Feasibility Report

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

Contract # 10/2020/GCF3Rs/Barbados/CCCCC

Prepared for:

Caribbean Community Climate Change Centre

Integrated Sustainability Consultants Ltd. **December 15, 2021**

WATER | WASTE | ENERGY

Report Submission To:	Dr. Donneil Cain, CCCCC
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

Document Number:	BP20-CCC-01-00-RPT-Feasibility-Report-Rev1.docx
Document Path:	P:\CCC\BP20-CCC-01-00\7.0_Deliverables\7.2_Reports\Feasibility Study\BP20-CCC-01-00-RPT-Feasibility-Report-Rev1.docx
Document Revision Number:	1

INTEGRATED SUSTAINABILITY

Disclaimer

The information presented in this document is intended for internal use only and is not to be copied or distributed without authorization. Hard copies are un-controlled.

Integrated Sustainability has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this document but makes no guarantees or warranties as to the accuracy or completeness of this information. The information contained in this document is based upon, and limited by, the circumstances and conditions acknowledged herein, and upon information available at the time of its preparation. The information provided by others is believed to be accurate but cannot be guaranteed.

Integrated Sustainability does not accept any responsibility for the use of this document for any purpose other than that stated in the title of this document and does not accept responsibility to any third party for the use in whole or in part of the contents of this document. Any alternative use, including that by a third party, or any reliance on, or decisions based on this document, is the responsibility of the alternative user or third party.

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

Document Revision History

Rev No.	Rev Description	Author	Reviewer	Approver	Rev Date
A	Issued as a Draft	Troy Vassos	Nick St-Georges	Stuart Torr	Oct. 25, 2021
B	Issued as an Updated Draft	Troy Vassos	Nick St-Georges	Stuart Torr	Nov. 22, 2021
0	Issued as Final	Troy Vassos	Nick St-Georges	Stuart Torr	Dec. 11, 2021
1	Issued as a Revised Final Report	Troy D Vassos Troy Vassos	Nick St-Georges Nick St-Georges	Stuart Torr Stuart Torr	Dec. 15, 2021

Table of Contents

List of Figures

List of Tables

Appendices

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
3R's	Reduce, Reuse and Recycle
A^2O	Anaerobic/Anoxic/Aerobic
AAF	Average Annual Flow
AC	Asbestos Cement
AD	Anaerobic Digestion
ADWF	Average Dry Weather Flow
AS	Activated Sludge (Suspended Growth Wastewater Treatment Process)
ASTM	American Society for Testing and Materials
atm	standard atmosphere (unit for pressure)
BMP	Biomethane Potential
BMS	Barbados Meteorological Service
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BOD_5	5-Day Biochemical Oxygen Demand
BSTP	Bridgetown Sewage Treatment Plant
BWA	Barbados Water Authority
BWRO	Brackish Water Reverse Osmosis
CARPHA	The Caribbean Public Health Agency
CAS	Conventional Activated Sludge
CBA	Cost Benefit Analysis
$CBOD_5$	5-Day Carbonaceous Biochemical Oxygen Demand
CCCCC	Caribbean Community Climate Change Centre
CCREEE	Caribbean Centre for Renewable Energy and Energy Efficiency
CDB	Caribbean Development Bank
CE	Choice Experiment
CFU	Colony Forming Units

Acronym/Abbreviation	Definition
CH_4	Methane
CHP	Combined Heat and Power
CIMH	Caribbean Institute for Meteorology and Hydrology
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
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
DPR	Direct Potable-Water Reuse
EBPR	Enhanced Biological Phosphorus Removal
E. Coli	Escherichia Coli
EDC	Endocrine Disruptive Compound
EEZ	Ecological Economic Zoning
EIB	European Investment Bank
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
ESIA	Environmental and Social Impact Assessment
FC	Faecal Coliforms (Indicator Bacteria)
FOG	Fats, Oils and Grease
FTC	Fair-Trading Commission
GCF	Green Climate Fund
GEF	Global Environment Facility

Acronym/Abbreviation	Definition
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
HFC	Hydrogen Fuel Cell
HSE	Health, Safety & Environmental
I&I	Inflow and Infiltration
IDB	Inter-American Development Bank
IDPR	Indirect Potable-Water Reuse
IFI	International Financial Institutions
IPR	Indirect Potable Reuse
IRWR	Internal Renewable Water Resources
ISO	International Organization for Standardization
KAP	Knowledge, Attitude and Practice
kg	kilograms
KJ/Sm^3	Kilojoule per Standard cubic meter
km	kilometres
LGBTQIA	Lesbian, Gay, Bisexual, Transgender, Queer, Intersex, Asexual
LHV	Lower Heating Value
m^2	Square metres
m^3	Cubic metres
MAFS	Ministry of Agriculture and Food Security
MBBR	Moving Bed Biofilm Reactor

Acronym/Abbreviation	Definition
mbgs	Metres Below Ground Surface
MBR	Membrane Bioreactor
MEWR	Ministry of Energy and Water Resource
mg	milligrams
MGD	Million Gallons per Day
mg/L	milligrams per litre
mg-N/L	milligrams as 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
N	Nitrogen
NDC	Nationally Determined Contributions
NH_3	Unionized Ammonia
NH_4	Ammonium
NH_3-N	Unionized Ammonia expressed as Nitrogen
NH_4-N	Ammonium expressed as Nitrogen
Nitrate-N	Nitrate expressed as Nitrogen
NRW	Non-Revenue Water
NTU	Nephelometric Turbidity Unit

Acronym/Abbreviation	Definition
O&M	O&M
O&G	Oil & Grease
P	Phosphorus
PDD	Planning and Development Department
PE	Population Equivalent
pH	Potential of Hydrogen
PM	Preventative Maintenance
PPE	Personal Protection Equipment
ppm	Parts Per Million
PTL	Project Team Leader (from CCCCC)
PV	Photovoltaic
PVC	Polyvinyl Chloride
PWWF	Peak Wet Weather Flow
QMS	Quality Management System
R2RP	Roofs to Reefs Programme
RAFF	Revolving Adaptation Fund Facility
RAS	Return Activated Sludge
RNG	Renewable Natural Gas
RO	Reverse Osmosis
SBR	Sequential Batch Reactor
SCADA	Supervisory Control and Data Acquisition
SCSTP	South Coast Sewage Treatment Plant
SIDS	Small Island Developing States
SLR	Solids Loading Rate
Sm^3/d	Standard cubic metres per day
SOP	Standard Operating Procedures
SOR	Surface Overflow (loading) Rate

Acronym/Abbreviation	Definition
SOTE	Standard Oxygen Transfer Efficiency
SPACC	Special Programme on Adaptation to Climate Change
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
WTP	Water Treatment Plant

EXECUTIVE SUMMARY

Impacts of Climate Change on Wastewater Management

This report presents a Feasibility Study regarding proposed activities to modify, upgrade and adapt wastewater infrastructure to meet climate change impacts for Barbados, including energy and resource recovery opportunities to meet GHG emission objectives as set out in Barbados' NDCs. Changes in precipitation patterns, wind, temperature, ocean and geotechnical characteristics can significantly impact wastewater infrastructure in Barbados.

Precipitation:

- Higher intensity, frequency and duration of precipitation events often lead to infrastructure flooding and overflow conditions to the sewage collection system;
- Increased inflow to the sewage collection system;
- Increased likelihood and frequency of sewer flooding, overflows, and spills. This could lead to safety and health concerns if sewage overflows onto the surface;
- Increased surface erosion and introduction of sediment to sewers;
- Extended periods of drought leading to reduced water availability and higher sewage contaminant concentrations (less dilution) increased sewer related odour generation and release;
- Excessive loading to wastewater sewage treatment works; and
- Surface flooding, due to intense rainfall events, can lower the efficiency and efficacy of onsite wastewater treatment systems, such as soak-away fields and pit latrines.

Wind:

- Increased wind loading on wastewater infrastructure assets and buildings. Depending on the wind severity, during severe storm or hurricane events, it is possible for severe weather conditions to cause damage to wastewater infrastructure and cause power outages.

Temperature:

- Extended periods of high temperatures leading to increased hydrogen sulphide production resulting in increased infrastructure damage due to corrosion; and
- Increased environmental impacts of residual contaminants including nutrient impacts due to elevated receiving water temperatures.

Ocean and Geotechnical:

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

Lack of Data

The proposed scope of work established at the onset of this study intended to correlate weather and climate events with historical flow, raw wastewater quality and wastewater effluent quality for the Bridgetown and South Coast sewage collection and treatment facilities for evidence of climate change impacts. Unfortunately, very little historical data was available for reasons documented in the Baseline Study report. Instead, the study team was required to make assumptions regarding wastewater characteristics and the performance capabilities of the existing infrastructure, based on modelling, to provide a reasonable estimate and basis to assess the potential climate change impacts of climate change and potential for GHG emissions. The available information did identify the collection systems and the treatment plants have experienced wide flow and load variations that impede efforts of the operators to attain optimal performance of the treatment systems. Climate data also confirmed the importance of wastewater reclamation and reuse in the face of declining precipitation and/or reduced groundwater recharge due to changes in rainfall intensity and duration patterns in addition to potential effects of storm surges on marine outfall performance and dispersion characteristics assessed.

From a regulatory perspective the baseline work revealed that many standards and guidelines have remained in draft and that the requisite legislation has yet to be brought into law.

Change in Scope

After completing the Baseline Study, the GoB announced plans to award a project to relocate and upgrade the SCSTP as well as repairing sections of the South Coast wastewater collection system. Consequently, the Conceptual Design study was changed to focus on the centralized Bridgetown wastewater collection and treatment system, along with consideration for the decentralized onsite wastewater disposal systems that serve the majority of Barbados in the form of pit-latrines, soak-away fields and septic treatment and disposal fields.

Sewage Collection System Inflow Reduction

A review of historical power consumption data for the sewage lift-stations within the Bridgetown wastewater collection system provides evidence supporting operations staff observations of unusually high flow events within the system but provides with no direct correlation to wet weather. This suggests the primary precipitation-related impact on the sewage collection system is the inflow of surface water due to surface flooding near or around manholes that could be addressed through improved surface drainage. Consequently, climate change induced conditions determined to be of most concern to the wastewater collection system are those that would lead to increased inflow from surface flooding over manholes, or due to high groundwater levels, with a detrimental impact on the ability to collect and convey wastewater due to hydraulic backups and sewage overflows, impacting the treatment plant performance and effluent water quality, as well as impacting the receiving environment. Accordingly, it is recommended that work be done to improve surface stormwater drainage in the vicinity of the existing collection system, in particular where there are manhole covers present.

Wastewater as a Means of Drought-Proofing

The most significant potential climate change impact on wastewater management is in regard to the potable water supply and the potential for wastewater to be treated and reused to satisfy non-potable water demands, including irrigation and groundwater augmentation. Water security emerged as a priority wastewater associated impact of climate change. The goal of water security risk analysis is ensuring sustained business operations and taking into consideration stakeholder, regulatory, and corporate drivers. Recent (2019) drought conditions resulted in low groundwater levels and reduced potable water availability, underscoring how easily water resources could be seriously impacted by climate change, and how important water management (including wastewater) is to the economy and public health. The current wastewater, discharged through ocean outfalls, could be put to beneficial use to supply water to meet non-potable water requirements and thereby reduce potable water demands.

