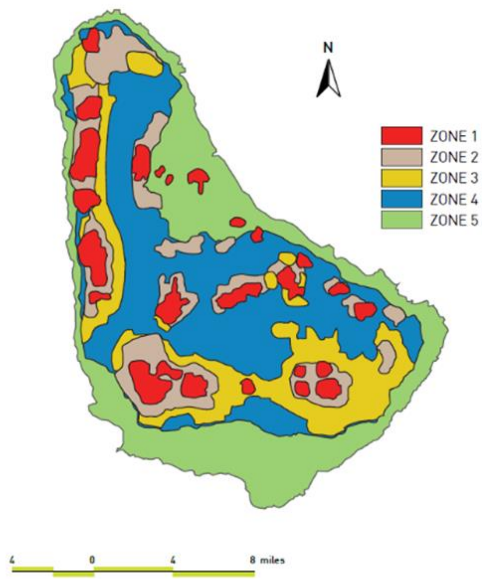
3.6.2 Groundwater Protection Zoning Policy

The Groundwater Protection Zoning Policy, that was developed in 1963 and revised in 1973, established a system of five zones (Figure J) to guard against bacteriological contamination of the public water supply wells. Zones 1 and 2 are closely monitored to ensure that the groundwater is not contaminated, as these are near the public water supply. The most stringent regulations are enforced in the Zone I area which is located immediately around all existing and potential public water supply sites. Zones 2 to 5 are provided progressively less stringent controls. The boundaries of the zones were selected such that no wastewater would reach a public well within 300 days travel time, anticipated to be sufficient time for the removal of any pathogens of concern (i.e. viruses, bacteria, parasites and parasitic cysts). At the time the policy was developed the main concern was with respect to pathogen removal rather than chemical concerns. Consequently, the policy does not address such issues as chemical contributions to groundwater from such sources as agricultural fertilizers, cleaning chemicals. industrial waste, and emerging contaminants including. dissolved metals, cytotoxic chemicals, pharmaceuticals, EDCs, and personal care products.

Under current regulations the prohibition of new development in Zone 1 has been incorporated into the Development Order under the Town and Country Planning Act (amended in 2003). The Barbados Physical Development Plan, mandated by the Town and Country Planning Act, addresses the issues of sewage, and lists the requirements guiding the GZP. The BWA and PDD have the joint task of policing the zoning policy; however, the PDD has sole responsibility for its enforcement.

The Town and Country Planning Development Order (1972) was amended in 1997 to ensure that the water protection policy restrictions on land-use were incorporated and controlled through the Physical Development Plan. Although the protection measures have generally been successful in protecting public health, there are several issues associated with the protection policy including its ineffectiveness against persistent chemical pollutants and only focuses on protecting groundwater to the detriment of coastal waters. As a result, a study was commissioned in 2008 to investigate a possible review and overhaul of the Groundwater Protection Zoning Policy and System. The review made several recommendations including revising the zoning such as to provide effective protection against emerging threats and to move towards a system where contamination of the groundwater is controlled at source. This would entail:

- Prohibiting septic tanks and soak away fields as the primary means of wastewater treatment;
- Development of communal wastewater treatment facilities; and
- Provision of guidance for wastewater treatment.



In 2020, a Government Green Paper "Water Protection and Land Use Zoning Policy" (MEWR, 2020) set out proposals for changes in the Zoning taking into account the emerging threats, proposing changes to the zoning and requirements for treatment of wastewaters. Consequently, although significantly more land would become available for development, there would be higher minimum standards for wastewater disposal imposed which would likely result in increased construction costs. The proposed new Zones A – E (see Figure K) although having no legal status as yet, have been incorporated into the National Physical Development Plan. The Green Paper proposed that coastal areas now be designated as Zone D – Recharge Contributing Area where wastewater disposal regulations will apply.

Figure J. BWA Water Protection Zones

Understanding that all groundwater quality affects the adjacent coastal marine environment, the MPCA established discharge standards for all wastewater into the groundwater as well as the marine environment. The EPD has continued its routine monitoring programmes for groundwater, marine water, and wastewater. Through specialised projects and partnerships, the EPD has also sought inter alia to ascertain the incidence of antibiotic resistant bacteria in select water sources and to assess sources contributing to nitrate concentrations in groundwater.

3.7 Standards and Relevant Best Practices

As recognized in the GEF CReWS Regional Wastewater Management Policy Template and Toolkit document (2013) "*a major weakness for GEF CReWS participating countries is the inadequate legal framework for wastewater*". This holds true for Barbados as the authorities responsible for public health and environmental protection in Barbados have no formal legislated regulations in place that address wastewater effluent quality requirements. We were able to locate a document issued by the EPD that discusses a prospective *List of Prohibited Concentrations* that was prepared by the University of the West Indies for the Government of Barbados and issued for public consultation in October 2004, although we could find no further reference to the status of that initiative on the EPD web site or through an internet search. The document's list of proposed end-of-pipe standards are summarized in Table B.

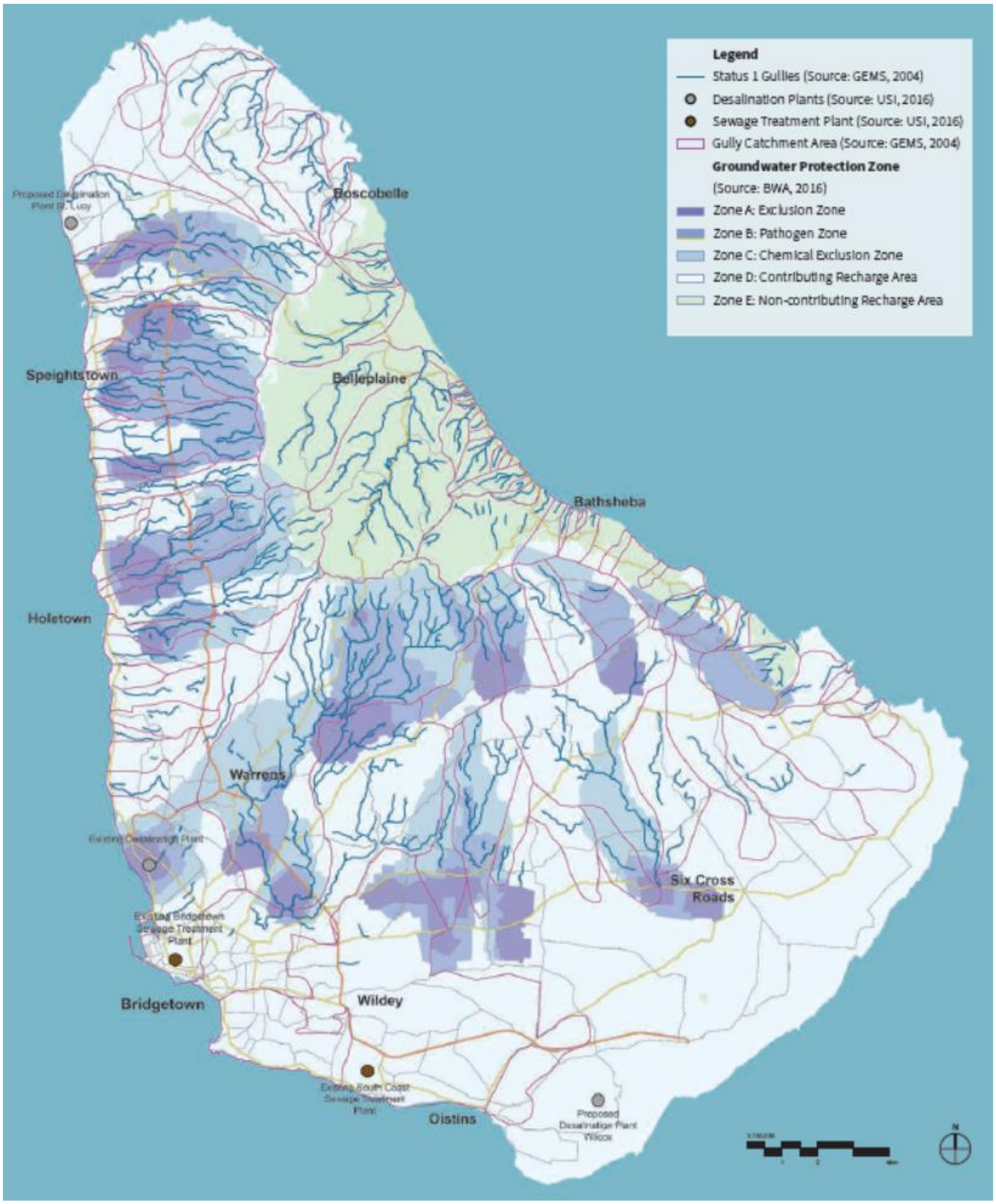


Figure K. Proposed Revised Groundwater Protection Zones[12]

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[12] Government of Barbados (2017). Barbados Physical Development Plan Amendment: Towards a Green, Prosperous and Resilient Nation.

Table B. Proposed List of Prohibited Treated Wastewater Effluent Discharge Concentrations

Parameter	Units	Class 1	Class 2	Comments (1)
BOD_5	mg/L	$\leq$ 30	150	
TSS	mg/L	$\leq$ 30	150	
Total N	mg/L	$\leq$ 5	45	
Total P	mg/L	1	10	
pH	-	6-9	6-9	
Faecal streptococci	CFU/100mL	$\leq$ 35	-	Geometric mean of (min) 5 samples over 30 days
Faecal Coliform	CFU/100mL	$\leq$ 200	-	Geometric mean of (min) 5 samples over 30 days
FOG	mg/L	15	50	
TRC	mg/L	0.1	-	
Floatables	-	Not Visible	-	

Note: (1) From Table 2 in "List of Prohibited Concentrations" prepared by the UWI for the GoB issued for public consultation in October 2004.

Table C. EPD Guidelines for Treated Wastewater Effluent Direct Discharge

Parameter	Units	Class 1	Comments (1)
BOD_5	mg/L	$\leq$ 30	
TSS	mg/L	$\leq$ 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	$\leq$ 200	Geometric mean
Residual Chlorine	ppm	0.1	
Colour		none	
Odour		none	

Note: (1) From EPD (2015).

For comparative purposes, the following tables illustrate regulatory requirements established in other jurisdictions including the US and Europe. A representative comparison is summarized in Table D and Table E.

Table D. Representative International Wastewater Treatment Secondary Effluent Requirements

Parameter	Units	World Bank	EU	USA	Canada
BOD_5	mg/L	≤ 30	≤ 25	≤ 25-30	≤ 25-30
TSS	mg/L	≤ 50	35–60	≤ 25-30	≤ 25-30
COD	mg/L	≤ 125	≤ 125	-	-
Total-N	mg/L	≤ 10	10–15	Site specific	Site specific
Total-P	mg/L	≤ 2	1–2	Site specific	Site specific
pH	-	6–9	-	6–9	6–9

Table E. 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	≤ 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 (2015).

Table F. Representative International Reclaimed Water Quality Requirements

Parameter	Units	Reclaimed Water Quality
BOD	mg/L	$\leq$ 10
TSS	mg/L	$\leq$ 10
Turbidity	NTU	$\leq$ 2 (average) $\leq$ 5 (max)
Faecal Coliforms	CFU/100 mL	< 1 (median) $\leq$ 14 (max)
E. coli	CFU/100 mL	< 1 (median)
Residual Chlorine	mg/L as Cl_2	$\geq$ 0.5
pH	-	6 – 9

3.7.1 Environmental Protection Department Requirements for Tertiary Wastewater Treatment

The Barbados EPD has several requirements for tertiary wastewater treatment systems, as were outlined in their latest version published in October of 2015. Some of the relevant EPD guidelines are as follows:

- All treated wastewater effluent intended for reuse (irrigation) purposes shall satisfy reuse criteria as outlined in Table G (EPD, 2015).
- All treated wastewater effluent intended for direct discharge shall satisfy the minimum criteria outlined in Table H (EPD 2015).

Table G. EPD Treated Wastewater Effluent Requirements for Reuse/Irrigation

Parameter	Units	Recommended Effluent Quality
BOD	mg/L	< 10
TSS	mg/L	< 10
Volatile Solids	mg/L	< 10
Total Nitrogen	mg-N/L	20 (Max)
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

Table H. Treated Wastewater Effluent Requirements for Direct Discharge

Parameter	Units	Marine Pollution Control Discharge Standards
BOD_5	mg/L	30
TSS	mg/L	30
TP	mg/L	1
TN	mg/L	<20
NH_4-N	mg/L	<1
E. Coliforms	< 35 MPN/100 mL	Geometric mean
Total Coliforms	< 200 MPN/100mL	Geometric mean
Residual Chlorine	mg/L	0.1
pH	-	6–9
Colour	-	None
Odour	-	None

- There shall be provision for equalisation of wastewater to accommodate not less than 50% of the average daily flow generated.
- Adequate contingency for the storage of wastewater to accommodate at least three days the average daily generated flow of wastewater in the unlikely event of plant failure.
- N.B. Treated wastewater may only be used for non-potable purposes in drip irrigation in a manner that will not threaten the risk of infection or parasite or insect infestation. There shall be no irrigation of foliage crops for human consumption or flushing of toilets with treated wastewater.

3.7.2 Estimated Total Collected Wastewater Flow and Strength Characteristics (SCSTP and BTSTP combined)

Limited Available Data

At the time of writing this report, wastewater and effluent water quality data had not been provided by the BWA. The following sections review available wastewater related information from reports and other sources to produce useful data.

Total Domestic Residential Wastewater Flow Using Metered Potable Water Consumption

In the absence of flow data or chemical analyses the accepted practice is to estimate the wastewater flow based on water consumption, particularly during wet weather period without irrigation demands and much of the water that is consumed is drained to sewer. In addition, water consumption and wastewater characteristics for other communities of a similar size can also be used to obtain a reasonable estimate of wastewater flows and constituent strengths to establish reasonable capital and operating costs for treatment and carrying out a sustainability assessment of treatment and resource recovery options.

As noted above, metered residential water consumption records can provide a reasonably conservative estimate of domestic wastewater flows if all the water used, drains to the sewer. The water use application that does not conform to this assumption is irrigation. However, even in the absence of water metering data that can differentiate between wet weather (no or limited irrigation) and dry weather (high irrigation use), water consumption data is a good starting point for analysis. Water consumption during wet weather can serve as a good estimate of dry weather flows.

Table A, presented earlier, provided water consumption data for 2019. Total average annual metered water consumption for 2019 was 31.958 Mm^3/yr, or 87,556 m^3/day. Based on the estimate that 15% of the population is connected to sewer, if all the metered water uses were drained to sewer, which is a very conservative assumption, the expected average annual wastewater flow would be 13,133 m^3/day. For comparison, the BWA estimate of the average annual wastewater flow is 13,736 m^3/day. Consequently, for the purpose of this study, an average total annual average wastewater flow (i.e. for SCSTP and BTSTP combined) of 13,736 m^3/day (14 MLD) will be assumed.

Existing Wastewater Water Quality Information

The recent South Coast Outfall Environmental and Socio-Economic Impact Assessment – Final Report (Baird, 2019) contains a limited amount of raw wastewater and effluent water quality data from the SCSTP. This information was provided to Baird by the BWA in late October 2018. The data provided by the BWA spans from January 10, 2018 to October 10, 2018 and consists of samples collected on 15 occasions during that period.

The data provided was for samples collected at the entrance to the SCSTP (influent) and upon exit from the plant (effluent) are provided in Table I and also illustrated in Figure L. Of particular note is that the wastewater concentration or "strength" is much higher in January than in the September, reducing by about 40 percent over the 8-month period, while the ratio between COD and BOD remains about 3:1. The TSS to BOD ratio varies from 1.5 in January, down to about 1.0 in August. The higher concentrations in January suggests an industrial wastewater is being discharged to sewer during the first half of the year, with the maximum concentration in January tapering off through to August. Typical domestic wastewater has a BOD concentration of about 200 mg/L and often a slightly higher TSS concentration around 250 mg/L. This is consistent with the wastewater strength in August, but the strength in January appears to be double typical domestic strength.

Table I. SCSTP Influent Wastewater Constituent Concentrations

DATE	COD (mg/L)	BOD (mg/L)	COD:BOD RATIO	TSS (mg/L)	TN (mg-N/L)	TP (mg/L)	O&G (mg/L)
10-Jan-18	1230	413	3.0	632	63	9.4	57.7
25-Jan-18	676	298	2.3	432	62	7.0	29
21-Mar-18	811	220	3.7	271	59	6.7	17
04-Apr-18	589	250	2.4	189	52	7.9	44
09-May-18	438	155	2.8	113	66	3.2	4
18-May-18	459	205	2.2	112.5	64	4.3	9
23-May-18	512	165	3.1	175	68	4.8	17
29-Aug-18	528	150	3.5	152	36	5.0	22
12-Sep-08							316
29-Sep-18							22

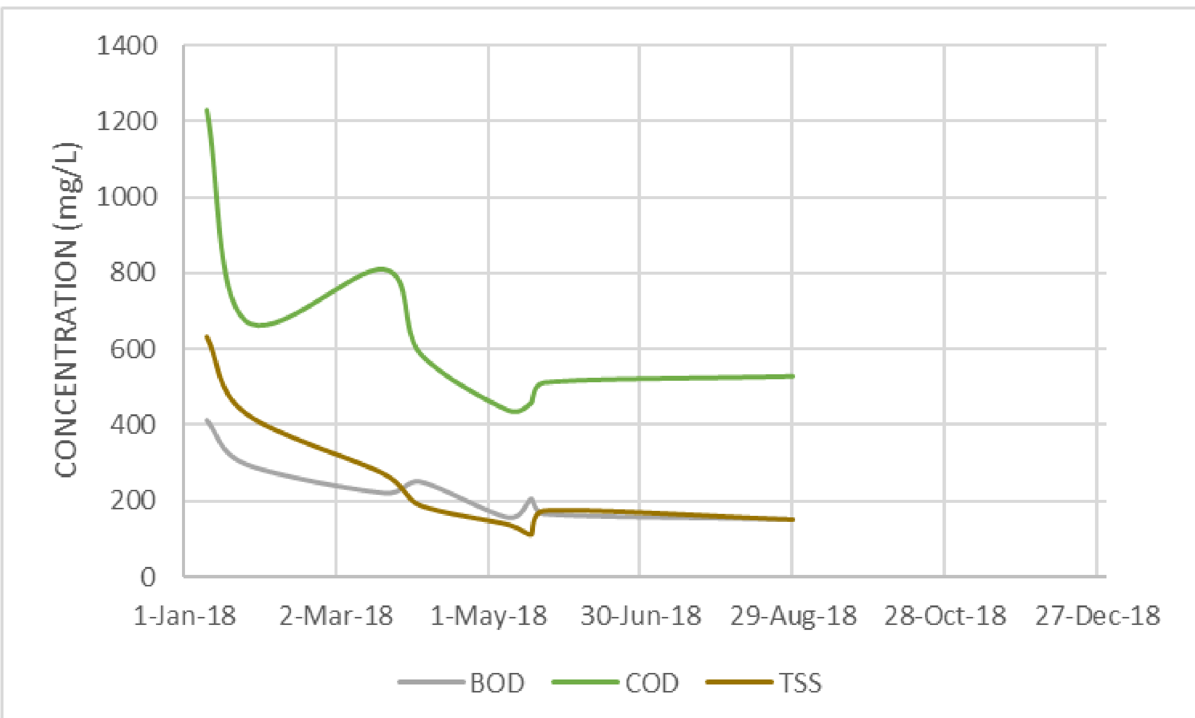

Figure L. South Coast STP Influent Wastewater COD, BOD & TSS Concentration Variations

Combined (SCSTP and BTSTP) Residential Domestic Wastewater Flow and Loading Estimates

Another method of estimating expected wastewater characteristics is to base them on individual (per capita) water consumption data and typical daily wastewater loading contributions, along with reasonable assumptions based on process design experience, and typical individual domestic constituent loading characteristics for BOD, TSS, nitrogen and phosphorus as described below:

- Total Domestic Water Consumption (BWA. 2019) = 22,044 Mm^3/year (60,395 m^3/day)
- 2019 Barbados Total Resident Population = 287,375
- Average Annual Residential Water Use per Capita = 60,395 m^3/day / 287,375 PE = 210 L/day.PE
- Population Served by Sewer = 0.15 x 287,375 = 43,106 PE
- Estimated Wastewater for Population Served = 43,106 PE x 210 L/day.PE = 9,052 m^3/day (AAF)
- Non-Resident Wastewater Flow = 13,736 m^3/day – 9,052 m^3/day = 4,684 m^3/day (34%)
- Assume Residential and Non-Residential Load is proportional to flow
- Assume Residential per capita BOD contribution is 40 g/day.PE
  - Average Annual Residential BOD Load = 43,106 PE x 40 g/day.PE = 1,724 kg/day BOD
  - Average Annual Non-Residential BOD Load = 1,724 kg/day BOD x 0.50 = 862 kg/day BOD
  - Total Average Annual BOD Load = 1,724 + 862 = 2,586 kg/day BOD
  - Average Annual BOD Concentration = 2,586 kg/day BOD / 13,736 m^3/day = 190 mg/L
  - This compares favourably with the 2018 influent wastewater characteristics reported by the BWA for the SCSTP of a BOD about 190 – 200 mg/L for the months of May through August.
- Assume per capital TSS contribution is 66 g/day.PE
  - Average Annual TSS Load = 43,106 PE x 50 g/day.PE = 2,155 kg/day TSS
  - AA Non-Residential TSS Load = 2,155 kg/day BOD x 0.5 = 1,080 kg/day TSS
  - Total Average Annual TSS Load = 2,155 + 1,080 = 3,235 kg/day BOD
  - Average Annual TSS Concentration = 3,235 kg/day BOD / 13,736 m^3/day = 235 mg/L
  - This compares favourably with the 2018 influent wastewater characteristics reported by the BWA for the SCSTP of a BOD about 170 – 180 mg/L for the months of May through August
- Assume VSS is 90 percent of TSS
  - Average Annual VSS Load = 0.90 x 3,235 kg/day = 2,911 kg/day
  - Average Annual VSS Concentration = 165 mg/L
- Assume NH_3 contribution per capita is 10 g/day/person
  - Residential NH_3 Load = 10 g/day.PE x 43,106 = 431 kg-N/day NH_3
  - Non-Residential NH_3 Load = 431 kg/day BOD x 0.52 = 224 kg-N/day NH_3
  - Total Average Annual NH_3 Load = 431 + 224 = 655 kg-N/day NH_3

- Average Annual NH_3 Concentration = 665 kg/day BOD / 13,736 m^3/day = 48 mg-N/L
- This compares favourably with the 2018 influent wastewater characteristics reported by the BWA for the SCSTP of a NH_4 (ammonia) concentration of about 50 mg/L for the months of May through August

- Assume TP contribution per capita is 1 g/day/person
  - Residential TP Load = 1 g/day.PE x 43,106 = 43 kg-N/day NH_3
  - Non-Residential TP Load = 43 kg/day BOD x 0.52 = 22 kg-N/day NH_3
  - Total Average Annual TP Load = 43 + 22 = 65 kg-P/day TP
  - Average Annual TP Concentration = 65 kg-P/day TP / 13,736 m^3/day = 5 mg-P/L TP
  - This compares favourably with the 2018 influent wastewater characteristics reported by the BWA for the SCSTP of Total Phosphorus concentration of about 5 mg/L for the months of May through August

Screenings

Screenings consist of washed rags and other debris that are collected using screens as part of preliminary treatment to prevent such substances from entering the treatment plant and causing operations and maintenance problems. Screenings are reported by BWA as being a significant operations problem due to the large quantity or rags and other materials discharged to sewer to be collected at the treatment plants. However, there do not appear to be any records available regarding the quantity of screenings that have been collected and disposed of for either the BTSTP or SCSTP; consequently, the following estimate of theoretical screenings is proposed.

Table 9.2 of the WEF MOP No 8 (WEF, 1991) provides a list of 39 treatment facilities indicating the average annual amount of wastewater treated and the amount of screenings that were generated by each of the facilities. Of the 39 facilities listed, 19 have flows less than 400 MLD. The screenings for each of the 19 facilities is plotted in Figure M.

Table 9.3 of WEF MOP No.8 (WEF, 1991) also states that for separate sewer systems:

- Average Screenings: 3.5 – 35 L/1000 m^3
- Peaking Factor (hourly flows): 1:1 – 5:1
- Solids Content: 10 – 20 %
- Specific weight: 640 – 1100 kg/m^3
- Volatile content of solids: 70 – 95%

The range in screenings of from 3.5 to 35 L/MLD stated in Table 9.3 of WEF MOP No.8 (WEF, 1991) is supported by the screenings data for the 19 facilities shown in Figure M. Not indicated in Table 9.3 of WEF MOP No.8 (WEF, 1991) is the inverse correlation between the plant capacity and the range of screenings collected; with variability and average annual screenings diminishing as plant capacity increases. For plants treating flows of 10 MLD – 20 MLD, the volume of screenings collected shown in Figure M is between 30 - 35 L/MLD. For an annual average annual flow of about 14 MLD this between 0.42 – 0.49 m^3/day of screenings (300 - 350 kg/day assuming a screenings density of 700 kg/m^3). We will assume screenings generation of 0.5 m^3/day (350 kg/day), although operators report screenings are well more than this.

Grit

Grit can be a significant problem for treatment plant equipment operations and maintenance if not removed from the incoming wastewater as part of preliminary treatment. The grit tends to accumulate at the bottom of tanks, and impact and wear mechanical components.

However, no grit removal process was included as part of the original BTSTP design and there is no grit collection information available for the SCSTP. As such, we will propose to base the estimate f grit on common practices from similar sized wastewater treatment plants as described below.

Table 9.2 of the WEF MOP No 8 (WEF, 1991) provides a list of 39 treatment facilities indicating the average annual amount of wastewater treated and the amount of grit that is generated by those facilities. Of those 39 facilities listed, 19 have flows less than 400 MLD. The grit collected for each of the 19 facilities is plotted in Figure N.

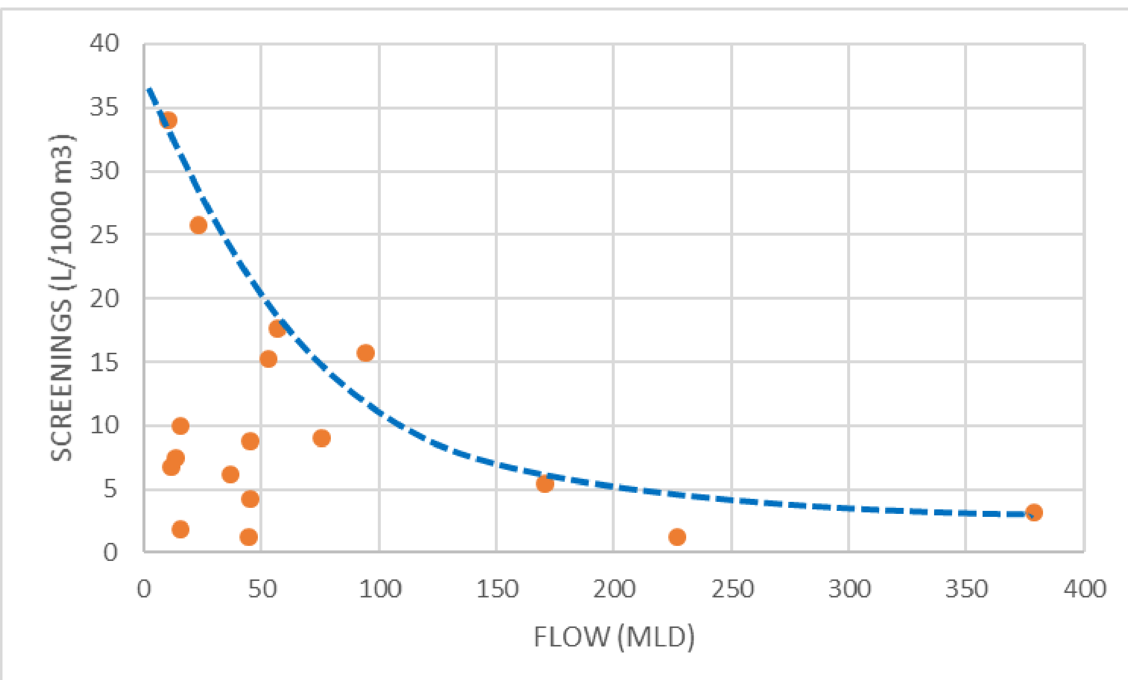

Figure M. Screenings Reported in WEF MOP No.8 for 19 WWTPs

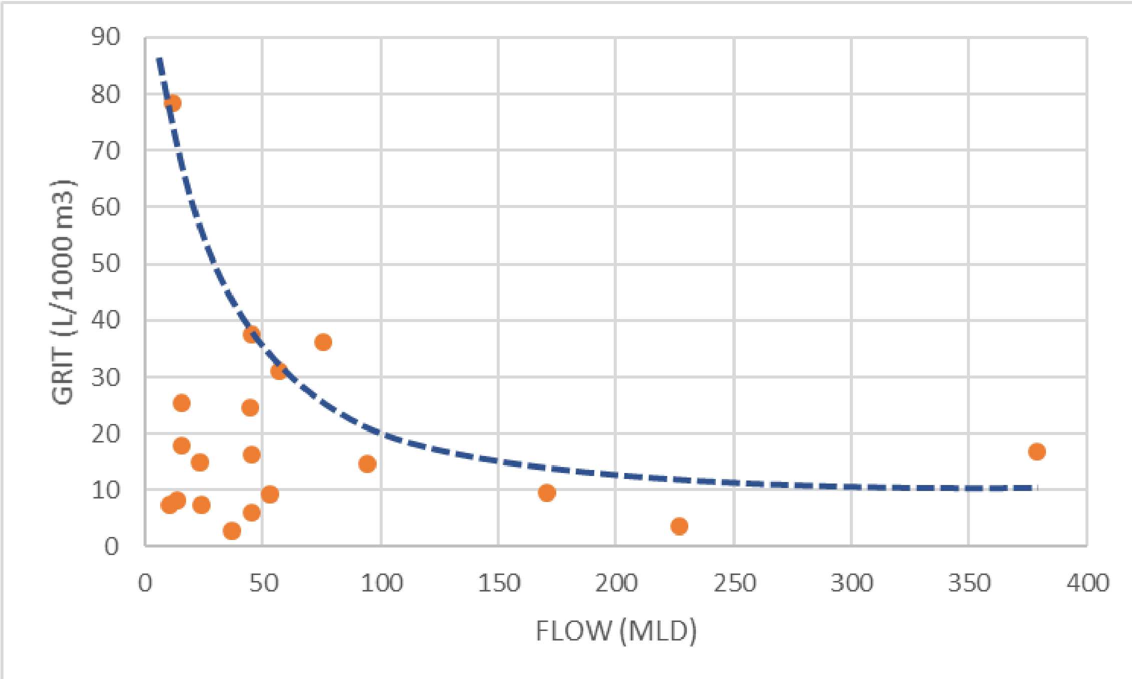

Figure N. Average Grit Generated for 19 WWTP Facilities Listed in Table 9.2 of WEF MOP No 8.

Figure N illustrates the average annual grit collected for all facilities ranges from about 2 to 80 L/MLD. Similar to screenings collection, there is a clear relationship between the plant capacity and the range of average grit generation with the greatest range occurring for the lowest capacity facilities. The variation in reported screenings production is much greater for smaller facilities than for larger facilities, and there is a clear relationship between the plant capacity and the range of grit collected.

For treatment plants with average annual flows between 10 – 15 MLD, the rate of grit collection shown in Figure N could be as high as 70 - 80 L/MLD, although 30 – 40 appears to be more representative of the plants surveyed.

Applying a 2:1 peak ratio result in a maximum day grit collection of 60 - 80 L/MLD. Multiplying this by the average annual flow of about 14 MLD, the maximum rate of screenings collection would be between 0.84 – 1.12 m^3/day (1,350 – 1,800 kg/day assuming a grit density of 1600 kg/m^3). For this study we will assume 1 m^3/day (1,600 kg/day).

3.7.3 South Coast Wastewater Flow Data

The BWA was able to provide 2019 weekly flow statistics for the SCSTP in the form of minimum, average and maximum flows for each week. The measured wastewater flow data is plotted in Table J along with data showing the monthly precipitation totals. The graph shows the highest wastewater flows of about 8500 m^3/day occur during the month of January, a period with little to no precipitation. The flows then decrease over the year to a low of about 1750 m^3/day in the month of October, before increasing again through the remainder of the year.

Also shown in Table J is the total precipitation in each month, with the least precipitation occurring from mid-January through April increasing gradually to a period of maximum monthly precipitation in October through mid-November. The precipitation is inversely proportional to the average weekly flow record for 2019.

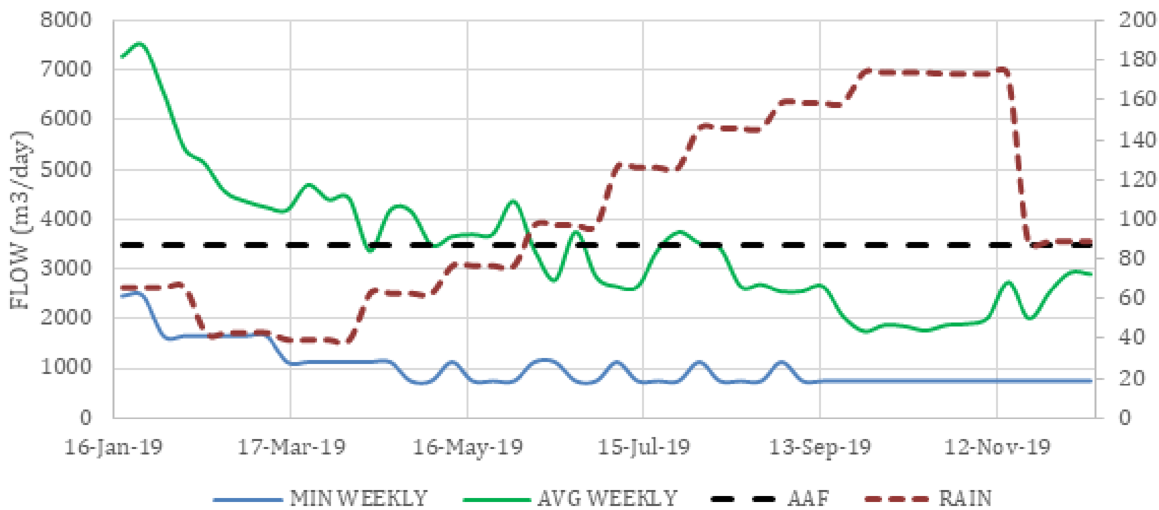

Table J. Summary of SCSTP Weekly Flow Statistics and Monthly Rainfall for 2019

Often communities with poorly constructed leaky sewers and high groundwater tables will exhibit the highest wastewater flows during periods of high precipitation. The SCSTP sewer system has the lowest wastewater flows during the rainy season, indicating that precipitation is not responsible for the high wastewater flows January through March. We question what is responsible for the high flows. This will require further investigation.

3.7.4 Impacts of Tourism on Wastewater Flows

Tourism, sugarcane, and rum production are the three most prominent industries in Barbados. Information on tourist arrivals obtained from the MTIT records for the first 9-months of 2019 are summarized in Table K and plotted in Figure O, As can be seen from Figure O, there is a very strong correlation between the weekly average flows at the SCSTP and the number of tourist arrivals. In the absence of any other factor that could affect wastewater flows to this extent, it is concluded that the high wastewater flows are due to "tourist-associated" activities that contribute to wastewater generation. This could be the generation of wastewater by hotels in providing services (showers/baths, toilet flushing, laundry, cleaning and restaurants) and amenities for guests (e.g. pool water exchange), as well as commercial or industrial operations (e.g. distilleries or wine) that may have a coincidental or tourist-basis peak in their activities that generate wastewater,

Table K. Tourist Arrival Data for 2019

Month	Annual Long-Stay Arrivals	Cruise Ship Landed Passengers	Total	SCSTP Flow (MGD US)
January	69,496	34,179	103,675	1.765
February	68,609	31,328	99,937	1.205
March	70,669	27,255	97,924	1.168
April	63,364	17,053	80,417	1.004
May	50,717	892	51,609	1.017
June	50,160	725	50,885	0.842
July	60,248	811	61,059	0.821
August	50,757	941	51,698	0.811
September	36,861	754	37,615	0.647

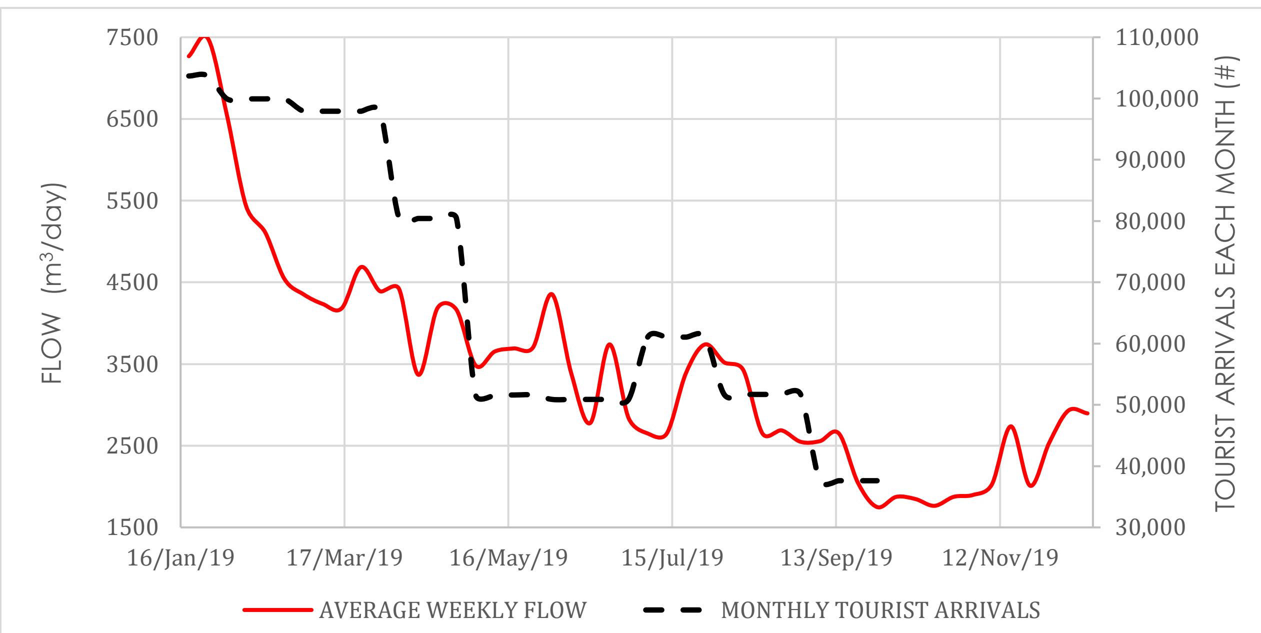

Figure O. Average SCSTP Weekly Flow and Monthly Tourist Arrivals

The strong relationship between tourism and the population of Barbados is illustrated in Figure P, This figure displays the total number of tourist arrivals each year for the period of 1976 through to 2019, versus the increase in the population over that same period. For every 5,000 increase in arrivals there has been about a 7,000 increase in the island population.