Renewable Energy Offsets and GHG Emissions Reduction

Reductions in GHG can also be achieved through the introduction of energy management tools to reduce and optimize power consumption and consideration for renewable energy through additional deployment of photovoltaic panels and bioenergy through anaerobic digestion of waste biosolids produced by the centralized wastewater treatment plants and septage from decentralized onsite treatment systems. The BSTP has a significant number of ground-mounted solar panels that could also be impacted by a category 2, or larger, hurricane, and the plant site is exposed to significant storm surges, associated with major storm events such as hurricanes, as it is only 6m above sea level.

Decentralized Wastewater Reclamation and Reuse Alternatives

Extending centralized wastewater collection and treatment to reuse water quality standards to serve all of Barbados is considered to be too expensive to be a practical or sustainable consideration. However, during the study the BWA and the GoB began considering small-scale (cluster) decentralized wastewater collection and treatment systems in sensitive groundwater protection zones (Zone A - Exclusion Zones, as illustrated within the Baseline Study), with treatment to a reuse water quality suitable for agricultural irrigation.

Consideration of Onsite Wastewater Ground Disposal as a Water Resource

As noted earlier, decentralized onsite wastewater disposal to ground, such as soak away and pit latrines, are the most common form of wastewater management in Barbados. Increasing rainfall intensity and duration can saturate surface soils, resulting in reduced treatment and increased contaminant contributions to groundwater. However, despite negatively impacting groundwater quality along the coastline and contributions to nitrogen loading, onsite systems have a number of positive attributes including contributing to groundwater resources with little to no energy consumption and minimal capital and operating cost. A logical approach would be to maintain the status quo for both decentralized and centralized wastewater management strategies, upgrade the level of treatment for the existing two centralized wastewater treatment systems (i.e. BSTP and SCSP) so that the treated reclaimed water can be beneficially reused. Additionally, provide cluster wastewater collection and reuse treatment systems for specific decentralized populated areas of Barbados with a high potential to impact ground water quality (i.e. Zone A locations).

Reuse Upgrade Options for BSTP

Three upgrade treatment technologies were considered, during the Conceptual Design phase, to upgrade the existing centralized treatment facilities to produce reuse water including. The options considered included examining a modification of the existing conventional activated sludge process currently being operated at the BSTP, converting the BSTP to an attached growth process using moving bed biofilm reactor media; and converting the BSTP to membrane bioreactor configuration. The evaluation parameters included: capital and operating costs; water resource recovery; energy consumption; renewable energy potential, nutrient recovery, and residuals management; and minimizing GHG emissions.

Bioenergy Recovery

Bioenergy production, at the scale of either the BSTP or SCSTP facilities, is deemed to be non-viable from an economic perspective; however, combining the waste biomass produced at both facilities, with septage from onsite systems and biodegradable food-related, within an off-site co-generation anaerobic digestion facility has merit.

Operator Training Program and Management Tools Development

The proposed centralized treatment and cluster treatment implementation strategy will increase the need for both the number of skilled operators and the operator skill development related to water reuse and renewable energy production. It is important to consider the ability of BWA operations staff to operate and maintain wastewater infrastructure modifications that are proposed to address climate change.

The number of personnel would be roughly in proportion to the number of treatment plants, less a percentage for plants with shared operations staff. The concern regarding the availability of training is the BWA's plan to add RO technology to filter tertiary wastewater effluent will require a greater number of highly skilled operators. Currently the only RO plant operating is a private sector operated facility under contract to the BWA. The greater the number of public and private sector tertiary wastewater treatment reuse facilities the greater then demand for staff to operate and maintain such facilities.

Expanding the collection system would not have the same impact as expanding the number of treatment facilities, just as expanding the treatment capacity of a single facility would not require the same increase in operator availability as would increasing the number of plants. However, the BWA, and government have stated they have no immediate plans for expanding either the BSTP or SCSTP collection systems.

The shift in maintenance focus from emergency breakdown maintenance to preventative maintenance will be of particular benefit to preparing for and adapting to climate change impacts. This maintenance focus will benefit both the two centralized collection and treatment systems, as well as extending the life cycle of the equipment and help to reduce breakdown maintenance that can come with a high financial and environmental cost. Recommendations are made to support a maintenance training programme that includes heightened awareness of the impacts of climate change on infrastructure and operational measures to mitigate these impacts. Of particular importance in planning for climate change impacts is establishing a robust operations information database in the form of a CMMS to establish a core electronic data collection, operation, and maintenance programme. Recognizing that valuable hard-copy data was destroyed by fire in the past, an electronic CMMS information system will enable important information to be stored and readily accessed for analysis and will be less susceptible to potential damage from fires or storm events potentially associated with climate change.

A review of current operational and maintenance practices also highlighted there is a lack of adequate maintenance, with equipment generally only receiving attention resulting from breakdowns, as opposed to preventative maintenance through a robust, documented, maintenance management system. It also highlighted a lack of enforceable legislation and policy governing collection system. This results in an excessive amount of time and effort required to resolve collection and treatment system issues. Improvements in documentation, procedures, training, as well as the health and safety of field staff, will benefit both collection and treatment system performance.

LogFrame Development

Risks associated with the proposed recommended Activities have been captured in a Logic Frame, or LogFrame, spreadsheet that was produced to reflect the recommended Activities arising from the Feasibility Study taking into consideration stakeholder engagement responses to the concepts and proposed outcomes described in this report.

Gender-sensitive development improvements were also examined and are further outlined within the Gender Analysis report, that was prepared separately. Similarly, a Stakeholder Engagement Report has also been developed separately that outlines the various stakeholder's involvement in the design process related to this project.

Summary of the Key Findings and Recommendations

To be able to reuse the wastewater received by the two centralized treatment plants (BSTP and SCSTP), it is necessary to upgrade both plants to achieve a tertiary level of treatment. There are a wide range of process options that could be constructed to produce high quality reuse water, and of the three processes considered (conventional activated sludge, moving bed biofilm reactors, and membrane bioreactors), conventional activated sludge with tertiary filtration was deemed to be the most sustainable process configuration with respect to: 1) having the lowest capital and operating cost; 2) requiring minimal additional operator training; 3) ability to reliably produce reclaimed water for non-potable reuse purposes; 4) ability to repurpose all of the existing treatment infrastructure at the BSTP; and 5) waste biosolids from the proposed CAS process has the highest renewable bioenergy recovery potential of the three technologies.

In parallel with this study the BWA and the GoB have also been advancing strategies to upgrade the SCSTP to achieve a reclaimed water standard in conjunction with the implementation of reverse osmosis treatment to reduce effluent total dissolved solids concentrations to less than 450 mg/L in an effort to meet the MAFS safety requirements for agricultural irrigation use. The BWA and MAFS have proposed 3 reclaimed water pipeline options (some up to 27 kms in length) to transfer the RO treated water from the BSTP to locations such as St. Lucy in the northern part of Barbados.

The RO treatment will result in the production of a waste brine solution that will need to be managed to comply with environmental regulations and guidelines, and the reject volume diminishes the amount of reclaimed water available for reuse applications. Further, applying reverse osmosis filtration to the reclaimed water further increases the amount of energy and cost to treat the water. The RO treatment will result in the production of a waste brine solution that will need to be managed to comply with environmental regulations and guidelines and will diminish the amount of reclaimed water when compared to other options. Further, the implementation and operations of another RO treatment plant is also associated with increased energy requirement of the BWA as well as additional costs. As part of the BSTP upgrade, this study examined and recommends a fourth option that transfers the reclaimed water to the Spring Gardens BWRO WTP where it would be used to replenish groundwater used by the existing Spring Gardens BWRO facility to generate potable water to supplement groundwater supplies.

Groundwater recharge and agricultural irrigation are two of many possible reuse water applications that could be considered. Currently commercial facilities, including hotels, are able to treat their own wastewater to a reuse standard suitable for grounds and golf course irrigation, but there are no current legislated reuse water quality standards or building codes and guidelines do not exist to enable these other uses. Suitable legislation pertaining to reuse water quality standards and other non-potable applications (e.g. toilet & urinal flushing, landscape irrigation, dust and fire suppression, and building cooling) should be considered along with appropriate modifications to the building codes for dual plumbing systems.

Capacity building, with respect to operator training and improved operations management, will improve the efficient use of this wastewater infrastructure, which is needed when the system is being stressed by various climate change impacts.

As the release of GHG's are linked to climate change, reducing GHG emissions is an important plant upgrade consideration, as well as country initiative, and include improving energy efficiency as well as implementing renewable bioenergy recovery from wastewater biosolids, when applicable. The economic benefits associated with renewable energy and nutrient recovery were considered and were determined not to be sustainable or economically viable at the BSTP location; however, taking into consideration the benefits of renewable energy with respect to minimizing GHG emissions, a centralize bioenergy recovery facility should be considered.

The need for ground mounted solar to reach carbon neutrality was also considered. For a CAS treatment process system (without RO), it is estimated that an additional 700,000 kWh/year of power is required to offset the additional power required for aeration, mixing and pumping, equivalent to about 100 kW of solar power to reach carbon neutrality.

It is further recommended to replace the diesel back-up power generators with natural gas generators with reduced GHG emissions.

The refined Logic Frame or LogFrame (from the one illustrated in the Conceptual Design Report) is summarized and now consists of the following four central components.