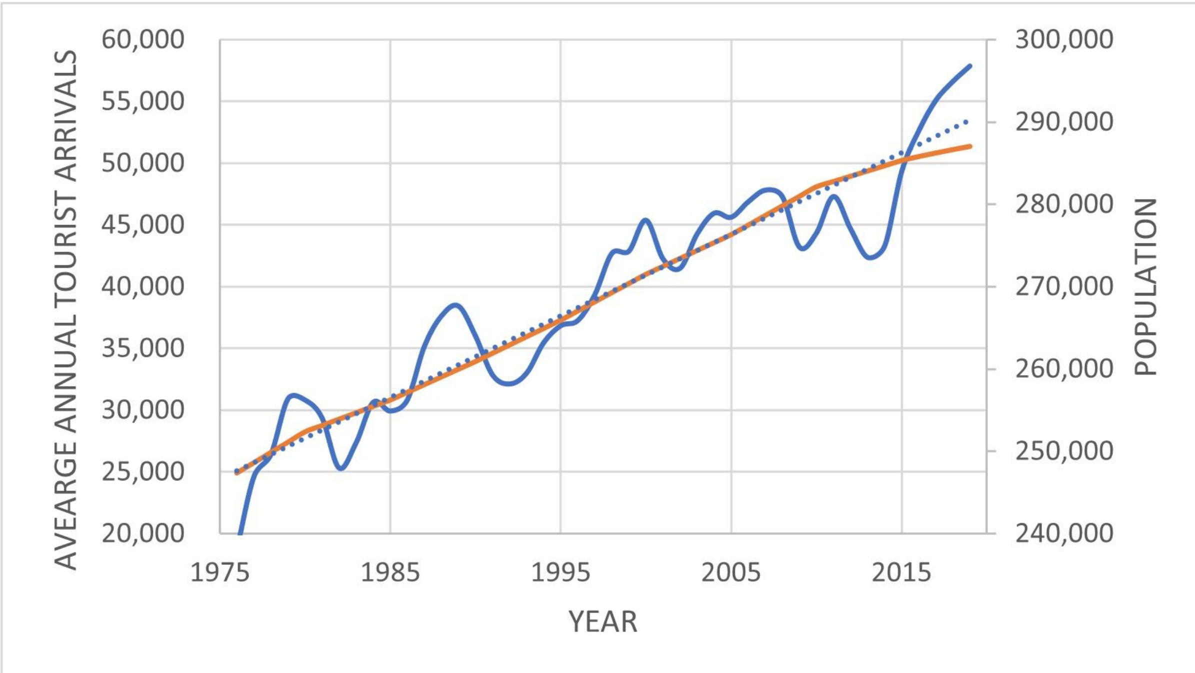

Figure P. Average Annual Tourist Arrivals and Population Growth

3.7.5 Estimated Tourist-Related Wastewater Flows

Considering the average weekly flows that are shown in Figure P, if we assume the minimum flow of 757 m^3/day that was recorded for the month of October 2019, when there were fewest tourists, represents the infiltration of groundwater or other precipitation-related influence, the average residential domestic wastewater flow during this period would be 1,000 m^3/day (i.e. 1750 m^3/day average weekly minus 757 m^3/day assumed I&I equals ~1,000 m^3/day). If we now consider the highest average weekly flow rate of 7,485 m^3/day in January, and we subtract the domestic residential flow and the groundwater infiltration flows, we are left with a maximum tourist-related wastewater flow of 5,735 m^3/day.

The average-weekly wastewater flow of 7,485 m^3/day in January is 4.3 times greater than the average-weekly wastewater flow of 1,750 m^3/day in October. Further, the estimated tourist-associated wastewater flow of 5,735 m^3/day rate in January is 5.7 times the estimated domestic residential wastewater flow of 1,000 m^3/day for the South Coast sewer.

Furthermore, Figure O indicates the contaminant concentrations during January are 2 to 3 times higher than in October, further exacerbating the loading disparity.

Treatment plants are biological systems that require as close to steady-state hydraulic and uniform organic loading conditions as possible. Equalization storage can help to reduce the diurnal variations that occur over a given 24-hour period, but storage is not practical considering the volume required to addressing the loading variations occurring within the South Coast wastewater collection system over the year. Treatment plants are often over-designed to accommodate community growth over a 30-year period. The current flow variations within the South Coast wastewater collection system are far greater than that, making high performance treatment a significantly difficult challenge.

Although there is no flow information available for the Bridgetown wastewater collections system, the population characteristics in terms of per person wastewater contributions, and the potential tourist-associated wastewater contributions are expected to be similar, and pose a similar design and performance challenge.

3.7.6 Summary of Estimated Wastewater Characteristics

Table L provides a summary of the overall design parameters including flow rates.

Table L. Estimated Total (SCSTP and BTSTP) Residential Wastewater Contribution Characteristics

Parameter	2020	Notes
Population	43,170	15% of 2019 Pop + 0.15%
Flow		
AVG LOW FLOW (MLD)	9	Resident Pop Sanitary Estimate
AAF (MLD)	13.7	Resident & Non-Resident
MMF (MLD)	17.4	1.3 x AAF
PWWF (MLD)	36	Nominal 4:1 Ratio
Average Load		
Total BOD_5 (kg/day)	3,270	Corresponds to 240 mg/L
TSS (kg/day)	4,400	Corresponds to 320 mg/L
VSS (kg/day)	3,960	Assume 90% volatile solids
Total Ammonia (kg-N/day)	668	Correspond to 50 mg-N/L
Total-Phosphorus (kg-P/day)	65	Corresponds to 5 mg-P/L
Screenings (m^3/day) and (kg/day)	0.5 / 350	Based on survey data
Grit (m^3/day) and (kg/day)	1.0 / 1,600	Based on survey data

4 SOUTH COAST SEWAGE TREATMENT PLANT

4.1 Evaluation of the Existing Treatment Process

The SCSTP (Figure Q) was constructed between 1994 to 1997, however, the associated sewage collection and conveyancing system took considerably longer to construct, and was finally completed in 2002, at which point the SCSTP was commissioned. Similar to the BTSTP, the SCSTP was designed to treat approximately 9,000 m^3/day (2 million imperial gallons per day) of wastewater. The SCSTP design and construction were under the direction of the Ministry of Health, and its subsequent O&M under the BWA. The site is located in Graeme Hall, Christ Church.

The SCSTP was conceptualised in the 1980s by the late Arthur Archer (former project director at the Ministry of Health) in response to two problems:

(i) an overload of septage at the BTSTP; and

(ii) deteriorating bathing beach water quality along the south coast.

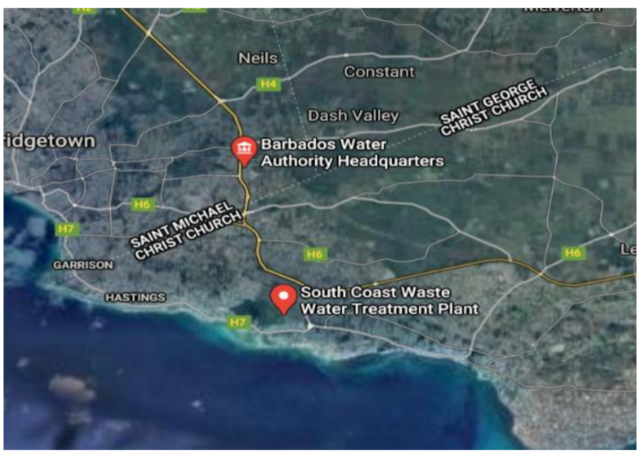

Figure Q. SCSTP Location

However, the SCSTP was never designed to accept septage as was proven when septage from BTSTP was diverted there as a part of the Cricket World Cup preparations. An upstand and loading area were constructed for the purpose of receiving the septage and left in place after the conclusion of the event. Operations staff indicate that the prolonged acceptance of septage was responsible for the premature wear and deterioration of the screw lift pumps to the SCSTP as was a corresponding increase in odour.

The SCSTP was designed to treat wastewater through a series of course, medium, and fine screens, with "*advanced preliminary standards*" (screens with a mesh size of 2 mm (0.08 inches) at Graeme Hall. The screened wastewater is pumped through a force main to a marine outfall. The marine outfall used to be located offshore of Needham's Point; however, it was relocated in 2018 to Worthing Beach after the original force main was compromised when a concrete carrier pipe collapsed on the force main in 2017.

The SCSTP was designed and built to international specifications with IDB oversight and funding. It also went through several review stages which would have included Town Planning and the Coastal Zone Management Unit. Primary or advanced preliminary treatment is an acceptable international method, if linked to a long marine outfall that discharges the treated wastewater outside of sensitive areas. This was the solution that the IDB was prepared to fund at the time. However, this will not be sufficient in the future because Barbados is now a signatory to the Cartagena Convention, although it has not proclaimed it as law. Protocol 4, pollution from Land

Based Sources, prohibits the dumping of effluent at the level of advanced preliminary treatment within recreational waters.

The outfall pipe was designed to be 850 long, ending outside the bank reef at a depth of 38 metres (125 feet). This outfall site was chosen after extensive studies conducted by Baird, had shown that there are strong, predominantly offshore currents in that area.

Figure R. South Coast Sewage Treatment Plant

The plant is designed to allow a total of 3 screw-lift pumps (see Figure R) but currently only have two installed, and only one is operational. The primary pump handles the design flow. Both pumps can only operate at a constant speed but are able to adjust the flow. The pumps are 4 HP (45 kW) each and run off 3-phase power. Neither the force main nor the outfall, was designed to take raw sewage, only treated (screened) effluent with particles less than 50 mm (2 inches) in diameter.

Power outages are infrequent in Barbados, and the plant is equipped with a back-up generator. This generator is run frequently for maintenance purposes.

Like the BTSTP, funds from the GSC are being used to bring the plant and sewage collection network up to a reasonable standard. With these funds, the BWA has replaced screens at the SCSTP and upgraded the ventilation system. But although the ventilation system was recently upgraded, further upgrades are still required to provide safe air quality and access to all systems. Although not installed yet, it was also noted that new VFD effluent pumps and controls have been delivered. No further data related to these new VFD pumps and controls has been provided.

The air scrubbing system which was supposed to inject ozone into the enclosed areas of the facility, spent most of its time under repair and was finally abandoned and replaced with a ducted forced air system.

4.2 Key Design Parameters

According to the Operation and Maintenance audit conducted recently, some key design parameters are as following:

- Design Capacity: 1.3 MGD (4.9 MLD) Minimum Flow
- Design Capacity: 3.0 MGD (11.3 MLD) Average Flow
- Design Capacity: 7.8 MGD (29.5 MLD) Peak Flow
- Design Influent BOD_5: 200 mg/L
- Design Influent TSS: 250 mg/L
- Average BOD_5 Loading: 4,972 lb/day (2,260 kg/day)
- Average TSS Loading: 6,215 lb/day (2,825 kg/day)
- Design Effluent BOD_5: 185 mg/L
- Design Effluent TSS: 185 mg/L
- BOD_5 Removal Efficiency: 7.5%
- TSS Removal Efficiency: 26.0%

4.3 Existing Information

4.3.1 Wastewater Flows

Section 3.7 presented summary flow statistics and limited wastewater quality data for the SCSTP collection system which will be used in conjunction with other data assumptions stated in those sections to assess the expected treatment process performance and upgrades.

It is reasonable to assume that the minimum weekly flow of 756 m^3/day (8.76 L/s) represents a period of little to no domestic or commercial wastewater flows and, and reflects groundwater I&I, it is a very significant amount of flow (representing 8.8/40.2 = 22% of the average annual wastewater flow). The meter should be examined and checked for calibration, particularly for low flow conditions, as it is unusual for a specific flow rate to be repeated.

4.3.2 Estimated Hydraulic Capacity

As there is no treatment being carried out, there are no hydraulic capacity restrictions other than liquid transport head losses associated with pipe diameters and pumping rates. The exception is the screens that have a finite design hydraulic loading capacity based on manufacturer specifications.

4.3.3 Wastewater Quality

The SCSTP does not have a laboratory or lab technician. As noted in Section 4, there is some limited water quality data that was indirectly obtained from the South Coast replacement outfall design report for 2018 which we have incorporated into the baseline wastewater characterization.

4.3.4 Screw Lifts

The plant is designed to allow a total of 3 screw-lift pumps (see Figure S) but currently only has two installed (see Figure T), and only one is operational. The current primary pump handles the design flow. Both pumps can only operate at a constant speed but are able to adjust the flow. The pumps are 4 HP (45 kW) each and run off 3-phase power.

The two screw-lift pumps that carried the raw sewage into the plant at Graeme Hall for treatment, began to lose efficiency in 2014 and could no longer lift all the incoming sewage to the top of the plant. As a result, in 2014, most of the sewage was diverted around the treatment plant and discharged without treatment through the force main and outfall at Needham's Point. Up to 100% of the sewage continued to be diverted without treatment until 2016 when a partially successful attempt was made to fix one of the screw-lift pumps, by relining the trough using concrete to close the gap between the bottom of the screw blades and the trough. No further maintenance work on the partially rehabilitated pump nor on the second damaged pump was conducted until 2017.

4.3.1 Screens

Inlet screening operation experiences significant downtime because of fouling due to high inputs of FOG as well as large solids that are removed as rags. No further data has been made available regarding the quantity of material that is collected on the screens or the frequency at which they are cleaned and maintained.

At present, the course (see Figure V) and medium screens (see Figure W) have been replaced using a Huber mechanical system. The fine screens (see Figure X) have not been replaced.

Figure S. Screw Lift Pump System

Figure T. Screw Pump System (Top of Channels)

Figure U. Inlet Screen - Trash Rack

Figure V. New Coarse Screen System

Figure W. New Medium Screen System (not yet in operation)

Figure X. Existing Fine Screen System

4.3.2 Disinfection System

The air scrubbing system which is supposed to inject ozone into the enclosed areas of the facility, spent most of its time under repair and was finally abandoned and replaced with a ducted forced air system.

Figure Y. Ozone Disinfection System (abandoned / not in operation)

4.3.3 Grit

Grit removal facilities are in place, but this unit process has not been put into service.

4.3.4 Infrastructure Information

The project team has access to an extensive number of drawings of the wastewater collection system, and the treatment plant. Still to be obtained from BWA are equipment model and specifications. We anticipate this can also be obtained from the photographs that were taken of the equipment plates taken during the site tour.

4.3.5 Theoretical Process Performance and Limitations

The SCSTP is based on primary treatment only. Attenuation of conventional wastewater contaminant constituents such as BOD, total suspended solids, and nutrients (i.e. soluble nitrogen and phosphorus) from preliminary treatment is incidental and insignificant, and limited to the amount of screenings of rags and debris, as well as grit that can be removed. The 2018 SCSTP water quality data discussed in Section 3.7.2 confirms this. To achieve higher effluent quality, the process can be expanded to enhanced primary and/or incorporate secondary and/or tertiary treatment.

The primary limitations of the existing screens, other than their inherent limitation in only being able to remove coarse solids, is the head loss through the plant that limits flow.

4.3.6 Required Treatment Capacity and Effluent Quality

While the SCSTP is referred to as a primary treatment plant, it in fact only provides preliminary treatment in the form of removing rags and other debris using screens. While fine screens can remove a portion of the BOD load associated with primary solids, the 2018 wastewater quality data that is available for the plant does not provide evidence this is occurring. The removal of primary solids with the screenings would also create odours and waste disposal problems due to its high volatile solids content. Primary treatment refers to the removal of primary solids and those solids are subject to either aerobic or anaerobic stabilization and removal from the process. As a consequence, since rags and other debris are responsible for only a small portion of the BOD and TSS received by the treatment process, there is, in effect no required treatment capacity of effluent quality as the wastewater is released to the marine environment without significant treatment.

4.3.7 Solids Production, Handling and Disposal

The only solids produced by the SCSTP are screenings. The inorganic screenings are collected and transferred off-site for disposal by truck to the Mangrove Landfill. There are no records of the weight, volume or frequency of screenings removed. As a result, we intend to use data sourced from other comparable wastewater treatment plants that can be used to estimate screenings that would be expected to be received by a treatment facility of this size and capacity. We also intend to us this data to provide an estimate of the amount of primary solids and associated anaerobic energy recovery that could be expected using data obtained from similar facilities.

4.3.8 Energy Efficiency

There are no records of energy consumption, however based on the horsepower and equipment types, a reasonable estimate of energy consumption can be made, as well as comparisons of alternative unit processes that may have lower energy consumption.

4.4 Performance Gaps, Challenges and Risks

4.4.1 Flow Capacity

The SCSTP appears to have excess capacity, based on the 2019 flow rates. A summary of 2019 flow rates compared to design values is shown in Table M. The flow data indicates the domestic wastewater contribution is significantly lower than the demand created from tourism or the effects of precipitation of wastewater flows. The prospective treatment upgrades will be based on the flow data records and reasonable assumptions regarding contaminant loading characteristics for similar sized treatment facilities.