1) **Component 1: Improve the water sector's resilience to climate change by enhancing availability, management and use of tertiary level treated wastewater.**
   - **BSTP Reuse Upgrade**: The existing Bridgetown Conventional Activated Sludge (CAS)Sewage Treatment Plant (BSTP) is upgraded to a 4-Stage Bardenpho tertiary wastewater treatment process to produce a reuse water-quality standard meeting national reclaimed water-quality standards.
   - **Non-Potable Water Reuse Water Applications**: Reverse Osmosis membrane filtration systems are used to reduce the total dissolved solids concentration of the reclaimed water produced at BSTP to meet Ministry of Agriculture requirements, and water not used for irrigation is injected into the ground to augment groundwater resources. Water is supplied for irrigation and groundwater injection purposes through a 9Km pipeline
   - **Decision-Support Tools and Infrastructure**: Establish a monitoring program to identify and address sources of inflow and infiltration to the BSTP sewer including the installation of flow measurement and rain-gauging equipment and investigate identified mechanisms that can reduce or mitigate vulnerabilities in the wastewater collection systems. Establish on-site laboratory facilities and personnel at the BSTP to generate influent and effluent water quality data to inform operations control strategies that optimize operations and reduce energy consumption and GHG emissions. Finally Implement process simulation and Computerized Real-time Management System (CMMS) software at the BSTP to inform decision making and climate resilient building.
   - **Decentralized Treatment Plants and Cluster Treatment Systems**. Construct two small (cluster) decentralized wastewater collection and treatment systems in Zone A locations to produce reuse quality water for domestic/commercial non-potable water applications.
2) **Component 2 – Achieve climate resilient net zero carbon operations at BSTP**
   - **Implement Energy Efficient and Renewable Energy Technologies**: This includes: 1) installing grid-tied Photovoltaic (PV) Renewable Energy Systems to offset increased power consumption associated with the centralized treatment plant process upgrades using Category 3 hurricane resistant solar panels; 2) implementing automated controls and energy efficiency measured within the upgraded centralized treatment processes to reduce the overall energy footprint and reduce GHG emissions; and 3) installing sludge dewatering equipment to improve energy efficiency and reduce the overall GHG and CO2 emissions associated with the biosolids .
3) **Component 3 – Enhance capacity and capability of the BSTP through preventative maintenance (PM) and climate resiliency programmes.**
   - **Improve technical personnel capabilities to operate, maintain and monitor and implement climate change adaptation planning strategies for wastewater**

management: This includes: 1) Develop and provide specialized and customized training to support the operations and maintenance of wastewater collection and treatment facilities including photovoltaic equipment; 2) update Standard Operating Procedures (SOP) and Operational Manual to address the requirements of the upgrades, preventative maintenance, operator safety, and environmental monitoring, including specific risks posed by to climate change and gender and social inclusion considerations adaptation and preventative maintenance; and 3) develop and implement a risk management framework to support the sustainable management of BWA's operations.

- **Establish a Strategic Plan to Guide the Replication of the Spring Garden Brackish Water RO Potable Water Treatment Plant: Efficient and Renewable Energy Technologies**: This includes investigating and developing a strategic plan for the installation of water treatment facilities along the west coast corridor for augmenting water supply and protecting the west coast ecosystem.

4) **Component 4 – Create an enabling environment for wastewater technologies and reuse in the public and private sectors.**

- **Governance and planning roadmaps developed to enable wastewater reuse in the public and private sectors:** Activities include: 1) Undertake a legislative review to promote the Planning and Development Act, Wastewater Reuse Bill and other related legislations for enhancing wastewater effluent quality, treatment options and re-use requirements and applications. The review will also include recommendations for strengthening - private sector engagement, public-private partnerships, building codes, resiliency to climate change and equal opportunities and access to males and females; and 2) develop a water and sanitation master plan that includes an optimal combination of decentralized, cluster and centralized water reclamation and reuse applications, with the centralized reclaimed water being transmitted and used for agricultural irrigation or industrial use (such as lower cost of reclaimed water transmission). This strategy will also take into consideration the social, gender-related and climate risks in the design and prioritizing of water reuse strategies
- **Develop and/or expand Mechanisms to encourage the adoption of wastewater treatment and reuse applications by private individuals and businesses.** Develop a strategy and action plan to engage the private sector in the provision and adoption of wastewater treatment technology and the utilization of wastewater by-products such as activated sludge. This includes conducting an assessment to identify opportunities for public-private partnership in the water and wastewater sector, especially for the expansion of the decentralized onsite cluster wastewater systems. The strategy will also promote gender equality and women empowerment. In addition, carry out a review and identify recommendations for a gender sensitive and socially inclusive incentive programme to encourage conservation, recycle, re-use. Finally, expand the Revolving Adaptation Fund Facility (RAFF) to provide resources for the adoption of decentralized onsite wastewater systems.

- **Implement a Gender Sensitive Public Education and Awareness Campaign:** Re-educate communities, teachers, students, farmers, and businesses about the impact of climate change on water resources and their impact on water quality and quantity (availability as well as the importance of water reuse activities and indirect potable reuse (IPR)) to building climate resilience in the Water Sector. Develop and implement a Gender Sensitive Public Awareness Campaign for community and visitors (tourists) through workshops, videos, community town hall meetings, site tours (demonstration of the plant technology and by-product reuse) and consultations. Emphasis will be placed on assuring the general public about food safety to ensure there is public acceptance and trust in the agriculture produce from local farms using the treated wastewater as well as the improved resilience of the water sector and the direct and indirect benefits on ecosystem services and ecotourism. Share lessons learnt to spur greater public and entrepreneurial involvement. Finally, develop a 3R-CReWS Project Page and social media accounts, which is dedicated to transparent measures of reporting, knowledge products, identify/host a link to the Redress Mechanism and provide update to all stakeholders on the project activities

1 BASELINE SUMMARY

The Government of Barbados, Barbados Water Authority and the Caribbean Community Climate Change Centre have developed a preparation project, funded by the Green Climate Fund, aimed at building climate resilience into the wastewater systems of Barbados. This project addresses challenges facing the wastewater collection and treatment systems and water availability under climate change, including water reuse and bio-energy resource-recovery opportunities as well as financial, environmental, public health and public opinion and perception related to water availability and wastewater management practices on the island.

The overall objectives are to recommend gender-sensitive (as outlined within the Gender Analysis Report) low-carbon climate-resilient wastewater system upgrade options for Barbados to achieve tertiary treated reuse water quality for the centralized BSTP with consideration for wastewater reuse, energy minimization and recovery and reduced GHG emissions in conjunction with a stakeholder engagement plan.

There is significant potential for climate change to impact groundwater resources and potable water availability as a result of changes in weather patterns affecting precipitation; increased air temperatures; increased sea level impacting erosion, coastal inundation and saline intrusion of coastal freshwater aquifers, and changes in seasonal weather patterns (amount and intensity of rainfall and changes in storm intensity)[1]. 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).

Barbados' location along the hurricane belt also makes the country vulnerable to associated storm surge and flooding and 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. Poor surface drainage conditions result in flooding and increased inflow of water to sewers impacting centralized sewage treatment as well as onsite wastewater ground disposal systems that serve the majority of the population.

Potential climate change related events and their associated impacts on wastewater infrastructure, as well as possible mitigation measures that can be taken, are summarized in **Table A**. While rising sea levels storm surges, and rainfall induced flooding are a serious concern, they can be resolved through improved drainage and siting future wastewater treatment infrastructure. While drought has no direct impact on the wastewater management infrastructure wastewater is considered to be a water resource if it is treated to a high-quality tertiary level for reuse purposes including indirect potable reuse, regardless of whether the treatment is centralized or decentralized.

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

Table A. Wastewater Infrastructure Impacts of Climate Change

Climate Change Factor	Potential Impact	Mitigation Measures
Rising Sea-Level	Wastewater treatment plant low-land site flooding with potential plant damage.	Relocate or construct new wastewater treatment plants to higher ground.
	Increases discharge head requirement for marine outfalls	Increase discharge head (achieved by relocating or constructing new plants on higher ground)
Storm Surges	Wastewater treatment plant low-land site flooding	Relocate or construct new wastewater treatment plants to higher ground (such as in the case of the SCSTP).
	Increases discharge head requirement for outfalls	Increased pump discharge head requirements during surge event may be tolerable depending on flows.
Increased Rainfall Intensity and duration	Flooding over sewer manholes resulting in high inflow to sewer.	Improve drainage to prevent flooding in vicinity of sewer manholes and prevent access.
	Increased soil saturation and groundwater infiltration to sewer.	Improve sewer construction joint seals and quality control for construction
Increase in Hurricane Risk	Collection & treatment facility damage, power loss to plant and infrastructure.	Provision of emergency power generators for wastewater lift stations and treatment plants.
Rainfall Reduction	Reduced rainfall could create a negative groundwater balance and the need to conserve water and identify alternative sources of water (e.g. reclaimed wastewater for reuse purposes).	Reclaim and reuse wastewater to supplement non-potable and possibly potable water needs and replenish groundwater.
		Upgrade wastewater treatment effluent to a high-quality tertiary standard suitable for urban and agricultural reuse applications, and groundwater recharge
		Develop and pass legislation to enable dual-plumbing and appropriate water reuse systems and applications.

1.1 Water Supply and Demand

1.1.1 Water Supply

Barbados is classified as being in the top 15 of the world's most water scarce countries (as reported by PAHO, 2012), not directly 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. Approximately 85% of the potable water supply comes from groundwater aquifers which, in turn relies on rainfall infiltration as a source of water. The BWA has reported drastic decreases in groundwater levels at the majority of the country's wells and potable water production has been reduced by as much as 3 million gallons per day during some of the severe droughts that have been experienced. 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.

1.1.2 Water Demand

Approximately 57 Mm^3/y is extracted from groundwater resources for domestic potable water distribution and an estimated 11 Mm^3/y is extracted for agricultural irrigation. The exact amount of water extracted by agriculture is much higher as most points of extraction are from un-metered private wells.

1.2 Wastewater Management

1.2.1 Centralized versus Decentralized

Only 10 to15 percent of the urban population is connected to the BSTP and the SCSTP sewage collection systems along the south coast of Barbados, with the majority of the population being served by onsite wastewater disposal systems to ground. Hotels and other tourist accommodations along the west coast are required to have their own decentralized wastewater treatment facilities – generally consisting of private-sector third-party operated package treatment plants which discharge the liquid effluent into coastal wells or reuse the treated water for onsite irrigation purposes. As of 2018, there were sixty-eight (68) private wastewater treatment plants of which eighteen (18) used the treated wastewater for reuse applications (Barbados Department of the Environment, 2018).

The wide use of decentralized onsite wastewater disposal systems is believed to have a significant impact on groundwater quality both within inland areas as well as along the coast, impacting the near-shore marine environment. The combination of onsite wastewater disposal and agriculture practices is responsible for elevated levels of nitrates in certain production wells. Of particular concern are groundwater resources in Zone A areas where potable water is extracted.

1.2.2 Roofs to Reefs Programme

The Barbados Government Roofs to Reefs Programme, which includes this 3R CReWS project, (as outlined within the Baseline Study) plans to replace residential septic tanks, and soak away fields, with a package wastewater treatment plant to reduce the amount of nitrate in groundwater. It would also promote the implementation of rainwater harvesting and improved stormwater collection, resource recovery and renewable energy. Currently under development, 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.

1.3 Wastewater Governance and the Policy Framework

1.3.1 Wastewater Management

The BSTP and the SCSTP collection, treatment and effluent disposal infrastructure are managed and operated by the BWA. 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 the appropriate authority before construction can begin.

1.3.2 Wastewater Guidelines and Policies

Although the BWA is tasked with the primary responsibility to manage wastewater in Barbados, other authorities involved include the EPD, the MoH and the PDD. The PDD's activities promote the reduction of coastal pollution.

Water resource protection in Barbados is enforced by implementing the "*Revised Policy of Private Sewerage and Wastewater Disposal Systems*." The BWA, EPD and PDD hold the primary responsibility for its enforcement. The policy seeks to control any development or liquid waste disposal system that could be injurious to the national water resources. The monitoring of groundwater quality is primarily administered by the EPD.