Table M. SCSTP Design Flow Rates vs. 2019 Measured Flow

	SCSTP Design		SCSTP 2019 Actual	
	MGD	MLD	MGD	MLD
Minimum	1.3	4.9	0.2	0.8
Average	3.0	11.3	0.9[13]	3.4
Maximum	7.8	29.5	5.7	21.5

4.4.2 System Reliability and Redundancy

There is no system redundancy incorporated into the screen design. When equipment maintenance is required the screens are bypassed to effect repairs and servicing. The SCSTP has also had extended periods (such as in 2015) of modified service, during which the screening systems were bypassed for a prolonged period.

4.4.3 Climate Change and Performance Resiliency

Climate change impacts, similar to the BTSTP, consist of the ability of the process to withstand storm surges that could affect the marine outfall performance, the ability of the treatment process to reclaim and reuse water to offset groundwater recharge losses due to diminished infiltration and gradual degradation of the wastewater collection system infrastructure with increased inflow and infiltration exacerbated by adverse precipitation conditions resulting from climate change.

Climate change could also increase weather associated hazards that could impact physical characteristics and resiliency of the overall treatment facility.

4.4.4 Risks and Proposed Risk Mitigation Measures

The primary risk that has been identified through the baseline assessment is related to the extreme variation in the wastewater flow and strength within the South Coast wastewater collection system. This extreme seasonal variation will make it very challenging to design a plant which can operate at the high-performance efficiency necessary for resource recovery while experiencing flow and load variations that are more than 5:1.

Mitigation will focus on identifying the source of the variation and examine methods to reduce the variation and incorporate unit processes and technology configurations that are impacted to a lesser extent by such wide ranges in operating conditions. Strategies that have been successfully deployed at other plants impacted by wide seasonal variations in influent flows and

[13] The average value is the average of weekly average flow values obtained from 2019 data, not a true average.

loading include designing the plant so that operators can shut down or restart entire modules as required by the wastewater conditions.

4.5 Potential System Upgrading Options and Future Study

4.5.1 System Upgrading Strategies and Potential Options

The SCSTP has considerable possibilities for wastewater treatment upgrade options that can assist the plant in adapting to climate change impacts under already challenging conditions. Key considerations include examining opportunities for a range of resource recovery options including water, bioenergy, and nutrients. It is expected that some of the strategies that will be considered include decentralized options, source control and discharge pre-treatment considerations. To be effective, these options will also require improvements to the existing regulatory framework, particularly if decentralized opportunities are to be implemented.

4.5.2 Treated Effluent Reclamation and Receiving Environment

One of the key climate change concerns is a reduced potable water supply and an increasing reliance on hydrocarbon-based energy intensive desalination technologies to offset the impacts of reduced groundwater infiltration and increased evapotranspiration-associated water demands for irrigation. The water supply in Barbados is highly dependent on precipitation and sensitive to the need for improved integrated water management strategies that include water conservation measures and consideration for both non-potable water applications and indirect potable water reuse (aquifer recharge). Increased levels of wastewater treatment and water reuse will also reduce the number and volume of contaminants entering the soil and the marine environment.

4.5.3 Energy Efficiency and Recovery

By implementing technologies that can cost effectively and efficiently collect and contain volatile solids and convert soluble organic matter into biomass, the amount of potential bioenergy that can be produced can be optimized and the economics improved.

5 BRIDGETOWN SEWAGE TREATMENT PLANT

5.1 Evaluation of the Existing Treatment Process

The BTSTP was commissioned in August of 1982, 15-years before the SCSTP. As indicated in Figure Z, the BTSTP is located in Lakes Folly, St. Michael, and is operated and maintained by the BWA. The BTSTP plant O&M manual (1982) indicates that the facility was designed with a theoretical average flow capacity of 2.4 MGD (9.1 MLD) and a peak flow 9.6 MGD (36.3 MLD). However, information gathered to date suggests that the plant receives much less flow from fewer connections.

Although the BTSTP was intended to only treat domestic wastewater, the collection system is now attached to many the commercial businesses in the Bridgetown.

The biological treatment process grows bacteria on the waste food in the sewage, and excess bacteria produced must be periodically extracted and transferred to an aerated sludge digestion tank for stabilization. The two aerated reactors and the aerated sludge digestion tank are located around the clarifier tanks serving each module. The treatment system was originally constructed with a chlorination unit to disinfect the treated effluent before being discharged into the ocean, however, the chlorination unit stopped working and has not since been replaced.

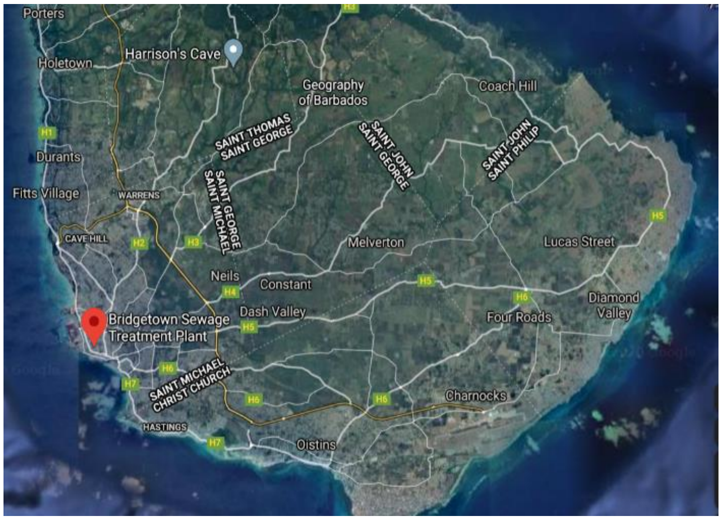

Figure Z. Location of the BTSTP

The BTSTP treatment process is based on a contact stabilization secondary treatment process configuration (see Figure AA), which is a modification of the conventional activated sludge treatment process that uses two separate aeration tanks (Figure BB); the first tank is used for reaerating the return sludge which takes about 4 hours before it is combined with primary effluent in the second aerated tank. The treated wastewater is transferred to a centrally located sedimentation tank (clarifier) to remove suspended solids. The separated solids are recycled back into the treatment process and the clarified effluent is discharged through a marine outfall located in Carlisle Bay, 300 m off Trevor's Way. Figure AA is a simplified process schematic illustrating the configuration of the plant at the present time.

Since mid-2019, Barbadians have been paying a GSC fee as part of their water bills, with the funds being intended for use in effecting necessary repairs, equipment replacement, and upgrades to the BTSTP and the SCSTP. The plant has been upgraded and modified several times since it was first commissioned including:

- A recently installed mechanical screen with a screening handling and bagging function that replaced the original influent comminutor;
- Four recently purchased positive displacement aeration blowers with VFD controls; and
- A new septage receiving station integrated with screen, grit trap, screening and grit washing mechanisms.

BWA operations staff indicate all the original aeration diffusers in the plant (believed to originally have been coarse bubble diffusers) have been replaced with micro bubble diffusers.

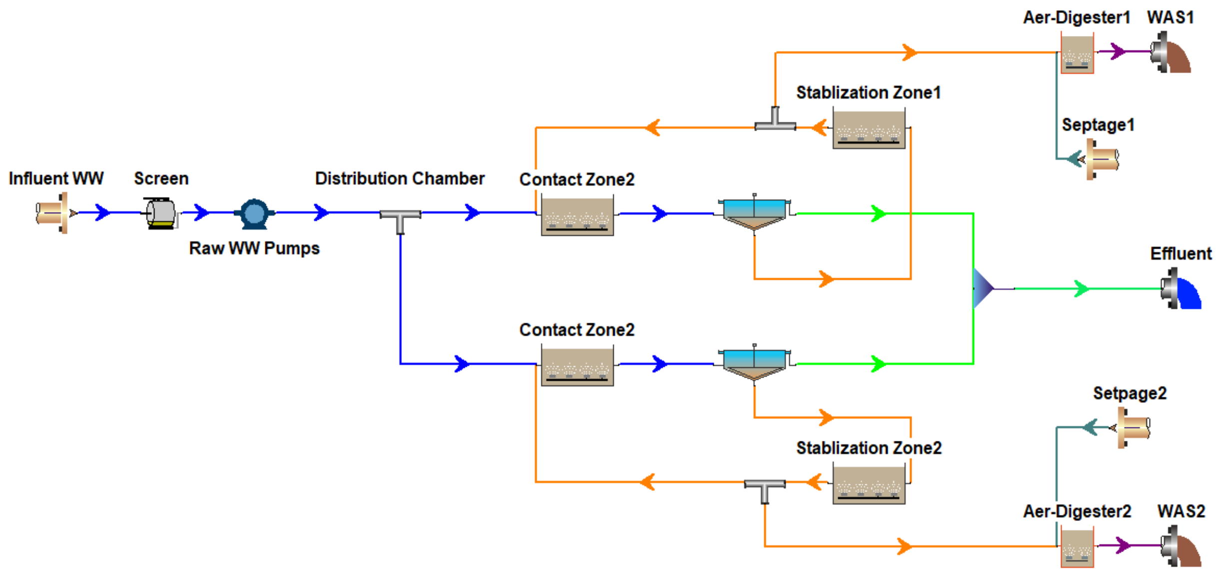

Figure AA. Biowin Model Diagram of the BTSTP Process

Figure BB. Bridgetown Wastewater Treatment Plant

The bar screens that were provided have proven to be very ineffective in catching rags before they pass through to the pumps and other mechanical process components; clogging the entire secondary treatment process. The flow measurement system also soon became inoperable and the float system that was intended to activate the main pumps soon failed because of grease and solids build-up on the float switches. The influent flow meter became inoperable several years ago and has not been repaired or replaced. All previous flow meter data has also been lost, as the paper documents became contaminated with rodent faeces and were disposed of. Therefore, no wastewater flow data is available for this site, however, the BWA estimate that the plant is currently operating at an average flow of 7,600 m^3/day, which is well below its original designed capacity.

Due to the fact the bar screen largely being ineffective at preventing rags into the secondary treatment process, the BWA recently responded by purchasing a new Huber course mechanical screening system. The current incoming wastewater now passed through a mechanical screen to remove rags and other debris, and then discharged into a wet well. The screened wastewater is pumped from the wet well into a concrete distribution chamber that splits the flow into two streams and each stream directed to one of two secondary treatment modules. Each module consists of three aerated concrete tanks surrounding a central circular concrete secondary clarifier. The three aerated exterior tanks consist of a contact chamber, a stabilization chamber, and a sludge digester.

The screened wastewater first enters the contact chamber where it is mixed with RAS consisting of biomass that has been growing in the treatment system. The well-mixed conditions enable the bacteria to contact both particulate and dissolved organic matter, which are adsorbed by the bacteria. In contact with food, the contents of the contact chamber pass through to the stabilization chamber where the bacteria continue to digest the organic matter. The contents of the stabilization chamber are then passed through to the central clarifier where the suspended solids (mostly suspended bacteria or biomass) are separated from the treated effluent. The separated biomass is then transferred back to the contact chamber to repeat the treatment process, and the clarified effluent from the two treatment modules is then combined before being discharged by gravity through an ocean discharge.

Excess biomass is periodically "wasted" from the process stabilization chamber and transferred into the sludge digestion tank which is operated in a batch mode. The aerobic digestion process reduces the pathogen content as well as reducing odour and vector attraction levels. Aeration in the digester tanks is periodically stopped to allow the sludge to settle to the bottom of the digester tanks and the supernatant from the surface of the digester is then transferred to the contact chamber for treatment. Depending on the sludge contents of the digester, the operator may then "waste" additional biomass from the process stabilization chamber, or may elect to pump out some of the sludge that has settled to the bottom of the digester, and truck it to a land spray operation for beneficial use in agriculture, taking advantage of the nutrient (phosphorus and nitrogen) content of the waste biomass.

The plant also receives septage (septic tank contents with a high solids content) that is delivered by trucks, which was previously discharged at the mouth of the Careenage. The grit in the septage is first removed from the septage before the septage is pumped into the digester tanks (Figure AA). The BTSTP is reported to have been designed to accept up to 20 m^3/day (5,000 gallons/day) of septage but, instead, it is estimated that they receive an average of 115 m^3/day (30,000 gallons/day).

There is no influent equalization tank, grit removal, or primary clarification in the treatment process.

The plant was commissioned with a saltwater electrolytic hydrolysis chlorine generation system to disinfect the treated effluent before being discharged to the ocean, but this system is reported to be out of service for some time.

The digested sludge is transported by tanker truck to a field, located NE of the airport, where it is injected into the soil and rotavated. It is understood that the lands that the sludge is rotavated into, is owned by the GoB but it is unclear if this land is also used for agriculture purposes.

5.2 Key Design Parameters

According to the O&M Manual (1982), some key design parameters related to the BTSTP are as following:

- Design Capacity: 2.4 MGD (9 MLD) Average Flow
- Design Capacity: 9.6 MGD (36 MLD) Peak Flow
- Design Septage Quantity: 500 gpd (19 m^3/day)
  actual believed to be 30,000 gpd (1.14 MLD)
- Design Influent BOD_5: 200 mg/L
- Design Influent TSS: 250 mg/L
- Average BOD_5 Loading: 4,000 lb/day (1,814 kg/day)
- Average TSS Loading: 5,000 lb/day (2,268 kg/day)
- Design Process SRT: 7.5 days
- Design Digester SRT: 15 days
- Design Clarifier Hydraulic Loading: 554 gpd/ft2 (22 m^3/m^2/day), average flow
  2216 gpd/ft2 (89 m^3/m^2/day), peak flow
- Design Effluent BOD_5: 30 mg/L
- Design Effluent TSS: 12.5 mg/L
- BOD_5 Removal Efficiency: 85%
- TSS Removal Efficiency: 95%

Based on the plant information available, the plant design and the technologies employed historically represent the status of the mainstay of the wastewater treatment industry about 40-years ago. Since then tremendous progress has been made, not only with respect to the treatment technology and process development, but there has also been improved understanding of the fundamentals of biological wastewater treatment. It is now possible to achieve a much better effluent quality to enable the treated effluent to be repurposed or reused for a wide range of non-potable water applications including groundwater recharge, irrigation. Currently, however, the EPD guidelines do not allow wastewater to be reused for toilet/urinal flushing. In addition to being able to recover and reuse the water, it is also now possible to recover nutrients and energy through the wastewater treatment process.

5.3 Existing Information

In order to accurately evaluate the existing treatment process at the plant properly, the plant operating data along with plant design documents and major equipment datasheets should be examined, reviewed and analysed. However, no influent flow or wastewater characteristics data are available from the BTSTP. The BTSTP flow meter stopped operating years ago and was never replaced. Any historical flow data that has been collected are reported to have been destroyed during a chemical fire in 2014. The treatment facility does not have a laboratory technician or an adequate laboratory on-site. Consequently, no raw wastewater analyses or plant performance information are available. The primary sources of information that is available are the original design drawings that were issued from 1974 to 1978, the O&M Manual (1982), and visual observations made during the September 24th, 2020 site visit at BTSTP.

In the absence of plant data, the assessment will need to be based on recognized well-accepted design criteria such as that presented in Wastewater Engineering: Treatment and Reuse by Metcalf & Eddy (2004, 4th Edition) and the Design of Municipal Wastewater Treatment - WEF Practice Manual No.8 (2010, 5th Edition), as well as the experience of our design team – keeping in mind this information is to be used for comparative purposes and not design.

5.3.1 Flow Rates

The inlet Parshall flume is not currently being used to measure flow as the level measuring device became inoperable and has not been replaced. BWA operations staff indicate that they are considering a laser measuring device that measures velocity as well as liquid depth, to replace the previous level sensor; however, it is not clear why the specific device being considered is required, versus a lower cost ultrasonic level sensor or other simple primary level measuring device.

5.3.2 Wastewater Quality

The BTSTP does not have a functioning laboratory, nor a lab technician, consequently no wastewater analyses or plant performance information have been made available to us to analyse.

5.3.3 Bypass Trash Rack

The bypass inlet trash rack (as illustrated in Figure CC) is a manually cleared bar screen that is reported to be subject to frequent clogging by rags and other debris including FOG, as well as being an operations hazard.

5.3.4 Screens

Mechanically cleaned screens are also is present, however the coarse screens have yet to be installed (Figure DD).

Figure CC. Inlet Trash Rack

Figure DD. Inlet Course Screen System (not installed)

No information has been reported regarding the frequency of clearing the trash rack or quantity of inorganic solids that are collected and sent to the Mangrove landfill. As such, we have interpolated our own data based on common practices from similar sized wastewater treatment plants.

5.3.5 Infrastructure Component Details

The evaluation is limited to information obtained from the BWA O&M Manual (1982) for the bioreactor tanks (i.e. Contact Chambers, Stabilization Chambers and Digesters) and the Clarifiers in the plant has no equipment specifications available.

Contact-Stabilization Bioreactor

The bioreactor process configuration at the BTSTP is referred to as a contact-stabilization bioreactor. Figure EE shows one of the two treatment modules that is out of service and drained for repair. The repair involved replacing the aeration diffusers (brown corroded pipe shown in Figure EE). The contact-stabilization process is a variation of the conventional activated sludge process and was fairly popular in the 1980's. While the activated sludge process returns "hungry" or "activated" bacteria from the clarifier to the head end of the plant where the bacteria are mixed with incoming raw wastewater, the contact-stabilization process returns the bacteria to a tank which is aerated (provided with oxygen) but without food, causing the bacteria to consume themselves, before the bacteria is mixed with the incoming wastewater. The main advantage of the contact stabilization process over a conventional process is the shorter hydraulic retention time required for BOD reduction in the contact reactor (i.e. lower costs as the overall bioreactor size is smaller than would be required for a conventional activated sludge process design). The reduced hydraulic retention time is due to the adsorptive capacity of the bacteria and the greater availability of organic matter for the bacteria to feed on.

Each contact chamber has a volume of 356 m^3 (12,577 ft^3). The total volume of the two contact chambers is 712 m^3 (25,154 ft^3). The hydraulic capacity of the two contact chambers can be estimated based on the design criteria provided by Metcalf & Eddy or the WEF Practice Manual No.8, for a contact-stabilization process as noted in Table N.

Table N. Contact Chamber HRT Design Criteria

Design Criteria	Metcalf & Eddy	WEF Practice Manual No.8
HRT – Low, hr	0.5	0.5
HRT – High, hr	1	1

Based on the design criteria shown in Table N and given the volume of the two contact chambers in the plant, the total hydraulic capacity of the two contact chambers can be calculated, and the results are tabulated in Table O.

Figure EE. Contact Stabilization Bioreactor (Undergoing Replacement of Diffusers)

Table O. Calculated Contact Chamber Hydraulic Capacity

Total Capacity	Metcalf & Eddy		WEF Practice Manual No.8	
	MGD	MLD	MGD	MLD
Low End	4.5	17.1	4.5	17.1
High End	9	34.2	9	34.2

The total volume of the two stabilization chambers is 1330 m^3 (46,952 ft^3) with 665 m^3 (23,476 ft^3) each. The hydraulic capacity of stabilization chambers in the plant, and the design criteria for the calculated capacity are summarized in Table P and Table Q, respectively.