The Groundwater Protection Zoning Policy establishes a system of five zones to guard against bacteriological contamination of the public water supply wells. In 2020, a Government Green Paper "Water Protection and Land Use Zoning Policy" (MEWR, 2020) set out proposals for changes in the Zoning considering the emerging threats, proposing changes to the zoning and requirements for treatment of wastewaters. Zones A and B 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 A areas, which are located immediately around all existing and potential public water supply sites. 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). The Zones A – E have been incorporated into the National Physical Development Plan, although they have no legal status as yet. The Green Paper proposed that coastal areas now be designed as Zone D – Recharge Contributing Area where wastewater disposal regulations will apply.

The Barbados EPD has several requirements for tertiary wastewater treatment systems, as outlined in their latest version published in October of 2015. The EPD effluent guidelines for reuse/irrigation are summarized in **Table B**.

Table B. EPD Treated Wastewater Effluent Requirements for Reuse/Irrigation (1)

Parameter	Units	Recommended Effluent Quality	Comments
BOD	mg/L	< 10	< 30 if used for non-potable aquifer injection
TSS	mg/L	< 10	< 30 if used for non-potable aquifer injection
Volatile Solids	mg/L	< 10	Not included for non-potable aquifer injection.
Total Nitrogen	mg-N/L	$\leq$ 5	
Faecal Coliforms	CFU/100mL	<1	None-detect for non-potable aquifer injection
Total Coliforms	CFU/100mL	<1	
Faecal Strepi	CFU/100mL	<1	
Residual Chlorine	ppm	$\geq$ 0.5	(range 0.2 to 1.5)
pH	-	6– 8	6.5 – 8.5 for non-potable aquifer injection.

Note: (1) From Table 7 of EPD. 2015. Guidelines for the Submission of Building Development Applications.)

1.4 Wastewater Characteristics

1.4.1 BSTP Wastewater Characteristics

As noted in the Baseline Study, there is no wastewater flow or influent/effluent water quality data available for the BSTP so it was necessary to estimate wastewater flows based on metered water consumption records reported by the BWA as an estimate of average dry weather flow. The 2019 water production records show the total residential water consumption that year was about 32 Mm^3, which is an average of about 87,600 m^3/day. Dividing this value by the total resident population in Barbados in 2019 of 287,000 people results in an average water consumption of 210 L/d per person. BWA estimates 5 percent of the properties in Bridgetown are connected to sewer, indicating a population contribution of 5,600 which based on a residential water consumption of 210 L/d per person would generate about 1,200 m^3/d. This is significantly lower than the flow operations staff indicate is received by the plant, who indicated wastewater flows approach the plant capacity at times. Recognizing there are also commercial sources of wastewater, it was decided to use a nominal flow of 9,000 m^3/d to assess upgrading costs.

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

The BWA provided weekly flow statistics for the SCSTP in the form of minimum, average, and maximum flows for each week, with the highest wastewater flows of about 8,500 m^3/day during the month of January and a low of about 1,750 m^3/day in the month of October. The high wastewater flows in January are likely due to "tourist-related" 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) and bed & breakfast private accommodations, as well as commercial or industrial operations (e.g. distilleries or wine) that may have a coinciding or tourist-basis peak in their activities that generate wastewater.

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

Table C. Estimated Wastewater Contribution Characteristics

Parameter	2020	Notes
Population Connected to Sewer	5,600	5% Connected to Sewer
Flow		
Population Contribution (m^3/d)	1,400	Based on 270 L/person
Design Flow (m^3/d) (1)	9,000	Using 6:1 (1) seasonal range between ADWF and Max Flow
Average Load		
Total BOD_5 (kg/day)	2,160	Corresponds to 240 mg/L
TSS (kg/day)	2,880	Corresponds to 320 mg/L
VSS (kg/day)	2,600	Assume 90% volatile solids
Total Ammonia (kg-N/day)	450	Design Flow x 50 mg-N/L
Total-Phosphorus (kg-P/day)	45	Design Flow x 5 mg-P/L
Screenings (m^3/day) and (kg/day)	0.5 / 350	Based on literature data
Grit (m^3/day) and (kg/day)	1.0 / 1,600	Based on literature data

NOTES: *(1) No flow records were available for BSTP; however, SCSTP for 2019 shows January flows that are about 6 times of Octobers' flows. Theoretical design average flow capacity (BSTP O&M Manual) is 2.4 MGD (9,100 m^3/d)*

1.5 Bridgetown Sewage Treatment Plant

1.5.1 General

The BSTP is located in Lakes Folly, St. Michael, and was commissioned in August of 1982. The BSTP plant O&M manual (1982) indicates that the facility was designed with a theoretical average flow capacity of 2.4 MGD (9,000 m^3/d) and a peak flow 9.6 MGD (36.3 MLD). However, information gathered to date suggests that the plant receives much less flow and serves less than 5 percent of the potential connections in the area, corresponding to a population contribution of about than 5,600 people (low flow during the fall of about 1,400 m^3/d), as indicated in **Table C**.

Although the BSTP was intended to only treat domestic wastewater, the collection system serves many of the commercial businesses in Bridgetown.

The treatment process is based on a contact stabilization secondary treatment process configuration, which is a modification of the conventional activated sludge treatment process that uses two separate aeration tanks. 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. The treatment system was originally constructed with a chlorination disinfection system; however, the chlorination unit stopped working and has not since been replaced.

Excess bacteria produced is periodically extracted and stabilized through aerobic digestion prior to being transported to land-spreading or anaerobic treatment or dewatered and transported for disposal at another site. The BSTP process consists of the two aerated reactors with an aerated sludge digestion tank oriented about the clarifier tank that serves each module.

Figure A 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 BSTP and the SCSTP. The BSTP 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.

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 recently obtained some flow measurement data for BSTP with flows in October 2021 reported to be in the order of 3,400 m^3/d, which is well below the original average flow design capacity stated in the O&M manual of 9,000 m^3/d and much greater than would be indicated based on the number of properties served by the existing collection system.

The BWA recently purchased a new Huber course mechanical screening system to remove rags and other debris. The screened wastewater is pumped and split into two streams, with each stream directed to one of two secondary treatment modules. Each module consists of three aerated concrete tanks consisting of a contact chamber, a stabilization chamber, and a sludge digester surrounding a central circular concrete secondary clarifier.

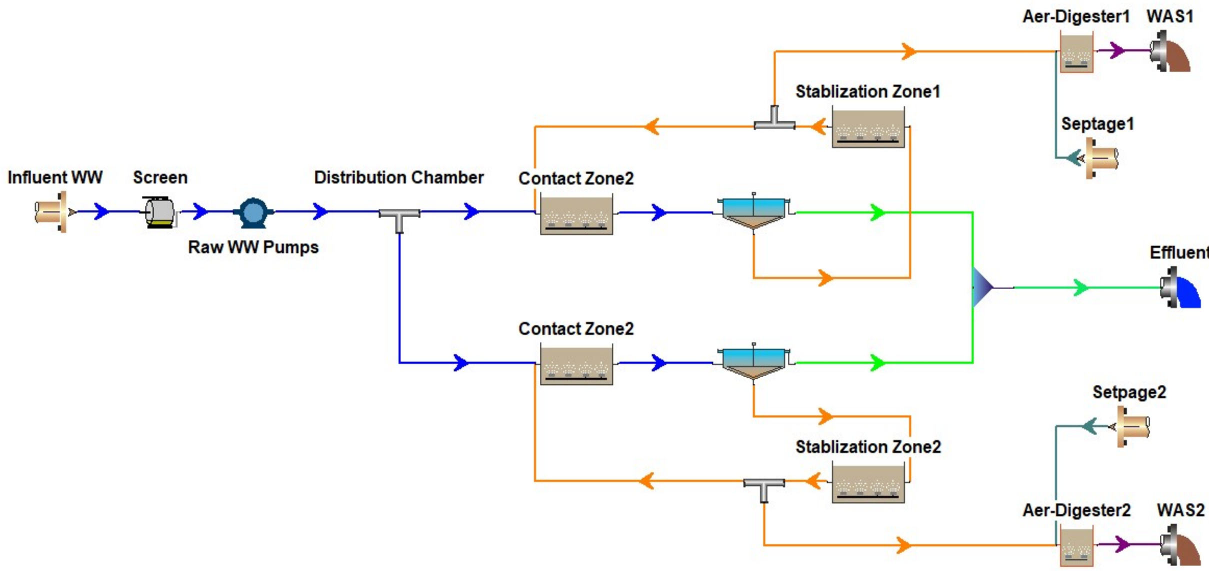


Figure A. Biowin Model Diagram of the BSTP Process

Figure B. Bridgetown Wastewater Treatment Plant

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 digester tank aeration 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 "waste" biomass from the process stabilization chamber or may elect to pump out 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. The grit in the septage is first removed from the septage before the septage is pumped into the digester tanks. The BSTP 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).

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 land that the sludge is rotavated into, is owned by the GoB but it is unclear if this land is also used for agriculture purposes.

A preliminary geotechnical investigation was conducted at the BSTP site, and provided in the Appendix, to illustrate any potential foundation design requirements related to the expansion of the site.

1.5.2 Key Design Parameters for the Existing BSTP

According to the O&M Manual (1982), some key design BSTP parameters are:

- Design Capacity: 2.4 MGD (9,000 m^3/d) Average Flow
- Peak Flow Capacity: 9.6 MGD (36,000 m^3/d) Peak Flow
- Design Septage Quantity: 500 gpd (19 m^3/day) (expected 1,140 m^3/d)
- 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%

1.5.3 Aeration Blowers

The BWA recently purchased and installed four positive displacement aeration blowers 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

1.5.4 Biosolids Production, Handling and Disposal

The current biosolids handling and disposal practice at BSTP is to truck aerobically digested sludge directly from the two aerobic 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.

1.5.5 Energy Efficiency

The aerobic digesters in the plant are energy intensive and require 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.

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 1.5.4.

1.5.6 Wastewater Treatment Power Consumption

In the absence of flow records, wastewater power consumption records can be used to estimate variations in flow as well as being a basis for determining the renewable energy required to achieve a net-zero condition.

Utility bills from Barbados Light and Power provided by BWA for the BSTP are presented in **Figure C** and illustrate the variation in power consumption over the past four years, averaging about 4,500 kWh per day (US$470,000 per year). The wide variations and discrepant power consumption data underscores the need to gather more data prior to committing to an upgrade path and detailed design.