Table P. Stabilization Chamber HRT Design Criteria

Design Criteria	Metcalf & Eddy	WEF Practice Manual No.8
HRT – Low, hr	2	3
HRT – High, hr	4	6

Table Q. Calculated Stabilization Chamber Hydraulic Capacity

Total Capacity	Metcalf & Eddy		WEF Practice Manual No.8	
	MGD	MLD	MGD	MLD
Low End	2.1	8.0	1.4	5.3
High End	4.2	16	2.8	10.6

From Table P and Table Q, it can be concluded that the hydraulic capacity of the contact-stabilization system at BTSTP would be limited by the volume of the stabilization stage, because the estimated hydraulic capacity based on the present day design criteria for stabilization stage is from 1.4 to 4.2 MGD (5.3 to 16 MLD). As the plant does not have an equalization facility before the secondary treatment, the high end of the estimated hydraulic capacity should only be considered for the peak flow conditions that normally last about 2 to 4 hours per day during the wet weather season, which was defined at 9.6 MGD (36 MLD) from the BWA O&M Manual (1982). This indicates the current system could have difficulty in meeting its treatment objective during the peak flow conditions that it was designed for, due to the undersized stabilization chambers.

Secondary Clarifier

The two identical circular secondary clarifiers (one is shown in Figure FF while it was being serviced) in the plant have a total surface area 402 m^2 (4,333 ft^2). The hydraulic capacity of the clarifiers can be estimated based on the hydraulic SOR for activated sludge secondary clarifiers. The design criteria and the calculated capacity are summarized in Table R and Table S, respectively.

Table R. Secondary Clarifier SOR Loading Design Criteria

Design Criteria	Metcalf & Eddy		WEF Practice Manual No.8	
	GPD/ft^2	m^3/m^2/day	GPD/ft^2	m^3/m^2/day
Average	400 to 700	16 to 28	300 to 1,000	15 to 40
Peak	1,000 to 1,600	40 to 64	1,600 to 1,800	64 to 72

Table S. Calculated Total Clarifier Hydraulic Capacity based on SOR

Total Capacity	Metcalf & Eddy		WEF Practice Manual No.8	
	MGD	MLD	MGD	MLD
Average	1.7 to 3.0	6.4 to 11.4	1.3 to 4.3	4.9 to 16.3
Peak	4.3 to 6.9	16.3 to 26.1	6.9 to 7.8	26.1 to 29.5

Figure FF. **Secondary Clarifier**

The information from Table S indicates the existing two secondary clarifiers should be able to provide sufficient hydraulic capacity at the average influent flow rate (2 MGD) they were designed for, however, they may experience notable compromised performance during the peak flow conditions.

It should be noted that the performance of the secondary clarifier is not only determined by the SOR, but also by the clarifier SLR. The hydraulic capacity of the clarifier may not be achieved if the SLR exceeds the limitation. As a check, the SLR under both design average and peak flow conditions were calculated based on the MLVSS (1,300 mg/L per as per the BWA O&M, 1982) in the Contact Chambers which feed into the clarifiers, and with the assumption that the MLVSS to MLSS ratio is 0.75. The results are represented in Table T.

The Table T indicates the estimated hydraulic capacity of the secondary clarifiers at BTSTP is not likely limited by the SLR, if the MLVSS concentration can be maintained close to the design value at 1,300 mg/L or a little higher.

As stated in the O&M Manual (1982), the aerobic digesters at BTSTP were designed for 15 days of SRT. This value represents the typical design criteria for aerobic digestion before the promulgation of US EPA 40 CFR Part 503 Standard for the use and disposal of sewage sludge, which was from 10 to 20 days of SRT. The old design criteria were mainly concerned about the solids reduction and vector-attraction reduction, while the current design criteria also emphasise the pathogen and odour reductions that are important for safe and beneficial reuse and disposal of the digested sludge, such as land applications including land spray. The required SRT values for aerobic digestion at the present day are compared with original design SRT were compared in Table U.

Table T.Calculated SLR vs Design Criteria

SLR	Calculated		Metcalf & Eddy		WEF Practice Manual No.8	
	lb/day/ft^2	Kg/m^2/day	lb/day/ft^2	Kg/m^2/day	lb/day/ft^2	Kg/m^2/day
Average	8	39	19 to 29	96 to 144	20 to 30	100 to 150
Peak	32	156	38	192	40 to 50	200 to 240

Aerobic Digester

Table U. Current Aerobic Digester SRT Requirement vs Plant Design SRT

Metcalf & Eddy	WEF Practice Manual No.8	BTSTP Design
40 day at 20 °C	40 day at 20 °C	15 day

The existing aerobic digesters in BTSTP are significantly undersized according to present-day design criteria. It should also be noted that after more than 40-years, the actual SRT provided by the digesters would be less than the number used for this analysis due to the anticipated increase of the plant hydraulic and organic loadings over the 40-years of time period.

5.3.6 Chemical Injection

No chemicals are used in the plant for solids dewatering, as there is no dewatering equipment, and the only waste biosolids thickening that is carried out is when the digester aeration system is shut off and the digester solids are allowed to settle prior to the solids being pumped from the digester and trucked away for off-site disposal.

5.3.7 Disinfection

The BTSTP had an on-site sea water electrolytic hydrolysis chlorine generation system included in the original design but has been out of service for many years. The reason for previously generating on-site chlorine was said to be due to the high cost of importation for commercial disinfectants, such as sodium hypochlorite.

5.3.8 Aeration Blowers

The BWA recently purchased and installed four positive displacement aeration blowers (see Figure GG) with VFD controls that replaced four original centrifugal blowers. It is understood that these blowers were recently purchased in response to receiving odour complaints from neighbouring communities surrounding the wastewater treatment plant

Figure GG. **Aeration Blowers**

5.3.9 Performance Expectations and Limitations

As a modified activated sludge process, the major advantage of the contact-stabilization process is the smaller aeration volume requirement to achieve the same process SRT compared to a conventional activated sludge process. However, the trade-off is a reduced BOD removal efficiency and poor nitrification performance. These parameters may not have been a concern at the time of the plant was designed and constructed but are important for meeting the treatment objectives of this project.

In general, the BOD removal from a contact-stabilization process for municipal wastewater treatment is expected to be about 80% to 90%, in line with the design value of 85% used for the original design. In comparison, more than 85% to 95% BOD_5 removal could be expected from a conventional activated sludge process in treating municipal wastewater.

The reduced HRT of the aeration reactor (because of reduced aeration volume), reduces the growth of autotrophs/nitrifiers which are needed to oxidize ammonia and remove organic nitrogen. This less effective nitrification capacity would also limit the potential for the integration of a pre-anoxic zone into the existing process for biological denitrification and energy saving purposes.

The reduced HRT also makes the process less efficient for the biodegradation of oil and grease in the water as oil and grease requires more time to be hydrolysed before it can be consumed by microbial communities. This may be important in the future, as was pointed out by the plant operating staff, because the influent wastewater to the BTSTP contains elevated levels of oil and grease that are causing operating and maintenance issues in the plant. Currently, there is no oil and grease removal facility in the plant.

There is also no provision of phosphorus removal in the treatment process, neither biologically nor chemically. Currently the treated effluent from the plant is not disinfected, as the on-site sea water electrolytic hydrolysis chlorine generation system has not been functioning for many years.

5.3.10 Required Treatment Capacity and Effluent Quality

The required treatment capacity and effluent quality will be based on the effluent criteria the BWA is required to meet, based on the assumption the values stated in the O&M Manual (1989) are consistent with, and reflect, the government-set treatment effluent quality criteria and treatment objectives.

5.3.11 Biosolids Production, Handling and Disposal

The current biosolids handling and disposal practice at BTSTP is to truck aerobically digested sludge directly from the two digesters and dispose of the sludge on a dedicated sludge spray zone. It was reported that the spray zone is experiencing clogging problems, which could be attributed to the incomplete digestion process due to low SRT in the digesters as discussed previously.

This practice is also not taking advantage of the nutrient content in the sludge which could benefit agriculture production. Trucking wet sludge directly from the digesters without dewatering could also be costly. The wet sludge contains about 2% solids according to the O&M Manual, (1982). If the sludge can be dewatered to have 15% to 20% solids content, which is very typical with modern sludge dewatering technology, the volume of the sludge needing to be trucked out and disposed of would be reduced to only roughly 15% to 10% of the current volume. This would result in significant saving on sludge transportation and labour, and the environmental benefits due to reduced fuel consumption and risk of spill.

5.3.12 Energy Efficiency

While simple and easy for operation with low capital cost, the aerobic digesters in the plant are energy intensive, requiring a prolonged aeration time. While an anaerobic digestion process can recover energy from the biomass, this aerobic digestion process consumes additional energy to oxidize the volatile fraction of the primary solids and waste secondary biosolids that could be otherwise be recovered as energy through anaerobic digestion.

It is recognized that there will be technical, financial, economic, and operational challenges to implement anaerobic digestion at BTSTP due to the relatively small scale. However, because of the very high energy costs on the island and strong desire to fight climate change and protect the environment, the opportunity to recover the energy from the biomass generated from the plant should not be overlooked. More detailed analysis and evaluation will be conducted in the Feasibility Study stage.

As nutrient (nitrogen and phosphorus) removal will be required for this project to reclaim the treated water, denitrification using a pre-anoxic zone could be employed to improve the energy efficiency of the plant. With this configuration, the readily biodegradable organic matter in the influent wastewater can be utilized by denitrifying bacteria (heterotrophs) as the electron donor, utilizing the nitrate as an electron acceptor and converting the nitrate to nitrogen gas.

Currently, the dissolved oxygen in all bioreactors (contact chambers, stabilization chambers, aerobic digesters) is controlled manually, which is not very accurate. As the power for aeration is normally the largest energy consumption within the plant, typically consuming 40% or more of the total energy demand, even a small improvement in dissolved oxygen control can result in significant energy efficiency improvements. This can be achieved with the automatic control of the blowers based on the DO sensor readings in the bioreactors.

The plant energy efficiency could also be improved by implementing sludge dewatering as was mentioned in Section 5.3.11.

5.4 Performance Gaps, Challenges and Risks

5.4.1 Flow Capacity

The flow capacity of the plant is based on the required hydraulic retention times to effect treatment for the contact-stabilization process. Biowin modelling will be used to determine the process limitations based on the actual tank volumes determined from the plant drawings and BWA O&M Manual (1982) provided.

5.4.2 Effluent Quality

The effluent quality and plant performance are unknown, as there are no laboratory facilities at the treatment plant and no influent and effluent water quality analysis data (that may have been completed at another government laboratory) has been made available to date. In the absence of this data, we propose to use the Biowin modeling program to assess the expected treatment performance, based on best-estimate flows, contaminant concentrations and information that is available from drawings on tanks sizes and pumping rates.

5.4.3 System Reliability and Redundancy

The plant was built with two identical Contact-Stabilization trains, and most of the mechanical equipment components, such as aeration blowers and major pumps, were designed with multiple units, which provides good system redundancy and improved reliability.

The exception is the newly installed mechanical screen, which is a single unit without redundancy. When the mechanical screen needs to be taken offline for maintenance for repairing, the influent must be bypassed to the secondary treatment. This could increase the chance of mechanical failure of the downstream pumps.

The newly installed Septage Receiving Station is also a single unit without redundancy; however, the field experience has indicated that redundancy may not be necessary.

It has been noted that there is only one flow measurement device – a Parshall flume for influent measurement in the entire plant, and it has been out of operation for years due to the breakdown of the transducer on the Parshall flume. With this only flow measurement device out of service, there is no way to know how much wastewater comes to the plant and how much wastewater is treated. The plant operation will not be able to make adjustment to respond to the flow variation that consistently occurs.

The Parshall flume is also an old flow measurement technology that is largely replaced by magnetic flow meters in municipal wastewater treatment plants around world. We have been informed that the plant is considering the installation of a LeaserFlow EX flow meter on the Parshall Flume to restore the influent flow rate measurement. While this is the appropriate investment, it should be noted that the modern design of the municipal wastewater treatment requires multiple flow measurement in the process, including influent, effluent, sludge recirculation, sludge wasting and aeration etc. This approach not only provides redundancy and improved reliability for flow rate measurement as if any flow meter fail, the flow rate information still can be calculated by using flow rate readings from other flow meters, but also provide clear picture of the operation status for easy operating control and optimization.

5.4.4 Climate Change Impact

It has been recognized that simply increasing the hydraulic capacity of the plant is not a cost-effective approach to addressing potential climate change impacts at the treatment plant. Over sizing the treatment facility based on potential future extreme hydraulic conditions is not only costly, but also causes operating issues during the normal operations while potentially compromising the treatment plants' efficiency and effluent quality.

Careful selection of the treatment processes could be an option to make the system more resilient, as some treatment processes are more capable of withstanding hydraulic surges than others. Examples include an oxidation ditch, a modified activated sludge process, or an MBBR, or a growth technology for instances.

In upgrade of a treatment plant such as the BTSTP, the existing facilities and equipment in the plant should be utilized to its maximum extent to be financially responsible and effective. This would limit the options for the plant upgrading process selection, and the process selection alone may still not be enough to eliminate the climate change impacts to the plant.

Providing a flow equalization facility is another way to make the plant resilient against hydraulic surges caused by climate change if sufficient space is available for a plant upgrade. The equalization facility will only allow the influent flow rate, that can be properly processed by the downstream treatment facilities, to pass through while storing the excess incoming flow temporarily during the surge event, gradually sending back the stored wastewater when the surge event is over, so that the plant has the capacity available.

Chemically enhanced primary treatment may also be considered with other options to improve plant resilience. During a potential surge event, a portion of incoming wastewater could be treated with chemical coagulant and polymer, to remove the majority of the TSS and a significant portion of BOD (50% to 60%) that could not be otherwise removed by typical primary sedimentation. Then the chemically treated effluent could be combined with the biologically treated effluent for discharge. Primary clarifiers, would be required to be built to achieve this, located directly upstream of the secondary treatment.

All the options discussed above will have advantages and disadvantages. Careful study and analysis considering the site-specific conditions and needs will be required to determine the most effective way to improve the resilience of BTSTP against climate change. This will be accomplished when developing the feasibility study.

5.4.5 Risks and Proposed Risk Mitigation Measures

Like the SCSTP, the BTSTP is likely to be experience extreme and varying wastewater flow and loadings that will impact any treatment process, let alone one that is getting close to 40-years old. Load and flow equalization typically benefit from and involves storage, which the BTSTP does not have. Furthermore in. order to operate at optimal efficiency it is necessary to modularize the treatment process to improve the ability for the operators to take components in and out of service to match capacity to the varying loads. The operators do not have the necessary tools to monitor performance and adjust the process to adapt to changing influent conditions and are therefore operating "Blind". Mitigation needs to include laboratory and analytical capabilities to monitor and control key components, particularly if resource recovery measures are to be implemented. This also implies improved training opportunities as the plant operators that will need to learn how to use the new information on plant and process performance and loading conditions, which requires training and experience. One mitigation method that will be explored is the use of a computer-based plant modelling and advisory system.

5.5 Potential System Upgrading Options and Future Study

To meet the plant upgrading requirements for treated effluent reclamation, improved energy efficiency, and better resiliency against climate change, the following options may be considered as the starting point, and more detailed analysis and evaluation will be conducted during the feasibility study.

5.5.1 Grit Removal

The benefits of a grit removal process have been well recognized in municipal wastewater treatment. Grit removal reduces wear and abrasion of the downstream mechanical equipment and reduces the frequency of sludge digester cleaning requirement. This results in reduced maintenance effort and cost with improved system reliability. As the plant is experiencing serious FOG problems, the grit removal facility would also help by removing FOG at the same time with a surface skimmer mechanism integrated with the facility. As such, the addition of a grit removal facility will be considered for the upgrading of the BTSTP.

Two common grit removal systems include aerated grit chambers and vortex grit removal systems. Aerated grit chambers rely on a spiral rolling flow pattern, created by aeration air to separate heavier grits from the liquid to let them settle on the bottom of the chamber. The vortex grit removal system removes grits through a vortex flow pattern created mechanically or induced hydraulic power of the influent.

5.5.2 Flow Equalization

Flow equalization will be considered when upgrading this plant as it allows the treatment system to better withstand hydraulic and organic loading surges by stabilizing the process operating conditions and dampening peak flow events. This benefit of this is appealing to address climate change and plant resilience issues, as it is anticipated that more intensive and frequent peak flow events could occur.

5.5.3 Primary Clarification and Enhanced Primary Treatment

Primary clarification will remove the majority of the influent TSS by gravity sedimentation, along with a portion of BOD_5 associated with particulate organic matters. When this organic matter is sent to the anaerobic digestion process, they generate more energy in the form of methane gas, in comparison with that from the waste activated sludge that has been subject to aerobic process. Removing particulate BOD by gravity sedimentation is also much more energy efficient compared with aerobic biodegradation as no aeration power is required.

FOG that has caused plant operating problems can largely be removed through the primary clarification when the clarifier is equipped with a skimming mechanism. This scum (consisting of FOG) mixture is also a good energy source for anaerobic digestion due to the high energy density of FOG for anaerobic digestion compared to other types of organic matters found in municipal wastewater.

The primary clarification may be coupled with a coagulant and polymer additive to form an enhanced primary treatment process. Assisted by coagulation and flocculation, the primary clarifier can operate at much higher hydraulic loading and remove organic matters in the wastewater at a higher efficiency as needed for temporary peaks.

5.5.4 Nutrient Removal

To meet treated water reclamation requirements, as described in Section 3.7, the treatment system needs to provide nutrient removal, that the existing contact-stabilization process will not be able to provide. As a result, the existing treatment process needs to be modified and re-purposed or extended.

Giving the required total-nitrogen limitation of 20 mg/L in the treated effluent and influent TKN to be between 40 mg/L to 75 mg/L, the BNR process (with pre-denitrification configuration from a MLE process or a A^2O process) would be able to meet the treatment requirement. While converting nitrate-N to nitrogen gas, the pre-denitrification also removes readily biodegradable BOD without need for aeration, which improves the energy efficiency for organic matter removal in the plant.

Both chemical precipitation or EBPR processes, or their combination, could be used to reduce the effluent Total-P below 1 mg/L as required. The chemical precipitation for phosphorus removal is simple and costs less in capital, while it costs more for operation, and requires handling of the increased sludge volume. The EBPR on the other hand requires higher capital investment, with lower operational costs.

Technically speaking, there are many other technologies that would meet the nutrient removal requirement for BTSTP, such as SBR, or oxidation ditch, however, the existing treatment facility limitations reduce the opportunity for re-purpose or modification to suit these technologies. Some other technologies, such as MBBR and MBR, while also technically capable, would be disadvantaged due to their high energy consumption, which is contradictory to the project objective to energy efficient.

A much more thorough and detailed analysis, evaluation and investigation will follow into the conceptual design and feasibility study, including the treatment process modelling using Biowin, to help determine the most suitable and cost-effective nutrient removal process for BTSTP.

5.5.5 Energy Recovery and Utilization

To ensure the treated effluent meets the required TSS, Total-P, and BOD_5 requirements, tertiary filtration needs to be considered. The filtration process may be conventional rapid sand filtration or cloth disc filters. The cloth disc filter system is a relative new technology that offers compatible filtration performance as the conventional rapid sand filtration with reduced space, backwash, and hydraulic head requirements.

5.5.6 Energy Recovery and Utilization

The most practiced energy recovery method, from a municipal wastewater treatment plant, is anaerobic digestion of the waste sludge produced through the treatment process. When digestion is combined with primary and WAS, generally 0.8 to 1.0 m^3 of biogas can be produced for every kilogram of VSS destroyed. The biogas produced from the anaerobic digestion typically contains 55% to 75% methane that has a LHV of about 22,400 KJ/m^3 (600 BTU/ft^3), depending on the actual methane content in the biogas. With this LHV and after going through a purification process, the biogas may be used directly as a fuel for domestic, commercial or industrial application, or the biogas is used to power an engine-generator to generate electricity with another form of energy, such as steam or hot water. This co-generation of electricity with another form of energy is commonly called Cogeneration. Today, with the advance of the technology, many municipal wastewater treatment plants around the world are approaching the energy self-sufficiency, with 70% to 100% plant energy demand generated by the plant itself.

It requires significant financial investment to build, operate and maintain an anaerobic digestion system with energy recover, which is why this technology has been traditionally limited to plants with a treatment capacity larger than 5 MGD (20 MLD) at which it is believed to be economical. On the other hand, with increasing energy costs and the motivation to reduce energy consumption to combat climate change, more and more small municipal wastewater treatment plants are considering or have already adapted this technology. Co-digestion of food waste with biomass from the wastewater treatment plant is another method that has been successfully implemented in recent years to increase the energy production and improve the process economics.

From an economical point of view, it may be worth considering anaerobically digesting all biomass produced from both upgraded BTSTP and SCSTP, as the combined capacity of the two treatment plants are expected to produce close to 5 MGD after future upgrades and potential sewage collection networks are expanded to collect a greater volume of sewage.

Fuel cell technology is a recent innovation for energy recovery from biogas produced from anaerobic digestion at the wastewater treatment plant. Electricity is generated through an electrochemical reaction between oxygen and hydrogen that is produced from the methane in the biogas. This technology is "becoming an increasingly proven technology" (WEF. 2010) and is gaining more popularity due to its high power-generation efficiency and clean exhaust emission that is water.

5.5.7 Disinfection

Chlorination is a very commonly used wastewater disinfection method, that the BTSTP used to practice, but has abandoned. Other options, however, are available and should be evaluated for the effluent disinfection that would be mandatory for water reclamation.

UV radiation for wastewater disinfection as an alternative disinfection method "has grown tremendously" in recent years (WEF, 2010), as it does not produce DBP that could cause long-term human health or environmental problems when discharged with effluent. There is also no chemical handling requirement, which is a positive safety and storage benefit. On the other hand, unlike chlorination, UV radiation does not provide residual disinfection after application which is beneficial for controlling biological re-growth during the transportation of treated effluent.

5.5.8 Treated Effluent Reclamation

The contact stabilization process is optimized to minimize the amount of structural tankage and associated cost for organic carbon reduction (through BOD). This process is not optimized to minimize effluent BOD and TSS concentrations, or remove nutrients, that are key considerations for a water reclamation facility. Additionally, wastewater treatment processes designed to minimize these constituents generally require significant retention times. As a consequence, it is expected that while the existing tanks can be repurposed, upgrading the treatment process for biological nutrient removal for the purpose of recovering nutrients, or minimizing BOD and TSS concentration to facilitate a high degree of disinfection, will require a significant increase in overall tank capacity. The Biowin modeling program will be used to assess the overall volume requirements and we will make the best use of existing infrastructure.

5.5.9 Energy Efficiency and Recovery

There is no information available to assess energy efficiency or potential energy recovery. Energy efficiency can be estimated based on the existing mechanical equipment horsepower and from knowledge that the plant has not been equipped with much in the way of instrumentation and mechanisms for conserving or monitoring energy consumption. By utilizing information obtained from the Biowin model, this will enable us to emulate the expected energy efficiency associated with the existing blowers and air diffusers currently being deployed, in comparison to alternatives, including mechanical mixing.

With respect to energy recovery, we are confident that we can use established per capita wastewater contributions to estimate the amount of energy that could be recovered through the collection of primary solids and secondary biomass for the existing process configuration and for any proposed upgrades to improve discharge water quality and/or reclaim the water for non-potable or indirect potable uses.

6 SEWAGE COLLECTION SYSTEMS

The sewage collection system on the island was estimated to have approximately 4,500 sewage connections (Nurse et al., 2012), and serving less than 15% of the total population that is currently estimated to be over 287,000[14]. The coverage is mainly centred at the most populated area around Bridgetown, and the south coast between Bay Street and Oistins.

6.1 South Coast Sewage Collection System

6.1.1 Coverage of the Sewage Collection System

The system was designed to collect wastewater from the entire South Coast tourist area, including about 3,000 properties from Bay Street to Oistins (see Figure HH), along the south coast and some distance inland. But the BWA has reported that the SCSTP only receives sewage from approximately 2,500 connections and therefore has excess capacity to allow for property growth in the area.

The construction of the South Coast sewage collection system took considerable effort to install considering it was connecting into established and developed neighbourhoods. The construction caused significant disturbances, especially related to traffic re-routing efforts.

The sewage collection system construction was carried out in four contract components. Contract 1 included the construction of the treatment plant and Contract 3 included the construction of the marine outfall. Contract 2 involved the construction of some 44 kilometres (~ 27 miles) of inter-connected sewers with 5 lift stations. For several reasons, Contracts 2 and 4 took longer than was originally projected.

Finally, Contract 4 included the completion of the collection system and the individual property connections. The sewer connections required the cooperation of property owners which was not always readily forthcoming. This wok was eventually completed sometime around 2002, when the system was tested, commissioned, and handed over to the BWA.

6.1.1 Gravity System

As in normal cases, the network is primarily comprised of PVC gravity pipes with some sections that used clay pipe near the Brown Sugar restaurant, near Needham's Point. The biggest gravity pipe in the system is a 750 mm (30") PVC line, right before the SCSTP, according to the as-built drawings that were reviewed. Although some video inspections were conducted within specific sections of the gravity sewage collection system, we assume these inspections were all conducted near the

[14] World Population Review (Barbados 2020): http://worldpopulationreview.com/countries/barbados-population/

area where the 1,350mm concrete carrier pipe (that collapsed in 2017) and we have not been given access to review any of the videos. As such, we do not know any current information regarding the collection systems existing condition, but assume the conditions are generally in good order.

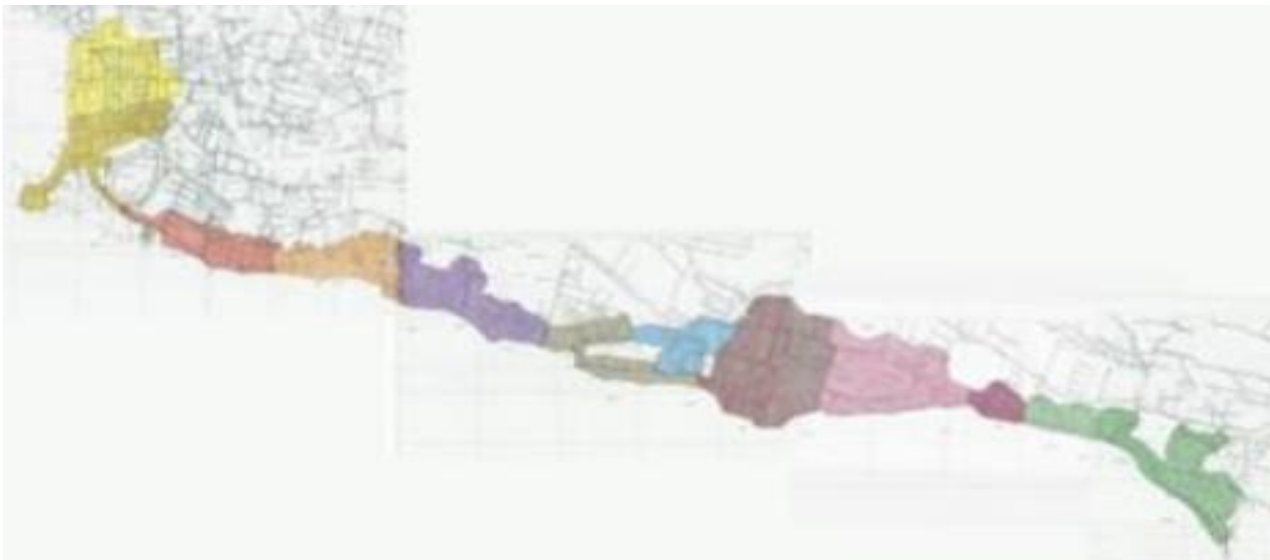

Figure HH. South Coast Catchment Area Contributing Sewage to the SCSTP

A significant portion of the main sewer trucks are 675 mm (27") PVC along Highway 7. These PVC mains are typically installed within 1350 mm diameter concrete carrier pipes with a 500 mm sewage force main from the SCSTP between the Worthing Beach area and Browning Cap in the St. Lawrence area.

The BWA reported that the 1350 mm carrier pipe collapsed between manholes R6-5 and DS-2 in 2017 that resulted in the damage of the 675 mm gravity sewage truck main and the 500 mm (20") force main within it. The 500 mm (8") gravity sewage truck main was later repaired by inserting a fibreglass liner within the existing pipe, but this cause the pipe to lose approximately 25 mm (1") of its inside pipe diameter along the repair. The collapse of this 1,350 mm concrete carrier pipe, and the sewage lines within it, cause sewage to back up and flow along Highway 7 for several weeks. The BWA responded by sucking and trucking sewage between manholes and lift stations to bypass the collapsed section. This collapse also compromised the outfall which as discussed previously, resulted in the BWA installing two temporary outfalls off Worthing Beach that are reported to extend at least 850 m out to sea.

6.1.2 Lift Stations and Related Force Mains

There are five sewage life stations within the south cost sewage collection system, of which the Aquatic Gap lift station is the largest, however, we were only provide as-built drawings for four out of the five: Aquatic Gap, Deal Gardens, Palm Beach, and the Welches lift station.

The Aquatic Gap lift station includes three submersible pumps within the wet well. The wet well is constructed of concrete, with what looks like a steel lining on the inside of the tank, presumably designed to provide some H_2S protection to the concrete. All the other structures within the wet well including steel piping, appear to have met their life expectancy and are need of replacement. The air scrubber was also not in operation which creates odour issues that could be detected on the adjacent street (Highway 7).

The other lift stations are constructed using circular concrete underground structures, housing two submersible sewage pumps within a dry chamber. We were unable to obtain any additional information from the BWA regarding pump horsepower, pump curves and the flow capacities of the lift station pumps, nor was this information available on the as-built drawings. Backup power generators were provided for all the lift stations, and they appear to be in good condition. In fact, Mr. Coswin Carington, the sewer Foreman, mentioned how he regularly manually shuts down the power to the lift stations to trigger the generators to start and run them for at least 30-minutes each.

There is no screen installed in any of the lift stations and as a result, rags become a problem for pumping Operators. All lift stations within South Coast sewage collection system are equipped with the air scrubbers to deal with odour. Except for the Aquatic Gap lift station, all the remaining air scrubbers were reported to be functioning properly, but they are all approaching their service life.

There are also SCADA malfunction issues reported at all the lift stations. Similar to the Bridgetown sewage collection system SCADA units, we believe the entire system needs to be re-programmed and the Operators need to be appropriately trained on SCADA system maintenance.

The South Coast sewage collection system appears to have more force mains compared to Bridgetown sewage collection system. The largest and the longest is the one 500 mm (20") diameter from SCSTP discharging primary treated sewage to the ocean outfall.

6.1.3 Hydraulic Capacity

Similar conclusion may be made for South Coast sewage collection system as that for Bridgetown sewage collection system where the hydraulic capacity of the system should be more than adequate for serving 2,500 properties it connects. A 750 mm (30") PVC gravity line at moderate design slope (assume 2%) would have theoretical hydraulic capacity of more than 26,000 m^3/day or 0.3 m^3/s. Recent maximum flow data, for 2019, entering the SCSTP was provided to us by the BWA that illustrated a maximum flow rate of 18,128.3 m^3/day (4.789 MGD US), therefore the sewage collection system entering the SCSTP is appropriately oversized to handle this maximum flow rate.

It is recognized that it would be possible that at some locations, the capacity of the sewer system could be inefficient due to localized hydraulic conditions such as; under sized pipes at a particular point, large point discharges at other particular points, or significant stormwater inflow. However, without detailed technical information and without a hydraulic model, those potential points of concern would be almost impossible for anyone to detect.

6.2 Bridgetown Sewage Collection System

6.2.1 Coverage of the Sewage Collection System

The sewage collection system within the Bridgetown catchment area is sent to BTSTP for secondary treatment before being discharged to Caribbean Sea through a 750 mm (30") ocean outfall that begins near Prescod Boulevard.

6.2.2 Gravity System

Bridgetown sewage collection system is currently serving approximately 2,000 properties in the area but is designed to allow up to 3,000 connections. The BWA has expressed interest to extend the sewage collection system, within the Bridgetown sewage collection catchment, but no details have been shared to date. The BWA did report that the National Housing Corporation constructed a small collection system, complete with a lift station at the Garden Land Country Road, and this system was added to the Bridgetown sewage collection system, but no as-built information is available to review.

While no detailed information is available at this point, it seems most of the gravity pipes in the system are PVC pipes. Exceptions that exists are between manholes #185 to 250 (as per the BWA as-built drawings) along Swan Street that is AC pipe.

The BWA have reported that they have sealed some of the manholes within the sewage collection system to lower inflows and also to stop individuals from lifting manhole lids and dumping waste (typically with high FOG) into the system. This practice is also believed to have created high H_2S build-up in the sewage system, which attacks the concrete manholes and any structures (such as the ladder rungs). H_2S is also a major heath/safety concern that tends to collect at the sewage life stations.

The sewage collection network has also experienced several pipe breaks, but most of these are believed to be caused by private contractors undertaking excavation activities without clearance from the BWA.

The staff at Bridgetown have developed a sewer flushing schedule for the collection system which is working well to resuspend solids that have deposited within the sewer pipes. However, the sewer flushing program is not able to address the problems caused by illegal dumping of FOG from restaurants, and this situation needs to be urgently addressed.

6.2.3 Lift Stations and Related Force Mains

The Bridgetown sewage collection system includes one major lift station (the River Road lift station) and four smaller lift stations operated by BWA. With the commissioning of the South Coast Sewerage system in 2002, the function of a small lift station at Government headquarters was replaced by the new lift station at Aquatic Gap. Most of the force mains are made of DI pipe. HDPE and concrete pipes may also have been used, but it's not identifiable from the "as-built" drawings received.

Very little information is available for the lift stations within Bridgetown sewage collection system, except a single mechanical drawing (M-201) for the River Road lift station. The drawing shows a Parshall flume, and a manual screen were included in the construction of this lift station. The River Road lift station also includes four sewage pumps installed in a dry well of the underground structure. No provision of odour control was found and was evident when we visited this lift station. Odours were detected from the road leading up to the building.

Like the BTSTP, excessive quantities of rags and other debris clog the lift station pumps and it continues to be a constant operations problem, as is the disposal of excessive quantities of FOG which thickly coat all surfaces. The rags and screening must be manually cleaned. The River Road lift station has an opening on the main floor directly over the screen. It is unclear if an automatic screening machine used to be installed in this space but should be considered in the future.

All the lift stations appear to have obvious H_2S problems, possibly due to most of the manholes being sealed and not allowing proper ventilation into the gravity collection system.

All the lift stations were equipped with a SCADA system; however, none were reported by the BWA to be functioning properly due to programming "bugs." It appears that the SCADA system needs to be re-programmed as a whole in order to properly operate again. The Operators also need to be trained on how to properly maintain the SCADA system.

6.2.4 Hydraulic Capacity

Based on the general observation of the as-built drawings, the hydraulic capacity of the system should be more than adequate for serving only 2,000 properties. A 400 mm (16") gravity line at a moderate design slope of 2% would have theoretical hydraulic capacity of at least 7,800 m^3/day or 0.09 m^3/s, and the largest gravity line before the system connects to the BTSTP is 850 mm (34") that has more than 4 times the hydraulic capacity of a 400 mm (16") line (35,000 m^3/day or 0.4 m^3/s). In comparison, the BWA estimates the AAF of sewage for both BTSTP and SCSTP for 2019 to be 13,736 m^3/day.

It is recognized that it would be possible that at some locations, the capacity of the sewer system could be inefficient due to localized hydraulic conditions such as; under sized pipes at a particular point, large point discharges at other particular points, or significant stormwater inflow. However, without very detailed technical information and without a hydraulic model, those potential points of concern would be almost impossible for anyone to detect.

7 POTENTIAL ENERGY RECOVERY

In order to accurately determine the energy recovery potential of the treatment facilities, more information on the characteristics of the wastewater is required. Wastewater samples were taken from both treatment facilities and processed at a local laboratory at the Cave Hill UWI campus. This information together with limited information that has been received from the BWA, is not sufficient to accurately calculate the energy content of the collected wastewater. For the BTSTP, some additional information, from the plant O&M Manual was available that offered some planning-related specifications for wastewater flows and BOD_5. However, we have not yet been able to receive the same information for the SCSTP.

Regarding the sewage collection systems, the BWA has stated that the BTSTP has approximately 1,200 connections while the SCSTP is estimated to have 2,000 connections. However, the sewage characteristics of the connected facilities is unclear, which means that limited conclusions can be made regarding the connected population equivalents.

In the absence of historical data, estimates will be made in the form of scenarios. Two scenarios for the BTSTP and 1 scenario for the SCSTP, as well as a population-based scenarios will be carried out (see Table V). These scenarios are based on the available statements and sources of data from the BWA or on the assumption that 10%, 15% or 20% of the population of Barbados are connected to the sewer system. It also assumes that the energy content of the wastewater is transformed into methane through anaerobic digestion. Methane can then be used as fuel for combined heat and power plants and converted into electricity and heat/cooling.