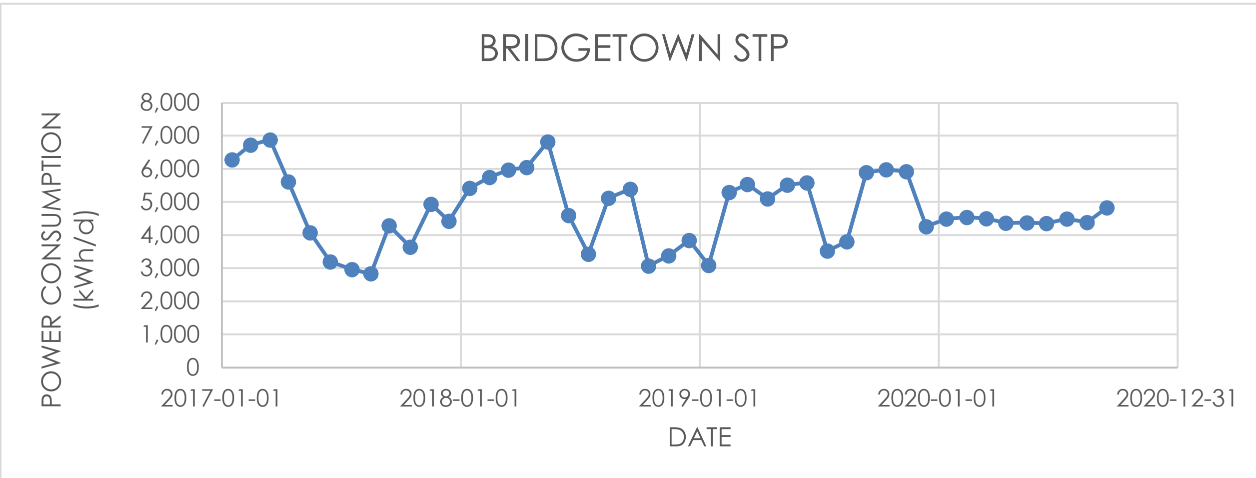


Figure C. Bridgetown Sewage Treatment Plant Power Consumption for 2017 - 2020

1.5.7 Storm Surges and Rising Sea Level

The increase in the number and magnitude of climate change influenced storm events, including hurricanes, that result in storm surges and rising sea levels has and will impact the ability to discharge wastewater through the marine outfalls as well as result in saltwater entry into the wastewater collection system. This, in turn, impact hydraulic capacity and the ability to treat salt contaminated wastewater biologically (i.e impacting the ability to treat and effluent quality). It could also impact the quality of reuse water that is intended for plant irrigation with respect to elevated sodium and chloride content. Storm surges, rising sea levels, and precipitation events that have a higher intensity or longer duration caused by climate change could also result in flooding conditions affecting the BSTP site location. This risk, along with risk management measure, was included in **Appendix 2** within the Conceptual Design report.

1.6 Bridgetown Sewage Collection System

1.6.1 General Conditions

The Bridgetown wastewater collection, and treatment system is illustrated in **Figure D** and is currently estimated to serve about 2,000 properties within the collection catchment area, representing less than 5 percent of the properties and population in Bridgetown.

1.7 Sewer Surface Flooding

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

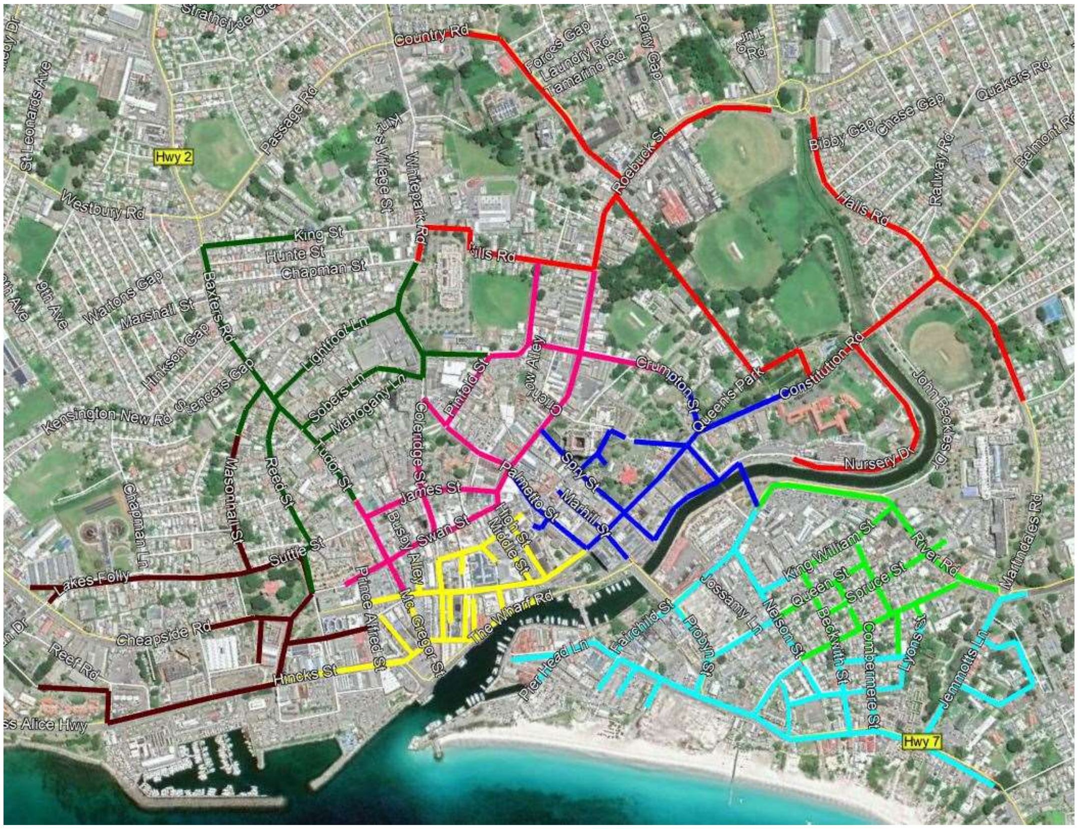


Figure D. Existing Bridgetown Wastewater Collection System

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

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

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

1.7.1 Hydraulic Capacity

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

1.7.2 SCADA

All the lift stations were equipped with a SCADA system; however, none were reported by the BWA to be functioning properly due to programming issues. It appears that the SCADA system needs to be re-programmed to properly operate again. The Operators will need training to be able to maintain the SCADA system as well as how to analyse and use the data to improve process performance and improve overall O&M conditions.

1.8 Environmental and Social Considerations

A full Environmental and Social Impact Assessment report is being completed by others and available for review.

1.8.1 Potential Environmental Impacts

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 water resources. The tertiary treatment of wastewater will allow for the treated water to be reused for non-potable sources including agricultural irrigation and groundwater injection.

The proposed treatment process upgrade also aims to achieve a net zero energy consumption which would reduce the overall carbon footprint. Considerations for harnessing of energy from the primary solids and waste secondary biomass is also incorporated into this project.

To achieve the upgrades to the BSTP there will be on-site construction and an anticipated increased facility footprint. Construction activities have potential to add to GHG's (truck exhaust etc.).

1.8.2 Water Availability and Water Quality

The proposed project can alleviate stress on the potable water supply by providing an additional source of water suitable for use in non-potable applications including agricultural irrigation and groundwater recharge.

1.8.3 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 will support agriculture by providing a supplemented water source from treated wastewater and will enable agriculture to be more resilient to the impacts of climate change.

1.8.4 Biosolids Use

Treated biosolids can be used as a supplemental nutrient source providing carbon, nitrogen, and phosphorus for use in landscaping, turf maintenance, land reclamation, erosion control and dump covering. This can return nutrients to the soil and, may offset some commercial fertilizer use.

Untreated biosolids can contain pathogenic microorganisms as well as residual toxic organic and inorganic constituents that potentially impact beneficial use for agriculture. Conventional practice is to select a digestion technology with an elevated thermophilic operating temperature above 55 degrees Celsius to kill pathogens and analyse the biosolids to prove there are no toxic contaminants present and all chemical parameters are within accepted international standards. As the BSTP does not have heavy industry and manufacturing within the collection system, it is unlikely the organic and inorganic toxic chemical, pharmaceuticals, and EDC components will be of concern – however, the destruction and removal of pathogens is likely to be a factor. This could be addressed by operating the anaerobic digesters in a thermophilic mode to kill off pathogens. This would be a design decision for the bioenergy facility and regulators.

1.8.5 General Public Perception and Awareness

Wastewater reuse options include irrigation of golf courses and high amenity crops and groundwater recharge. For almost two decades there has been public acceptance of the treatment of brackish water that includes contributions from onsite wastewater disposal to groundwater at the Spring Garden BWRO plant, although the public may not be aware of the poor groundwater quality at this location. Negative social perceptions associated with the reuse of treated wastewater may be alleviated with education, stakeholder engagement, and the public dissemination of quality control procedures and results that include analytical testing of treated wastewater prior to reuse, to demonstrate the quality of the reclaimed water to the public and health officials. The potential negative social perception of sludge and wastewater reuse for agriculture purposes should also be addressed through public and stakeholder education.

1.8.6 Population, Health and Safety

This project has the potential to impact the local and tourist population of Barbados with respect to improve water availability and food availability through agricultural irrigation.

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.

Temporary disturbances during construction activities are expected to be related to traffic, noise, dust, vibration, and visual impacts. These disruptions should be considered in project planning and stakeholder communications.

1.9 Operation and Maintenance Considerations

1.9.1 Current Operations Support

To support the maintenance program for an upgraded treatment facility, staff must be trained on the maintenance aspects of all new equipment preferably prior to the commencement of use of the equipment. Operations 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 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 BSTP is required and considered a critical need. This is particularly needed so that the influent volumes to the BSTP 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.

1.10 Economic and Sustainability Considerations

1.10.1 Financial Impacts

Barbados is still recovering from economic hardships related to the reduction in tourism from 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 developments related to this 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 and can directly and indirectly lead to greater employment.

1.10.2 Food Production

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. Greater water availability, for irrigation purposes, should also lead to improved food security.

2 OPTIONS ASSESSMENT

2.1 Wastewater as a Resource

2.1.1 Resource Recovery Potential

That water drained away from a beneficial application is often referred to as wastewater. While this term may be appropriate when this drainage is wasted away to the environment, it does contain a range of valuable resources that, under certain circumstances, can be recovered as illustrated in **Figure E**. Of the indicated resources, the most common that can be recovered from wastewater are water, energy and nutrients.