Table V. Description of Energy Option Scenarios

Scenario	Description
Scenario 1	BTSTP based on planning related specifications
Scenario 2	BTSTP based on 1,200 of existing connections
Scenario 3	SCSTP based on 2,000 of existing connections
Scenario 4	10% of the population of Barbados is connected to the overall sewer system
Scenario 5	15% of the population of Barbados is connected to the overall sewer system
Scenario 6	20% of the population of Barbados is connected to the overall sewer system

The following additional assumptions were made for the calculations:

- For BOD_5 and COD values, standard values are used: 60 $g(O_2)$/cap/day and 120 $g(O_2)$/cap/day respectively;
- The energy content in the wastewater is estimated using the BOD_5 or COD value of the inflowing wastewater, since experience shows that the conversion rate in anaerobic digestion can lie between both values;
- The energy content of the sewage sludge is 50% of the energy content of the inflowing wastewater; and
- The resulting fuel is used in a modern connected combined heat and power plant, which converts 40% of the energy contained in the fuel into electricity.

7.1 Scenario Description and Results

7.1.1 Scenario 1

The influent data, provided in Table W is based on the planning specifications within the BWA BTSTP O&M Manual (dated 1982) for the average and maximal flow rates.

Table W. Influent to the BTSTP

	Flow Rates (MIGD)	Flow Rates (m^3/day)
Average	2.4	10,911
Maximum	9.6	43,642

According to statements by the BWA during the tour on September 28, 2020, the $BOD_{5\text{-in}}$ = 200 $g(O_2)/m^3$ for influent and $BOD_{5\text{-out}}$ = 30 $g(O_2)/m^3$ for effluent. These figures were used in the calculations for Scenario 1.

No information on the amount of sewage sludge produced has been provided to us by the BWA to date. Usually the excess sewage sludge is anaerobically fermented and if unpolluted, can be spread on agricultural land. It is assumed that during the aerobic treatment of wastewater, the energy is metabolized and 50% is used to form sewage sludge.

Based on the data in this section, the following results were estimated for Scenario 1 (see Table X):

Table X. Estimated Available Energy, According to Scenario 1

Parameter	Average	Maximum
Influx		
Volume Methane Produced	1,274 $m^3(CH_4)$/day	5,095 $m^3(CH_4)$/day
Power of Methane Gas	12,694 kWh/day	50,777 kWh/day
Power produced (CHP)	5,078 kWh/day	20,311 kWh/day
Electric Power (CHP)	212 kW	846 kW
Heat Produced (CHP)	6,982 kWh/day	27,927 kWh/day
Heat Power (CHP)	291 kW	1.164 kW
Sludge results		
Volume Methane Produced	541$m^3(CH_4)$/day	2,165 $m^3(CH_4)$/day
Power of Methane Gas	5,395 kWh/day	21,580 kWh/day
Power Produced (CHP)	2,158 kWh/day	8.632 kWh/day
Electric Power (CHP)	90 kW	360 kW
Heat Produced (CHP)	2,967 kWh/day	11,869 kWh/day
Heat Power (CHP)	124 kW	495 kW

These results indicate that the energy recovery by anaerobic transformation of the chemical energy bound in organic components of the wastewater is just sufficient to operate a digestion tower in conjunction with a CHP. However, profitability will most likely only be achieved if the maximum capacity is used.

7.1.2 Scenario 2

In this scenario, the number of connections, as stated by the BWA, and the BOD_5 / COD standards are used to calculate the energy transferred from the influx. It is expected the efficiency of the aerobic treatment is the same as in Scenario 1.

The following input values were assumed for Scenario 2 (see Table Y):

Table Y. Input Parameters for Scenario 2

Parameter	Value
Connections	1,200
Number of persons per connection	4
BOD_5	60 $g(O_2)$/cap/day
COD	120 $g(O_2)$/cap/day
Aerobic Treatment Efficiency	85%

Based on these input values, the power and heat quantities were calculated using the same scheme as in Scenario 1. The results are shown in Table Z:

Table Z. Estimated Available Energy, According to Scenario 2

Parameter	BOD_5	COD Based
Capita Assumed	4,800	4,800
Influx results		
Power of Methane Gas	2,010 kWh/day	4,021 kWh/day
Power produced (CHP)	804 kWh/day	508kWh/day
Electric Power (CHP)	33.5 kW	67.0 kW
Heat produced (CHP)	1,106 kWh/day	2,212 kWh/day
Heat Power (CHP)	46.1 kW	92.1 kW
Sludge results		
Power of Methane Gas	854 kWh/day	1,709 kWh/day
Power produced (CHP)	342 kWh/day	684 kWh/day
Electric Power (CHP)	14.2 kW	28.5 kW
Heat produced (CHP)	470 kWh/day	940 kWh/day
Heat Power (CHP)	19.6 kW	39.2 kW

The estimates in the case of Scenario 2 show that the energy transfer results are significantly lower than those recorded in the 1982 BWA Handbook. The reasons for this could be based on the lack of confirmed nature (residential sewage versus commercial sewage) and number of the sewage connections. It can be assumed that the number of members of the connected households is underestimated and that the connections of commercial units and their COD and BOD_5 values are not known.

7.1.3 Scenario 3

In this Scenario the number of connections mentioned by BWA and the BOD_5 and COD standards are used to calculate the energy transferred from the influx. The following input values were assumed for Scenario 3 (see Table AA):

Table AA. Input Parameters for Scenario 3

Parameter	Value
Connections	2,000
Number of persons per connection	4
BOD_5	60 g(O_2)/cap/day
COD	120 g(O_2)/cap/day
Aerobic Treatment Efficiency	85%

The results are shown in Table BB:

Table BB. Estimated Available Energy, According to Scenario 3

Parameter	BOD_5	COD Based
Capita Assumed	8,000	8,000
Influx results		
Power of Methane Gas	3,351 kWh/day	6,702 kWh/day
Power produced (CHP)	1,340 kWh/day	2,681 kWh/day
Electric Power (CHP)	56 kW	112 kW
Heat produced (CHP)	1,843 kWh/day	3,686 kWh/day
Heat Power (CHP)	77 kW	154 kW

As for Scenario 2, the same applies to Scenario 3: The estimates in the case of scenario 3 show that the energy transfer results are significantly lower than those recorded in the BWA 1982 Handbook. The reasons for this are based on not being able to accurately confirm the number and nature (residential sewage versus commercial sewage) of the connections. It can be assumed that the number of members of the connected households is underestimated and that the connections of commercial units and their COD and BOD_5 values are not known.

7.1.4 Scenarios 4 to 6

In these three Scenarios, it is assumed that of the total population of Barbados is 287,000[15], different proportions are connected to the sewerage system and the two treatment plants. Otherwise, the default values for BOD_5 and COD are assumed again (Table CC):

Table CC. Input Values for Scenarios 4 to 6

Parameter	Value
10% (Scenario 4)	28,700 caps
15% (Scenario 5)	43,050 caps
20% (Scenario 6)	57,400 caps
BOD_5	60 g(O_2)/cap/day
COD	120 g(O_2)/cap/day

Based on these assumptions and assuming the efficiency of energy transformation in methane gas, in the case of anaerobic digestion, lies between BOD_5 and COD, the following results can be estimated (see Table DD):

Table DD. Results of the Estimations from Scenarios 4 to 6 with Direct Use of the Wastewater without Aerobic Pre-Treatment

Parameter	Scenario 4	Scenario 5	Scenario 6
BOD_5 Based			
Volume Methane	1,206 m^3/day	1,809 m^3/day	2412 m^3/day
Power Produced	4,808 kWh/day	7,213 kWh/day	9,617 kWh/day
Electric Power	200.4 kW	300.5 kW	400.7 kW
Heat Produced	6,612 kWh/day	9,917 kWh/day	13,223 kWh/day
Heat Power	275.5 kW	413.2 kW	551.0 kW
COD Based			
Volume Methane	2,412 m^3/day	3,618 m^3/day	4,824 m^3/day
Power Produced	9,617 kWh/day	14,425 kWh/day	19,234 kWh/day
Electric Power	400.7 kW	601.1 kW	800.1 kW
Heat Produced	13,223 kWh/day	19,835 kWh/day	26,446 kWh/day
Heat Power	551.0 kW	826.4 kW	1,101.9 kW

[15] World Population Review (Barbados 2020): http://worldpopulationreview.com/countries/barbados-population/

If these scenarios were realistic, an implementation of anaerobic digestion of sewage sludge would make sense. In this case it is irrelevant whether anaerobic digestion of the wastewater or of the sewage sludge (which could provide about 40% of the methane flow rate shown in Table DD) takes place. The amount of electrical energy generated would be sufficient to feed it into the electricity grid and to contribute to the frequency stabilisation of the electricity grid and as a power shortfall filler. At the same time, a large amount of heat is generated at two different temperature levels, which could be used for both heating and cooling.

7.2 Summary of Results

The simulated data from Scenario 1 and Scenario 2 for the BTSTP are clearly contradictory. The reason for this is insufficient knowledge related to the number and nature of sewage collection tie-ins within the BTSTP catchment area. More precise estimates of potential energy recovery could be made if more wastewater data were available for COD and monthly wastewater quantities. In this respect, an accurate estimate based on calculations are not achievable.

However, when comparing the data from Scenario 1 with those in Scenarios 4 to 6, it can be concluded that, using population equivalents, slightly more than 10% of the population of Barbados is connected to BTSTP. Based on these calculations, the operation of a digestion tower with connected CHP could make sense, even if the amount of power produced is at the lower limit.

8 ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

It is important to consider the potential environmental and social impacts of the proposed project even in the conceptual phase. It is also recognized that the GCF, managed through the CCCCC, will be proceeding with a full ESIA project in parallel to this project, in accordance with the Performance Standards on Environmental and Social Sustainability (International Finance Corporation, 2012). This full ESIA will be complimentary to this scope of work.

As part of this Baseline Study, environmental and social considerations at the preliminary planning stage will be examined. Our intension for this scope of work is to focus on existing environmental and social assessment literature with the objective to provide the BWA a better understanding of present general environmental and social considerations related to this project. As new project information develops that is related to environmental and social impacts, this data will be included within the Feasibility Study.

The Performance Standards on Environmental and Social Sustainability, related to the ESIA, will provide "*guidance on how to identify risks and impacts, and are designed to help avoid, mitigate, and manage risks and impacts as a way of doing business in a sustainable way, including stakeholder engagement and disclosure obligations of the client in relation to project-level activities*" (International Finance Corporation, 2012).

These preliminary findings will evolve and become more refined as the project details, such as the proposed wastewater treatment technology, impacted population and stakeholder concerns are determined. It is expected that the ESIA will include an assessment of project impacts based on direct observations, interviews, stakeholder consultation and professional judgement (Trotz et al., 2018).

Although it is preliminary in nature, it is important to consider environment and social impacts during all phases of the project to achieve best overall development objectives. Overall environmental and social impacts of the improved wastewater treatment in Barbados, as well as those specific to each the BTSTP and SCSTP are outlined below.

8.1 Potential Environmental Impacts

8.1.1 Climate Change Resilience - "Reduce Reuse Recycle"

Barbados is directly impacted by the effects of climate change. Sea level rise and salt-water intrusion of potable water aquifers coupled with changing weather patterns (intermittent and higher intensity rainfall) stress Barbados' IRWR (CCCCC, 2019). One of this project's objectives is to consider upgrading the BTSTP and SCSTP treatment process to tertiary treatment levels that will reduce, reuse, and recycle material from the wastewater management process. The tertiary treatment of wastewater will allow for reuse of the treated water for non-potable sources, such as agriculture, landscaping, and turf maintenance (CCCCC, 2019). Secondary treated sludge can be used as fertilizer for the agricultural community and activated sludge can be used in landscaping, turf maintenance of lawns, golf courses, reclamation, soil erosion and dump covering (CCCCC, 2019).

The proposed treatment process aims to achieve a net 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.

To achieve the upgrades to the BTSTP and SCSTP, there will be on-site construction and an anticipated increased facility footprint, at least to the SCSTP. Construction activities have potential to add to GHG's (truck exhaust etc.). This impact, while limited requires further investigation with the ESIA and construction planning. Many of the environmental factors identified in this section also add to climate change resiliency and are discussed further below.

8.1.2 Water Availability & Water Quality

Droughts, periods of intense rainfall resulting in flooding, and salt-water intrusion impacts the availability and quality of water. Barbados has been ranked as one of the 15 most water stressed countries in the world (PAHO 2012). Aquifers provide approximately 85% of the island's potable water source and are at risk of salt-water intrusion and are experiencing decreasing underground recharge rates due to drought conditions. During previous times of drought, the BWA has had to impose restrictions on potable water use, droughts have affected both water and food security. Barbadian farmers are vulnerable to climate change as droughts can cause pre-mature death of livestock and poultry and reduce crop yields (CCCCC, 2019).

The proposed project can alleviate some stress put on the potable water supply by supplementing non-potable water sources such as agriculture and hotels, as well as recharging the aquifer.

Treated wastewater is to be reused, offsetting the volume of water relied on directly from rain to fill the aquifer (CCCCC, 2019).

Although groundwater quality along the coastlines are subject to saltwater-intrusion studies have also shown, like in the case of Spring Garden BWRO desalination plant situated in St. Michael, that the groundwater quality has nitrogen and bacteriological content comparable to untreated domestic wastewater (Sealy, 2009). This groundwater quality concern will need to be further investigated within the ESIA.

Currently, wastewater from the SCSTP and the BTSTP is being discharged to the ocean with primary and secondary treatment, respectively. The quality of the water being discharged contains nitrogen and phosphorus which can result in nutrient loading and can be detrimental to coral reefs and the near shore environment (W.F. Baird, 2019). In 2017 and early 2018 Highway 7 in the SCSTP region overflowed with sewage which was called a "National Crisis" by the Prime Minister and resulted in effluent from the SCSTP being discharged into the GHW. The impacts of the proposed project on water availability and water quality will have a subsequent impact on the people of Barbados and the environment and should be further assessed in the ESIA.

8.1.3 Marine Environment

The marine environment off the west coast of Barbados is crucial to the tourism industry, fishing industry, and general enjoyment of the island. "*It could be argued that the west coast of Barbados is its greatest physical economic asset, generating the majority of the island's tourism revenue. This coastal asset is now under threat partly due to inadequate inland water resource management*." (Sealy, 2009). The coral reefs provide habitat for marine animals and reef fish, recreation activities for tourists (scuba diving, snorkelling) and they act as natural break waters. Coral reefs are at risk of excess nutrient which contribute to near shore nutrient loading.

In a Social Impact Assessment for the South Coast Sewerage Project, which assessed the impact of the project against the continued use of suck wells or septic tanks by the South Coast population, it was stated that "*One expected negative environmental effect is an increase in algae, which deprives reefs of oxygen (and life). The resulting reef devastation can prompt beach erosion that would inevitably affect (negatively) the tourism industry and the economy as a whole. Another effect is the destruction of seagrass beds, which have diminished the near-shore fish population. The high levels of bacteria present in the sewage pose a health risk to persons bathing in the sea*." (Dey & Husbands, 2002). An ESIA conducted by Baird & Associates in relation to the installation of the outfall for the SCSTP stated "*Pharmaceutical compounds in sewage can also interfere with healthy ecosystem functioning of reef organisms, and potentially threaten shorebirds, waders, and seabirds, as well as fish, molluscs, and crustaceans in the nearshore. When bioaccumulated in marine organisms, the consumption of tainted seafood can have human health implications.*" (W.F. Baird, 2019)

The outfall discharge locations are also considerations for environmental impact. The SCSTP outfall was installed 850 m offshore with strong currents to limit impact on nearshore environment (W.F. Baird, 2019). No detailed information has been made available regarding the exact location of the BTSTP outfall or its exact distance from shore that it releases treated effluent into the Caribbean Sea.

This project aims to upgrade both wastewater treatment plants and use 100% of the treated effluent for non-potable water use and therefore eliminate the use of ocean discharge. The impacts to the marine environment including the water quality, benthic environment, and marine life should be reviewed further in the ESIA process as the health of the marine environment also impacts the economy (tourism and fishing), and public health.

There are potentially some impacts to the marine environment due to construction activities related to the proposed project. Construction at the treatment plants or in residential and commercial neighbourhoods with sewer connections, can cause sedimentation (from disturbing the surface), and spills/leaks from equipment and trucks (CCCCC, 2019). These impacts should be reviewed in the ESIA and considered during construction planning and execution.

8.1.4 Food Availability

Climate change causing temperature increase, droughts and large storm events can put stress on the agriculture industry. The MAFS Climate Change Unit has been developed with the goal to assist farm units in mitigating, adapting, and improving productivity and efficiency in the face of climate related events that impact local agriculture. This project would support agriculture by providing a supplemented water source from treated wastewater that would contain nutrients (fertilizer), such as nitrates. It is anticipated that the treated wastewater would allow the agricultural industry to be more resilient to the impacts of climate change. However, the EPD currently restricts using wastewater reuse for irrigation purposes to only ornamental plants (not for human consumption) and lawns.

8.1.5 Air Quality & Odour

It is anticipated that this project will result in improved air quality in the areas around the wastewater plants (CCCCC, 2019) due to an improved and potentially more efficient wastewater treatment process. In addition, by harnessing energy (collecting gases such as methane for reuse purposes) from the wastewater process, there will be a lower carbon and GHG footprint (CCCCC, 2019). The impacts of air quality and odours from the proposed project, construction activities (dust, vehicle emissions), and storage of treated wastewater and sludge should be further investigated in the ESIA.

It should be noted that there were odour complaints at the BTSTP, which resulted in the purchase of new aeration blowers at the facility in 2020. There has also been some concern of H_2S at both wastewater treatment facilities which is a significant health and safety concern and can be assessed and improved by upgrading to the facilities.

8.1.6 Noise

It is anticipated that there may be changes in noise generated during construction, or during ongoing operations at the facilities (generated by truck traffic, equipment, treatment process). Noise may impact nearby residents, businesses and wildlife and should be addressed in the ESIA.

8.1.7 Vegetation

In 2016, there were four endangered plants listed as "least concern" by the International Union for Conservation of Nature (Trotz et al., 2018). Although there is not much undeveloped land in Barbados, there is potential impact to vegetation if there is an expansion to the footprint of the facility or if there are disturbances due to additional sewer connections related to the proposed project. Construction at the treatment plants, that are currently situated within residential and commercial neighbourhoods, will more than likely require land clearing and vegetation removal. The impact of this can be determined with an assessment by a biologist or environmental professional prior to construction activities and should be further evaluated within the ESIA.

The SCSTP is adjacent to the GHW which is a central draining point for the Graeme Hall watershed and has many identified plant species (W.F. Baird, 2019). The predominant species identified in 1997 in the wetland include Mangrove, Rush, Crab Grass and Tassel Pond Weed (W.F. Baird, 2019). The GHW is designated as a World Heritage site under the Ramsar Wetland Convention and is a unique environmental feature as it is the only Mangrove habitat remaining in Barbados (W.F. Baird, 2019). At one point, after the sewage lines collapsed in 2017 resulting in wastewater flowing along Highway 7, wastewater (receiving only primary treatment) was being directly released into GHW. Discharge into the wetland with excessive nutrients and chemicals can cause die-back of mangroves and other wetland flora and fauna. As a Ramsar site, the GHW is to be preserved or improved, and if adverse effects are unavoidable it is to be compensated (W.F. Baird, 2019).

The impacts of the project to the GHW should be considered throughout the project. Having a use for tertiary treated wastewater should allow for the avoidance of primary treated wastewater being purposefully discharged into the GHW. Impacts to the wetland could include sedimentation or spills leaks from construction activity in the area, risk of this can be confirmed when the extent and location for the upgrades to the SCSTP are confirmed and can be mitigated.

8.1.8 Soil Quality

Treated sludge can be used as fertilizer for agriculture, providing a high carbon, nitrogen, and phosphorus content. Treated sludge from the wastewater treatment process can also be used in landscaping, turf maintenance, land reclamation, erosion control and dump covering. The ability to reuse this waste product can return nutrients to the soil and, may offset some commercial fertilizer use and therefore reduce some of the nutrient loading impacting the marine environment. Consideration of soil quality impact from the use of sludge as fertilizer should be assessed further in the ESIA.

There is potential to impact soil quality during construction activities, and during the operation of the facilities. These impacts can include spills/leaks from the treatment process or equipment, or erosion of cleared lands. These are common risks with construction and spills and can often be predicted, measured, and mitigated with topography assessment, baseline and routine sampling, and containment or run on/runoff erosion controls. These factors should be examined further within the ESIA.

8.1.9 Wildlife (Including Avifauna)

Tropical biodiversity is at risk without adequate aboveground freshwater sources, and freshwater sources above ground are decreasing due to Barbados' changing topography, impacting the lands ability to retain and maintain surface water. The addition of freshwater sources may provide additional habitat for wildlife. Recycling of treated wastewater may be able to support natural aquatic habitats and provide water courses for seasonal birds and other migratory organisms. (CCCCC, 2019).

Natural vegetation has been heavily impacted by farming and settlements throughout Barbados, resulting in low wildlife biodiversity (W.F. Baird, 2019). There are an estimated 48 bird species in Barbados, and four species of bats. The most common mammals are the African Green Monkey, introduced in the 17th century, the Burmese mongoose, introduced in the 19th century, and rats (W.F. Baird, 2019).

Barbados is located along the migratory bird path and has some locations which are key biodiversity areas (Trotz et al., 2018). Although there is currently not very much natural vegetation or wildlife biodiversity in Barbados, there is potential for the proposed project to impact wildlife and wildlife habitat. Any new development at the treatment facilities, or expansion of the sewage collection network, can impact wildlife and wildlife habitat due to construction activities or loss of land. Impacts from this project on wildlife should be fully assessed within the ESIA and should include consideration of key biodiversity areas and migratory bird timing.

8.2 Potential Social Impacts

8.2.1 General Public Perception and Awareness

Wastewater reuse options considered in Barbados include irrigation of golf courses and high amenity crops and groundwater recharge. Although technically feasible, direct potable reuse of collected domestic wastewater is generally not perceived as culturally acceptable in most countries. However, it is interesting to note that, for almost two decades now, there has been public acceptance of desalinated water produced by the BWRO plant at Spring Garden. Perhaps because the public is unaware that the feedwater to the BWRO plant may be as contaminated as raw sewage (Sealy H., 2009). 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, in order to demonstrate the quality of the reclaimed water to the public (and health officials) if necessary.

The potential negative social perception of sludge and wastewater reuse for agriculture purposes should be further investigated within the ESIA and stakeholder engagements. Additionally, another potential social impact topic that should be investigated is the distribution/availability of the treated wastewater for reuse purposes to vulnerable groups.

8.2.2 Population, Health & Safety

This project has the potential to significantly impact the local and tourist population of Barbados. As previously discussed, this project has the potential to alleviate issues related to the water supply system and therefore positively impact water and food availability. There may also be impacts to health and safety from the use of sludge as fertilizer and treated wastewater for non-potable sources, these can be addressed as part of the ESIA. There has also been concern for human health related to freshwater quality (Sealy, 2009), the water quality in the marine environment, and with unsafe wastewater management practices (CCCCC, 2019). There is also potential for this project to be utilized for public education around sustainability, water reuse, and safe water practices (CCCCC, 2019).

To ensure the best development outcome of the project, the project and potential impacts should be well communicated with the public and stakeholders. Especially those disproportionately impacted by climate change such as youth and gender groups. Other impacts to the population include potential for changes to ongoing truck traffic to and from the facilities with the receipt of wastewater and distribution of treated sludge. Truck traffic associated with delivering tertiary treated wastewater for aquifer recharge may also be required until the necessary piping distribution system is installed.

Temporary disturbance during construction activities are expected to be related to traffic, noise, dust, vibration and visual. These disruptions should be considered in project planning and stakeholder communications. There is potential for expansion of the facility footprint at both the BTSTP and the SCSTP, however, this is still in development. Any additional lands required for the project may impact the population (i.e. a lease, nearby neighbour, business owner). It may be necessary to work closely with and address concerns from stakeholders directly impacted by repurposing of lands and construction activities and should be further explored within the ESIA.

Section 6.2.2 also bring attention to the concern of H_2S within the wastewater management system which is a significant health and safety concern and can be assessed and improved by upgrading the treatment facility ventilation systems.

8.2.3 Willingness to Pay Study

A new or improved wastewater management system in Barbados will deliver a range of benefits and costs to the public. Benefits include climate resilient wastewater infrastructure designs that provide:

- Aquifer recharge and increased availability of potable water to households and businesses (reduced probability and incidence of water interruptions);
- Improved supply of water for purposes of agricultural irrigation;
- Increased supply of locally sourced renewable energy through methane capture (and other possible considerations);
- Reduced quantity of untreated sewage discharge into the nearshore marine environment; and
- Reduced probability / incidence of accidental sewage leaks into public spaces.

Costs include market-based costs associated with construction and maintenance of the new/improved system (which may be partially or wholly incurred by taxpayers and/or BWA consumers), indirect "non-market" costs associated with disruptions to traffic and commercial activity during the construction period, and potential land loss and community displacement.

The principle goal of the "Willingness to Pay" aspect of the project is to identify and understand the public's preferences and willingness to pay for various attributes of a new wastewater management system, including but not limited to those noted above, so that the system can be designed in accordance with the preferences of the general public to the extent practical. This goal will be accomplished in two phases, but only phase 1 will be completed during this project. In phase 1, to be conducted during the conceptual/preliminary design stage, we will assess the public's knowledge of and preferences for various characteristics ("attributes") that a new or upgraded wastewater system might provide, and the degree to which the public supports payment for those characteristics through higher water use fees, taxes and/or other charges that might be imposed for cost recovery. This phase of the study will identify the attributes that the public deems most important for the new system to deliver as well as those to avoid. In phase 2, to be conducted at the onset of the detailed design stage, a comprehensive willingness to pay study using the CE methodology to estimate the willingness to pay for alternative levels of wastewater system attributes deemed to be of the highest priority in the first phase of the study.

The public's preferences and willingness to pay for attributes of wastewater management systems will be assessed by collecting preference data through the administration of two surveys (one in phase 1 and the other proposed for phase 2 will be delivered online, with participation generated through solicitations in popular press and social media. The first survey will assess the Barbadian public's knowledge of wastewater treatment, preferences for attributes of wastewater treatment systems and general assessment of whether members of the public are willing to pay for those attributes.

The surveys will be designed with input from the BWA. In the phase 1 survey, specific data to be collected from respondents include; demographic characteristics (age, education, income, employment, dependents, parish of residence, etc.), Likert-scale ratings of knowledge regarding wastewater treatment characteristics and wastewater treatment. Likert-scale ratings of the importance of attributes delivered by wastewater treatment systems including:

- Aquifer recharge/increased availability of potable water to businesses and households (reduced probability and incidence of water interruptions);
- Improved supply of water for purposes of agricultural irrigation;
- Increased supply of locally sourced renewable energy through methane capture;
- Reduced quantity of untreated sewage discharge in the nearshore marine environment;
- Reduced probability and incidence of accidental sewage leaks into public spaces;
- Costs associated with construction and maintenance of the new/improved system;
- Disruptions to traffic and commercial activity during the construction period; and
- Potential land loss and community displacement.

Analysis of the survey data using regression analysis and other statistical methods are expected to provide a characterization of the public's baseline knowledge of wastewater treatment, the public's preferences for wastewater system attributes delineated by demographic variables, and a ranking of attributes that the public considers most important for a wastewater treatment system to deliver. To be clear, this phase of the project will not involve estimations of willingness to pay for attributes of wastewater treatment systems (seeing that level of design will not necessarily be known at the conceptual design level), but rather will provide a general assessment of which attributes/benefits the public values most and how the public thinks those attributes should be paid for. This baseline knowledge will be used for the detailed assessment of willingness to pay for the highest priority attributes (i.e. how much are people willing to pay?), this will be conducted at the onset of the detailed design stage of the project.

Specific data to be collected from respondents include demographic characteristics (age, education, income, employment, dependents, parish of residence, etc.), and choice experiment responses.

CE data will be analysed using multinomial logit regression analysis. Expected outcomes include point and interval estimates of the public's willingness to pay for alternative levels of wastewater system attributes, exploration of heterogeneity in preferences and willingness to pay across demographic variables, and an estimate of the economic value of alternative wastewater treatment system designs.

9 OPERATION AND MAINTENANCE CONSIDERATIONS

9.1 Current Operational Procedures

To support the maintenance program, staff must be trained on the maintenance aspects of all new equipment preferably prior to the commencement of use of the equipment. Operational staff should also be trained on minor maintenance and troubleshooting of equipment as they are the first line of identification of issues and with training may be able to address minor issues without having to involve additional staff.

For the amount of treatment equipment that requires monitoring and adjustments, as opposed to the mechanical work necessary to keep it performing, there appears to be a disproportionately high number of staff performing operational duties than mechanical duties on regular basis. This ratio has not changed over time although the maintenance requirements for the plant has increased as the various parts of the plant became worn and degraded.

There is not sufficient evidence to demonstrate that operational practices are documented, reviewed and revised as necessary. External training opportunities are very limited, and the internal training program is lacking.

The impacts of FOG from cookshops and food establishments have greatly affected the operational efficiency of the plants and creates a challenge for the BWA Operators. Addressing this issue in the treatment process and within the collection system requires significant operator effort. A lack of enforceable wastewater quality standards will continue to leave the lift stations and treatment plants vulnerable to the impacts of FOG, rags, spills and heavy loading events.

The appearance of inadequate scheduled maintenance has led to the breakdown of key equipment limiting operational ability for adjustments in the treatment process. There is also a lack of in-house wastewater analysis for laboratory testing to help operators monitor in real time, to manage the health of the plants and to make informed decisions regarding optimization of the treatment process. This is partially due to losing and not replacing their in-house laboratory technician. The BWA currently sends samples to be tested at government facilities, but it is our understanding that this practice is very infrequent and only occurs if a serious issue is disturbing the wastewater treatment facility.

Copies of records and documentation are not readily available within the facilities. These records may be available at the BWA office, but field information is limited and often relies on operator memory, or experiences when working in the collection system. Previously stored paper records suffered significant damage and/or loss after a chemical fire due to the storage environment and rats. Hence details of operational performance and flow rates (from when the flow meter was operational) have been lost.

9.2 Current Maintenance Practices

Cross training of staff to widen the skillsets of operators is not widely available. As a result, it is reported that minor maintenance issues often require a larger number of staff to perform minor tasks. There have been reports of the removal of manhole covers by private individuals to alleviate street flooding issues. Coupled with this is the inflow of stormwater into the system through manhole covers, or infiltration within the piping network. There is little quantitative measurement of these impacts due to the absence of influent data due to the absence of a functioning flow meter at the BTSTP facility. Some limited data (for 2019 only) has been received for the SCSTP, but the data does not suggest an issue with I&I within the sewage collection system that delivers influent to the SCSTP.

Some routine preventative maintenance such as the flushing of lift stations is being performed regularly, although it is somewhat limitied. A computer-based maintenance management system has been installed; however, the maintenance of the treatment system is done on a breakdown schedule rather than preventative maintenance in accordance with the schedule of the equipment manufacturers.

During the tour of the treatment facilities and collection systems on September 24 and 25, 2020, a definite improvement in the replacement of critical pieces of equipment was observed at both treatment facilities. This included blowers and mechanical screens at BTSTP and a new sea outfall, forced air system and mechanical screens (course and medium) at the SCSTP. However, it should be noted that if there is no preventative maintenance program instituted, then these new purchases will most likely become inoperable in a very short period.

There is a major problem in getting replacement parts for equipment. The most significant reason for this is that the equipment is old and that it is problematic to source parts. The BWA are making effort to standardise equipment to make it easier to source parts, for example the use of Flygt pumps in the collection system. It can also take significant time to obtain quotes which when coupled with challenges accessing funding for repair and maintenance, can result in the inability to complete orders. These constant challenges have continually resulted in deterioration of equipment over many years.

9.3 Current Health and Safety Practices

Although staff are aware of the safety related issues within the treatment facilities, including the lift stations, there does not appear to be a strong culture of safety among staff and often safety related equipment and PPE appeared in poor condition. Safety talks do not appear to be a common occurrence nor does the provision of Health and Safety information on a regular basis to field staff.

The chemical fire, in 2014, due to improper storage of various chemicals near each other, suggests that there are problems with guidance and/or training of operators in the handling of chemicals and an overall lack SOP. Although it was indicated that a Health and Safety Committee exists, regular documented inspections of the wastewater facilities and safety related equipment appears not to a regular occurrence.

9.4 Initial Considerations for Overall Improvements

Current operational practices should be documented, reviewed, and revised as necessary. Staff must be trained and follow the documented practices. As new equipment is installed or old equipment taken out of service, procedures must be re-evaluated and revised to ensure environmental targets are achieved. In order to achieve these goals a strong training program needs to be established and followed. To support the maintenance program, staff must be trained on the maintenance aspects of all new equipment preferably prior to the commencement of use of the equipment. Operational staff should also be trained on minor maintenance and troubleshooting of equipment as they are the first line of identification of issues and with training may be able to address minor issues without having to involve additional staff.

A documentation system should be established to preserve and make readily available all records related to plant operations and maintenance. Record keeping appears to be rudimentary and still reliant on paper. The use of tough books to electronically capture information should be considered.

Any alterations to equipment require as-built drawings to be updated to reflect these changes. A system should be put in place so that when maintenance work that alters the configuration is preformed, as shown in existing as-built drawings, the changes are captured in the drawings and any procedures referencing this equipment be revised.

The overall staffing levels and assigned roles has been studied and proposed changes have been put forward in the past. In a future report these changes should be reviewed and where relevant, acted upon. The commitment to the health and safety of staff would be strengthened by an active health and safety committee involving operator members and management staff.

Efforts to establish a robust computerized maintenance management system, focused on preventative maintenance, should lead to reduced breakdown maintenance time and costs. If the switch to such as system is not possible then a stronger paper-based system needs to be followed to ensure the proper operation and an increased life cycle of all equipment.

A new laboratory technician should be considered and included within the BWA team. The in-house laboratory testing for operational parameters should be re-established including a commitment to staffing and equipment.

The installation and calibration of flow measuring devices at the BTSTP is required and considered a critical need. This is particularly needed so that the influent volumes to the BTSTP can be accurately measured and an estimate of ground water intrusion into the collection system can be determined. Accurate flows are also required to document loadings for compliance reporting and to make operational adjustments.

In the absence of enforceable industrial effluent quality standards, BWA should establish internal limits and policies for working proactively with industrial dischargers and septage haulers, to reduce the impacts of FOG and shock loadings.

10 INITIAL ECONOMIC ASSESSMENT

10.1 Potential Economic Benefits

Included in the Conceptual Design and Feasibility Study of this Project will be a financial and economic assessments for a recommended climate resilient wastewater systems in Barbados, which includes the ability to significantly lower the carbon footprint and GHG emissions by providing sustainable methods to operate the wastewater treatment facilities and increasing water availability to reduce the strain on the existing aquifer that currently supplies 85% of the potable water source.

This financial and economic analysis for the project will include the development of a financial model and plan, specifically in the context of the Barbadian economy showing how this project can advance Barbados into the growth of a green economy model that can be sustained over the long term. Barbados is still recovering from the Financial Crisis and with the onset of the Covid-19 pandemic, the existing economic environment does not leave much fiscal space for public sector spending.

It is envisaged that the potential sustainable development positive impact of this proposed project will be significant and will result in Barbados being a more attractive investment destination for both regional and international tourists. Greater water availability will positively impact residents and businesses throughout Barbados that can directly and indirectly lead to greater employment.

10.1.1 Related to Water Availability

Using treated wastewater to recharge the aquifer and for irrigation purposes will improve water availability throughout the country. Over the past decade, Barbados has seen a slight increase in the population, coupled with an increase in the number of tourist arrivals. In addition, agriculture continues to compete with other sectors for scarce resources such as water, land, labour and capital, and the GoB has increased its call for greater domestic food production through new and improved methods of farming as a response to climate change. To this end, it will therefore be necessary for Barbados to not only develop their current wastewater management practices through the recycling and reuse of tertiary treated wastewater, but also via the implementation of new technologies that can be used to recharge the underground aquifers to be later used as potable water. Greater water availability, for irrigation purposes, should also lead to improved food security.

10.1.2 Related to Potential Energy Recover

One of the objectives of this project is to lower the carbon footprint and GHG emissions by capturing gases, such as methane, for renewable energy purposes. The BWA is challenged to restrain operating costs and increase efficiencies in delivering water and wastewater services through energy cost containment. Electricity costs are a significant component of the annual budget for the BWA and by adopting a strategy to reduce energy usage, would also contribute to cost savings.

11 CLOSURE

This report summarizes the baseline conditions for use in assessing options for upgrading and enabling the wastewater infrastructure to be able to adapt to climate change impacts as well as facilitate and enable energy and resource recovery opportunities and greenhouse gas emission objectives. Although the baseline work established that there is extremely little information available on the wastewater characteristics as well as the performance capabilities of the existing infrastructure, we have been able to gather enough information for the comparison of mitigation options and upgrades, as discussed in the body of this report. The greatest challenge that was identified was that the collection systems and the treatment facilities are experiencing a wide range of flow (between the peak and low tourist season) and load variations over the year that impede efforts of the operators to attain optimal performance of the treatment systems. The wide range in flows is expected to present a significant challenge for the project team to develop an adaptive strategy to mitigate the problem and design a system that can adapt to such a range.

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,

Troy Vassos, P.Eng.
Integrated Sustainability

Nick St-Georges, P.Eng.
Integrated Sustainability

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INTEGRATED SUSTAINABILITY

Appendix 1 – Stakeholder Mapping

Appendix 2 – Related Wastewater Policies