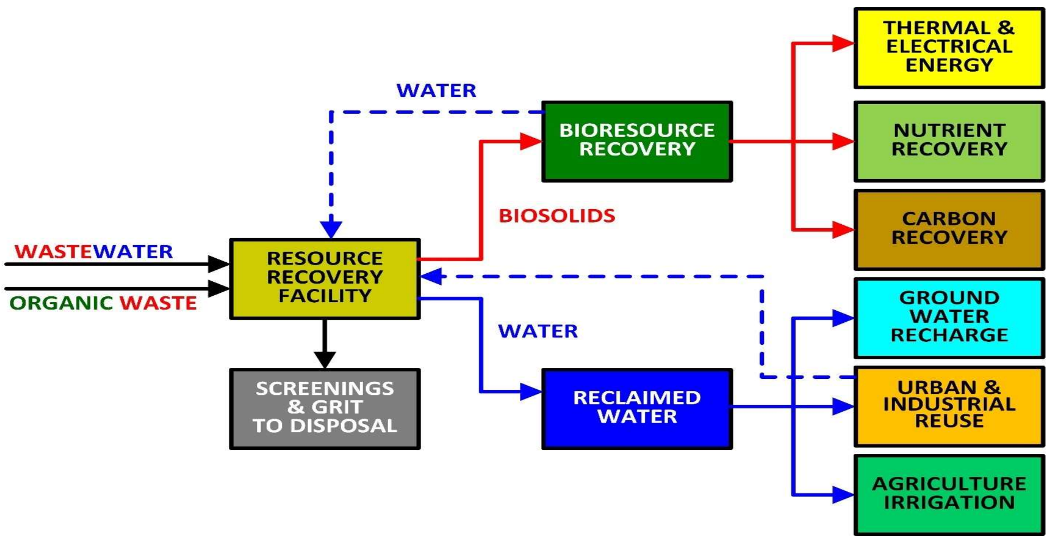


Figure E. Wastewater Resource Recovery Examples

2.1.2 Water Resource

Wastewater is more than 99.8 percent pure water; water that has significant value in areas of the world impacted by climate change and drought. Wastewater can be treated to a reuse water quality standard suitable for a wide range of water applications that have a high probability of human contact and public exposure. For example, approximately 25 to 30 percent of all domestic residential indoor water consumption is used to flush toilets; water that does not have to be potable (drinking water quality). Reclaimed water can be used to offset potable water demands at a significantly lower cost than the energy consumption associated with producing water through desalination.

In addition to being used to offset potable water demands, reclaimed water can be used as an indirect means of producing potable water. Most communities practice indirect potable reuse as the streams, lakes, rivers, and aquifers that serve as potable water resources are also used to dispose treated effluent, and wastewater that is dispersed to the ground becomes a groundwater resource. The BWRO facility in Spring Garden extracts non-potable brackish water from the ground, water that includes contributions from onsite wastewater disposal systems in the area and uses Reverse Osmosis (RO) filtration to produce drinking water.

2.1.3 Nutrient Resource

The organic matter in wastewater consists largely of carbon, nitrogen, and phosphorus, which are essential elements for biological growth. When organic matter decays or is digested, the nitrogen is typically released in the form of ammonia along with phosphorus. Biological nutrient removal processes are able to concentrate and release dissolved phosphorus that under certain conditions can be captured along with ammonia in a crystal form along with magnesium and calcium which has value as a fertilizer. However, even without producing a fertilizer by-product, applying the biosolids from a treatment plant to land inherently is a means of recycling and recovering the nitrogen and phosphorus that is bound in the biomass and will be released to the soil as the biomass degrades.

2.1.4 Energy Resource

Water and energy are inter-related, with energy production requiring large volumes of water, and water infrastructure requiring large amounts of energy. Similarly, energy is required to treat and purify wastewater, but the wastewater also contains a great deal of energy associated with the hydraulic characteristics, the thermal characteristics, and the organic matter in the wastewater. Wastewater often requires pumping and energy input to be conveyed to a wastewater treatment facility, but where it flows by gravity from higher elevations it can also be used to produce energy. Wastewater also contains a great deal of thermal energy and technologies have been developed to extract the excess heat, particularly in laundry and commercial/institutional dishwashing applications where the drainage to sewer has extremely high temperatures. While a great deal of energy input is required to aerobically digest and remove dissolved and particulate organic matter in wastewater, the organic solids and the bacteria that grows on the dissolved organic matter can be converted by anaerobic bacteria to methane which can be combusted as a fuel or even converted to electricity using fuel cell technology.

2.2 Reclaimed Water

2.2.1 Potential Wastewater Reuse Applications

Reclaimed wastewater that is treated to meet high quality reuse standards is internationally considered to be acceptable for satisfying a wide range of non-potable water uses including toilet and urinal flushing, landscape and agricultural irrigation, groundwater and surface water augmentation, vehicle and surface washing, and fire suppression. The challenge affecting reuse is the cost to distribute the reuse water to application locations, particularly if those locations are widely distributed in and about urban buildings. To minimize the cost of distribution it is often convenient to limit the reuse application to a few large-scale non-potable water uses, such as agricultural irrigation and groundwater augmentation.

Table D presents a high-level description of the water reuse categories proposed for Barbados.

Table D. Proposed Water Reuse Applications for Barbados

Water Reuse Category	Description
Agricultural Reuse	The use of reclaimed water to irrigate crops that are either processed before human consumption or not consumed by humans.
Groundwater Recharge	The use of reclaimed water to recharge groundwater aquifers that are not used as a potable water source.
Indirect Potable Reuse	Augmentation of groundwater resources with reclaimed water with an environmental buffer preceding groundwater extraction and treatment for potable water use.

2.2.2 Agricultural Water Reuse

The most significant water demand in Barbados that could directly benefit from the availability of an additional non-potable water resource through water reuse is agriculture. Agricultural irrigation is the single largest non-residential water consumption application in Barbados. However, potable water is not required for irrigation and many countries use reclaimed wastewater to satisfy agricultural water demands, particularly for non-food crops. While crops can benefit from the phosphorus and nitrogen content, and irrigation with reuse water reduces the demands on fresh water sources, it also results in greater crop production reliability due to more constant yields.

To be considered for food-crop irrigation the reclaimed wastewater needs to be highly treated, and food crop irrigation with reuse water is currently not permitted in Barbados due to current EPD guidelines. The Barbados Ministry of Agriculture and Food Security has determined that in addition to conventional reclaimed wastewater water quality considerations that a requirement for total dissolved solids of less than 450 mg/L also be met for all agriculture areas being irrigated with reuse water. As the TDS concentration of domestic wastewater is generally greater than 1000 mg/L, this means that all reuse water intended for agricultural irrigation application will need to be treated with reverse osmosis membrane filtration. This will effectively reduce the volume of reuse water available to supplement groundwater resources as RO works by separating the dissolved solids (salts) into a brine stream that will require disposal – likely to the ocean. The brine stream represents from 25 to 40 percent of the reuse water being filtered, reducing the amount of reuse water available for irrigation by that amount.

Dissolved salts present in wastewater have the potential to affect the structure and ability of the upper soil layer to retain water and can have negative environmental impact on crops by increasing the soil water pressure and energy requirements for plants to take up water from the soil. Where seasonal rainfall is insufficient to flush any salts of concern from the soil, salt accumulation can also be addressed by periodic irrigation with potable (fresh) water.

2.2.3 Groundwater Augmentation and Indirect Potable Reuse

As an alternative to agricultural irrigation, the reuse water could be directly injected into the ground for the purpose of either groundwater augmentation, where the groundwater in the area is used to satisfy water demands that do not require potable water, or it could be used to recharge aquifers in areas where groundwater is extracted for potable water use, referred to as Indirect Potable Reuse. While this is commonly practiced in various parts of the world, with groundwater subsequently extracted for potable water use without further treatment, the extracted water could also be treated prior to distribution for potable use. This is essentially the situation regarding the Brackish Water Reverse Osmosis potable water production facility located in Spring Garden, near the BSTP facility. The groundwater that is being extracted and treated by the BWRO reverse osmosis facility is impacted by onsite wastewater disposal discharges to ground in the area. The wastewater discharged from the onsite disposal systems is untreated; however, the passage of the water through the soil results in a high degree of treatment that with sufficient distance is superior to that achieved by a centralized wastewater treatment plant.

Another means of IPR that could be considered is to augment groundwater resources within the vicinity of an aquifer that is used as a potable water supply. As previously noted, the BWRO treatment facility located in Spring Garden extracts groundwater from an aquifer that receives water from onsite wastewater discharges. Augmenting the groundwater available at the BWRO in Spring Garden would increase the capacity of that facility to produce potable water without having to further treat the reuse water with RO prior to injection to the aquifer.

2.2.4 Urban Reuse Applications

An urban water reuse strategy could be developed for an optimal combination of decentralized, cluster and centralized water reclamation and reuse applications, with the centralized reclaimed water being transmitted and used for agricultural irrigation or industrial use (such as lower cost of reclaimed water transmission). This would require changes to legislation and regulations regarding the acceptable use and distribution of non-potable water, in addition to changes to plumbing and building codes.

A major challenge in considering urban reuse applications is the cost of distributing the reclaimed water into the community. However, applying water reuse in a decentralized manner greatly alleviates this cost if the reuse water is used at the location it is generated at. This is currently implemented in a number of locations in Barbados including hotels that use the reuse water for grounds and golf course irrigation and should be encouraged as a sustainable means of wastewater management in a drought impacted country.

As an alternative to both centralized and decentralized reuse strategies, the Barbados government is currently considering constructing smaller cluster sewage collection systems within sensitive groundwater extraction zones (Zone A) where there is evidence the current onsite wastewater disposal practices is or may be affecting groundwater quality. This is a lower cost strategy that focuses financial resources for wastewater management on areas with the greatest potential to impact groundwater resources and be impacted by climate change either due to the need for additional water resources due to drought or address the reduce effectiveness of onsite wastewater disposal system to protect groundwater quality under conditions of high rainfall that results in saturated soils.

2.3 Nutrient Recovery

2.3.1 Phosphorus and Nitrogen Resource Recovery

Wastewater represents a source of both nitrogen and phosphorus nutrients, and the discharge of wastewater to the ground through onsite wastewater disposal systems is a significant contributor of nitrate concentrations and through the diffusion of groundwater to the ocean, a source of nitrogen loading to coastal areas.

Depending on the volume of wastewater treated and the type of wastewater treatment process implemented it is possible to recover significant amounts of nitrogen and phosphorus from the wastewater as a fertilizer by-product. However, for this to produce a significant quantity of fertilizer, generally in the form of struvite crystals (magnesium ammonium phosphate) a process that can biologically remove phosphorus is required. Such processes are characteristically more complex, require greater operator skills and have a greater capital and operating cost than chemically precipitating phosphorus. Further, the ability to create an ammonia and phosphorus concentration sufficiently high enough to form a fertilizer also requires anaerobic digestion, further adding to the treatment costs.

Although the recovery of nutrients from wastewater in the form of a fertilizer by-product is inherently not cost effective at the BSTP scale of treatment, the nutrient value of the wastewater can still be realized and recovered through the land application of stabilized biosolids.

2.3.2 Phosphorus and Nitrogen Removal

While nitrogen and phosphorus recovery as a fertilizer by-product may not be cost effective or a practical consideration. As previously noted, based on a wastewater flow of 9,000 m3/d and a typical total phosphorus content of 5 mg-P/L, the total amount of phosphorus present in the wastewater is in the order of 45 kg-P/d which is equivalent to 350 kg/d of struvite. Taking into consideration that only about 40 percent of the total phosphorus present can be recovered, the actually amount of struvite that could be produced is only 140 kg/d. With a commercial value of about US$1,200 per tonne, the recoverable struvite would have an agricultural value of about US $168 per day. That value does not justify the millions of dollars of extra cost required to design, build and operate a biological nutrient removal facility at this scale.

The Barbados government water quality standards for reduce nitrogen and phosphorus still must be met and it is important the wastewater treatment process be able to effectively remove both to meet regulatory requirements. As noted, phosphorus is present in the organic solids and in dissolved form and can be removed either biologically or through chemical precipitation. Considering the higher costs of biological phosphorus treatment processes, chemical phosphorus precipitation is proposed for the BSTP upgrade.

Ammonia is the predominant form of nitrogen in wastewater and is removed with biological treatment processes involving at least two different bioreactor zones along with high-rate recirculation systems within the treatment process.

2.3.3 Biological Nitrogen Removal

Biological nitrogen removal is achieved using a treatment process that first oxidized ammonia to nitrate and then typically recirculates the nitrate for the purpose of denitrification to convert the nitrate to nitrogen gas within a second environmental zone. This increases the complexity and cost of biological treatment which is predominantly focussed on carbon removal and ammonia oxidation only. However, denitrification is an essential element of the treatment process to achieve the maximum total nitrogen requirement of 5 mg-N/L set by the Barbados government.

There are several biological nutrient removal process configurations that were considered during the conceptual design stage to upgrade the BSTP to achieve nitrogen removal. These included:

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

Although the exact configurations of each system differ, to remove total nitrogen, the treatment process configurations all have an aerobic environment for nitrification and an anoxic environment for denitrification and, depending on the process configuration, some biological phosphorus removal may also be realized.

2.3.4 Upgrading the BSTP for Biological Nitrogen Removal

Retrofitting the BSTP to remove nitrogen would involve re-purposing the existing wastewater treatment components to have different treatment functions, modifying the aeration and mixing conditions and adding a few additional components including disinfection equipment; however, the basic activated sludge process would remain the same which would be advantageous with respect to being able to utilize the existing operator skills and training.

Typically, the existing aeration basin size and overall process configuration dictates which BNR configurations are the most economical and feasible for a retrofit application, and the existing activated sludge treatment capacity and tank volumes represent a significant portion of that needed to convert the process for nitrogen removal.

2.4 Energy Recovery

2.4.1 Wastewater Energy Content

Opportunities for renewable energy are important considerations for Barbados in the quest for net zero emissions by 2030. As noted, wastewater contains a significant amount of biodegradable organic matter in both volatile solids and dissolved forms that have specific caloric (energy) values that can be recovered through biological treatment, by converting the dissolved organic matter into bacteria (biosolids) that can be anaerobically digested as a renewable energy resource, converting the volatile organic content into methane gas. Depending on the energy demands on or near the site of the wastewater treatment plant, the methane produced could be combusted to recover thermal heat, or it can be converted to electricity through various means including thermal combustion (stream to drive turbines), gas turbines or fuel cells.

2.4.2 Aerobic Versus Anaerobic Biosolids Treatment

The current practice is to apply (consume) energy to aerobically stabilize the biosolids that produced during treatment in order to minimize the mass that has to be transported and disposed of to land at an off-site location. The process of aerobic biological treatment requires both significant energy input and reduces the net energy content of the wastewater due to bacterial respiration, and endogenous decay, The longer the bacteria that are produced through the consumption of soluble organic waste are held in the treatment process, the greater the degree of endogenous decay (bacteria consuming bacteria) and the lower the net energy content available for anaerobic digestion energy recovery. The existing BSTP process configuration has been designed to retain the biosolids produced for a long time in order to reduce the quantity of biomass that requires off-site disposal and minimize the associated costs for disposal. Accordingly, if the objective were shifted to energy recovery, the process configuration at BSTP would need to be changed to one with a lower solids' retention time.

The alternative would be to minimize the amount of energy applied to stabilize and reduce the quantity of sludge and, instead, use anaerobic technology to recover the energy contained in the waste biomass in the form of methane. Greatly offsetting this potential for energy recovery is the fact the capital cost for anaerobic sludge digestion is significantly greater than for aerobic sludge digestion due to the slower metabolisms and growth of anaerobic bacteria, requiring larger bioreactor tank sizes and greater energy costs over a longer period of time for mixing.

2.4.3 Scale of Operation and Economics

Alternatively, instead of anaerobically digesting waste biosolids at the BSTP, the waste biosolids can be transported off-site to a location to be combined with other biosolids and solid organic waste streams and the caloric energy recovered through anaerobic digestion at that location through co-digestion of the wastewater biosolids with other organic biodegradable feedstocks, such as FOG waste from restaurants and waste food. Centralizing bioenergy recovery will improve the economics both from operating at a larger scale, particularly if other sources of organic waste can be obtained to increase the energy yields and locating the facility where the energy recovered has the highest value.

2.4.4 Combined Heat and Power Considerations

The costs of bioenergy recovery also extend to the need to treat the biogas. CHP facility operations require regular maintenance and high gas quality. In addition to drying the gas, the gas must be de-sulphurised so that the sulphur content is maintained at less than 5 ppm, and ideally less than 1 ppm.

Heat management and recovery is also an important economic consideration. The heat generated in the CHP is used to maintain the operating temperature in the anaerobic digestion system. Heat surpluses can be recovered and used to produce hot water for process.

Consideration can also be given to replacing conventional electricity-based air-conditioning systems with adsorptive air-conditioning systems.

The electricity generated by the CHP process can then be fed into the power grid or used in the sewage treatment plant itself and converting organic waste and wastewater biosolids into electricity can contribute to reducing the GHG effect in Barbados.

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

2.4.5 Modes of Anaerobic Digestion

There are various modes of anaerobic digestion that can be considered including the operating temperature range (mesophilic, thermophilic), whether it is single or multi-stage, batch, or continuous feed, mixed or fixed bed or hybrid combinations thereof. The selection of the most appropriate anaerobic digestion process depends to a great deal on the characteristics of the feed and the primary objective of digestion which could be, for example, to destroy pathogenic microorganisms and minimize the mass of digested waste biosolids that require disposal, or it could be to maximize energy yield and effect a reduction in GHG emissions.

2.4.6 Impact of Process Configuration on Bioenergy Recovery Potential at the BSTP

One of the challenges in selecting the most appropriate configuration is that a process designed to reduce total nitrogen characteristically requires the bacteria grown to be retained for a long period of time to enable slower growing nitrification and denitrification bacteria to develop, with the long retention time being counterproductive to optimizing energy recovery.

The BSTP is currently a conventional secondary treatment activated sludge process (providing secondary treatment) that incorporates contact stabilization as a simple and effective means of converting soluble organic matter into biomass, and then stabilizing and reducing the biomass to minimize disposal costs, requiring considerable amount of energy and GHG emissions associated with producing the electricity required by the treatment process. The conceptual design considered alternative process configurations that could achieve the nitrogen reduction levels required by regulation while maintaining the capability for bioenergy recovery by replacing aerobic sludge digestion with anaerobic sludge digestion and installing additional PV panels to offset the electricity increases due to the upgrade.

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

2.4.7 Electricity Production Potential

Limited available data provides a very rough estimate of how much electricity could be generated. Using assumptions based on international experience (as illustrated in **Table E**) provides some high-level estimates based on recovering 50 percent of the energy present in the volatile fraction of the waste biomass generated by conventional activated sludge wastewater treatment at the BSTP and SCSTP facilities.

Table E. Assumed Wastewater Characteristics for Bioenergy Production

	Parameter	Value	Units
A	2019 Barbados Population (1)	287,000	PE
B	2019 Bridgetown Population (1)	112,000	PE
C	2019 Residential Metered Water Consumption (2)	60,400	m^3/d
D	2019 Non-Residential Water Consumption (2)	27,200	m^3/d
E	Ratio Non-Residential/Residential Water Consumption (D / C)	0.45	
F	Estimated Per Capita Residential Wastewater (C / A) (3)	0.210	$m^3/d.PE$
G	Estimated Barbados Population Connected to Sewer (0.12 x A))	34,440	PE
H	Population connected to BSTP (0.05 x B)	5,600	PE
I	Population connected to SCSTP (G – H)	28,840	PE
J	Estimated Bridgetown ADWF (H x F) x (1 + E)	2,000	m^3/d
K	Estimated South Coast ADWF (I x F) x (1 + E)	9,000	m^3/d
L	Biochemical Oxygen Demand (BOD) (4)	232	g/m^3
M	Chemical Oxygen Demand (COD) (4)	655	g/m^3
N	Estimated TOC (L x 1.6)	370	g/m^3
O	Estimated Total Settleable Solids (2)	260	g/m^3
P	Estimate Total Volatile Settleable Solids (O x 0.80)	210	g/m^3
Q	Total Nitrogen (TN) (3)	60	g/m^3
R	Total Phosphorus (TP) (3)	6	g/m^3
S	Electric efficiency CHP	40	%
T	Thermal efficiency CHP	55	%

1 https://worldpopulationreview.com/countries/barbados-population
2 BWA (2019)
3 Based on BWA residential metered water consumption records.
4 BWA – 2018 SCSTP (January – August) Influent Wastewater Analyses

As previously presented, the CAS process is expected to produce approximately 0.19 kg of VS/m^3 of wastewater treated. The BSTP is expected to contain about 1.7 tonnes (9,000 m^3/d x 0.19 $kg.VS/m^3$) of volatile solids per day with a methane production potential through anaerobic digestion of about 475 m^3/d of methane gas, equivalent to about 4.7 MWh (based on 10 kWh/m^3 of methane) as well as about 0.5 MWh of heat per day. This is considered too small to justify the capital cost of anaerobic digestion at the BSTP. Additionally, the operation of anaerobic digesters and the management and energy recovery from biogas requires highly skilled qualified technical staff, anaerobic digestion, and bioenergy recovery at the BSTP is not recommended.

2.5 Requirement for Additional Photovoltaic Panels

The BSTP property boundary, shown in **Figure F**, covers approximately 34,000 m^2, of which approximately 2,900 m^2 is currently covered by PV panels including five structures in the south-west section of the property, three rows of panels in the open area to the north, and on the roof of the wastewater treatment building along the right side of the photo. There is also approximately 1,600 m^2 of existing building roof area in the north-west corner of the property that is not covered by PV panels.

Figure F. Sewage Treatment Plant Property Boundary

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

2.5.1 Greenhouse Gas Emissions Analysis

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.

The GHG emission analysis, detailed in the Appendix, concluded that implementing the new upgrades will enhance the treatment of wastewater at the BSTP, and will result in reducing the overall direct GHG emissions of treatment process. On the other hand, the upgrades will require more power, which negatively impact the overall carbon footprint of the BSTP upgrades. Introducing renewable energy initiatives such as solar panels have the potential to push the operation of the BSTP upgrades towards carbon neutrality.

2.6 Bridgetown Sewage Treatment Plant Technology Upgrade

2.6.1 Wastewater Treatment Technology Comparison

As previously discussed, the Conceptual Design Report considered three technology upgrade options for the BSTP capable of producing reuse water while also meeting the legislated effluent water quality requirements for total nitrogen of 5 mg-N/L. The technologies included a modification (to tertiary treatment level) of the current Conventional Activated Sludge at the BSTP, in addition to attached growth and suspended solids technologies that would require less land area but would be more complex and costly to operate in the form of Moving Bed Biofilm Reactor and Membrane Bioreactor technologies. MBBR and MBR technologies have a smaller footprint (land area requirement) but with a trade-off of being more complex and requiring higher energy inputs to manage a higher density of biosolids in comparison to CAS.

2.6.2 Process Evaluation Factors

The treatment process selection was based on comparing the three above referenced technologies with an establish capability of producing a reuse water quality as well as achieving the necessary nitrogen reduction to meet the regulatory requirement of a maximum of 5 mg-N/L. Other factors considered included:

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

2.6.3 Bridgetown Sewage Treatment Plant Capacity

While the initial technology assessment work considered a range of options regarding process capacity, including expanding the BSTP sewage collection system and plant treatment capacity to serve all of Bridgetown, in the end, in consultation with the BWA and government authorities, and concurrence of CCCCC's, it was decided to base the evaluation on the status quo with no significant increase in the current population who are served by the BSTP collection system and treatment facility.

2.7 Onsite Wastewater Management and Reuse

2.7.1 Onsite Decentralized versus Centralized Treatment

Onsite decentralized wastewater treatment systems such as pit latrines, septic tanks, and soak-away fields, that are extensively used in Barbados, can be a very sustainable means of wastewater management, assuming they are functioning in a manner that protects the environment and public health. These systems widely distribute the wastewater to the soil with the expectation that bacteria will (if functioning properly) provide the same level of treatment and environmental protection as a centralized system. Further, the dispersed wastewater is largely diffused around the perimeter of the island rather than being discharged at a single outfall location, and with less capital and operating (power) cost. However, these simple onsite wastewater management systems do not effectively remove nitrogen from the wastewater and contribute to the nitrate content of the groundwater in the area, which is also impacted by agricultural practices.

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

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

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

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

2.8 Potential Climate Change Impacts on the Wastewater Collection System

Two areas of concern related to climate change impacts on the BSTP wastewater collection system are surface flooding causing inflow into manholes and groundwater infiltrating into the sewer. These considerations have the potential to use up collection and conveyance capacity, dilute wastewater, and hydraulically overload the central treatment plant.

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

Although the BWA has welded some manhole lids closed, to prevent the public from lifting the lids, we recommend installing locking manhole covers, rather than welding the lids closed.

2.9 Bridgetown Sewage Treatment Plant Reuse Considerations

2.9.1 Effluent Quality Considerations

The Baseline Study summarized the required treated wastewater effluent qualities, as outlined within the current EPD requirements and guidelines for the treatment of wastewater for tertiary treatment for reuse and irrigation were presented previously in **Table B**.

Based on the information presented it is concluded that:

- Ammonia nitrogen and total phosphorus must be reduced to less than 1 mg-N/L, and 1 mg-P/L, respectively, for all discharge and reuse/irrigation options.
- Total nitrogen needs to be reduced to a maximum of 5 mg-N/L for all discharge and reuse/irrigation options.
- BOD_5 and TSS need to be reduced to less than 30 mg/L for direct discharge, and to less than 10 mg/L for reuse applications, including irrigation.
- Faecal coliform levels need to be reduced to less than 200 CFU/100 mL, and less than 1 CFU/100 mL for direct discharge and reuse, respectively, while there is no limitation for irrigation.
- Residual chlorine in the effluent needs to be a minimum of 0.1 mg/L for direct discharge, and 0.5 mg/L (0.2 to 1.5 mg/L) for reuse / irrigation.

The maximum total nitrogen standard of 5 mg-N/l has been established in recognition of the impact nitrogen has on groundwater quality and the coastal environment. A total nitrogen concentration of 5 mg-N/L requires a considerable amount of energy to recirculate nitrified wastewater to the head-end of the process and involves recirculation pumping at roughly eight (8) times the influent flow rate and requires anoxic and aerobic bioreactor components rather than only aerobic conditions as is the case for the existing BSTP configuration.

3 BRIDGETOWN SEWAGE TREATMENT PLANT AND COLLECTION SYSTEM UPGRADE OPTION EVALUATION

3.1 Upgrade Configurations Considered

As noted in the Baseline Study and Conceptual Design reports, the current BSTP contact-stabilization activated sludge treatment process (that is limited to secondary treatment) is not capable of meeting the reuse water quality standard as previously shown in **Table B**, in particular the nitrogen removal requirements. The BTSP was designed to achieve secondary effluent quality standards only and process upgrading, to tertiary levels, are required to enable the BSTP to provide reuse water quality requirements.

As previously noted, three treatment processes were considered as potential upgrade options for the existing BSTP, specifically:

1) **Conventional Activated Sludge** based Biological Nutrient Removal process configured as 4-Stage Bardenpho process;
2) **Moving Bed Biofilm Reactor** configured as Modified Ludzack-Etttingger process; and
3) **Membrane Bioreactor** configured as University of Cape Town process.

These technologies provide a reasonable representation of the wide range of process configurations that could achieve the tertiary reuse water quality, as previously summarized in **Table B**. Further, all three can make use of the existing wastewater treatment plant components by modifying the bioreactor conditions and repurposing component. In all cases chemical precipitation will also be implemented to remove phosphorus as required.

A comparison table was also included within **Appendix 1** of the Conceptual Design report to quickly compare the capabilities of these three treatment technologies. Updated related information is also provided in **Table Q** of Section 0 below.

3.1.1 Conventional Activated Sludge Process

Of the three process configurations, the CAS represents the simplest process configuration to operate and the least expensive to implement (similar in operation to the existing BSTP Contact Stabilization CAS process). As no expansion of the sewer or additional is contemplated that would need to increase the treatment capacity beyond the current CAS process capabilities, the existing contact stabilization could be upgraded by reconfiguring the existing aerobic, contact stabilization, sludge digestion and clarifiers into a pre-anoxic/aerobic configuration to achieve complete nitrification and high efficiency denitrification to meet the maximum total nitrogen concentration requirement of 5 mg-N/L, along with the addition of two new clarifiers, tertiary filtration and disinfection. Recirculation pumps, mixers and disinfection will also need to be added to achieve a water quality suitable for water reuse applications.

3.1.2 Moving Bed Biofilm Reactor – Modified Ludzack-Ettinger Process

The existing BSTP process could also be converted to an MBBR-MLE process configuration that will also remove nitrogen. The conversion would involve adding MBBR media to the bioreactors, converting the existing two stabilization tanks into anoxic reactors, and convert the two existing secondary clarifiers and aerobic digesters into aerated bioreactors. The existing aeration grids located in the stabilization chambers, contact chambers and aerobic digesters would be decommissioned and replaced with a coarse-bubble aeration grid. Like the CAS upgrade, two new secondary clarifiers along with tertiary filters and disinfection would need to achieve the reuse water quality requirements.

3.1.3 Membrane Bioreactor – University of Capetown Configuration Process Upgrade

The MBR-UCT configuration is the third option that was considered with the upgrade involving converting the two existing stabilization chambers into anaerobic bioreactor tanks that would be hydraulically positioned at the beginning of the process. The two existing secondary clarifiers could be converted to anoxic bioreactors and the two existing aerobic digesters would be converted to aerobic bioreactors. A CIP ultrafiltration membrane tank would also need to be added for to enclose the MBR membrane cassettes.

3.2 Repurposing Components

In carrying out an analysis of the three process upgrade options, an emphasis was placed on repurposing the existing BSTP treatment facility components to minimize the upgrade costs while still meeting the stringent effluent discharge limitations required by Barbados. Consideration was given to retaining and using all of the tanks and majority of the existing equipment, including blowers for all three process upgrade options under consideration, and adding new treatment components only when absolutely necessary (e.g. MBBR media and MBR UF membrane cassettes and pumps). This upgrading philosophy not only achieves the most cost-effective project implementation, but it also ensures the plant upgrading will be within the current plant perimeters and avoid additional land acquisition – which would be difficult and financially, politically, and socially risky in a densely populated commercial and tourist area.

3.3 BioWin Modelling

BioWin simulations were carried out for all three process configurations and used to establish and compare the expected treatment performance, including effluent quality and power consumption, based on the raw wastewater characteristics described in the Baseline Report.

3.3.1 Option 1: CAS 4-Stage Bardenpho Configuration

As illustrated in the BioWin process diagram (**Figure G)** for this option, the two existing Contact chambers (2 X 365 m^3) in the current Contact-Stabilization process will be converted to two pre-anoxic zones and the existing aeration grid in the two reactors could be decommissioned. Mechanical mixers could be installed in the two pre-anoxic reactors to provide necessary mixing to keep solids in suspension. The two existing circular clarifiers (2 X 904 m^3) that follow the existing contact chambers (now the Pre-Anoxic zones) could be modified as the first aeration stage once the clarifier mechanisms have been removed and fine-bubble aeration diffuser grids have been installed. The two existing Aerobic Digesters (2 X 974 m^3) could be re-purposed as the second aeration zone and the exiting fine bubble air diffusers and aeration grid in those existing tank could remain or be modified if necessary. The two existing stabilization chambers (2 X 665 m^3) could be converted to Post-Anoxic zones, requiring decommissioning of the existing aeration grid inside the reactors and the installation of submersible mechanical mixers.

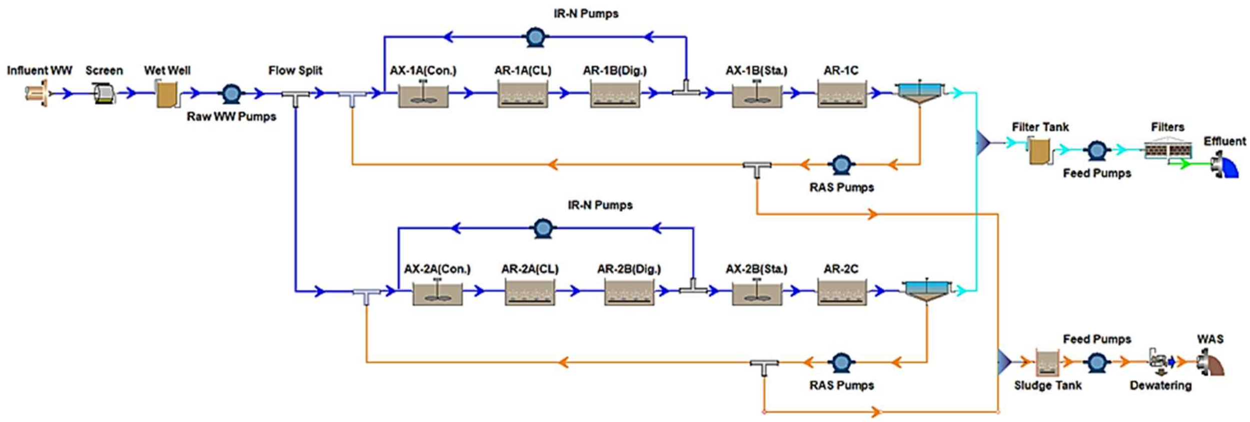


Figure G. Process Schematics for Option 1 – CAS 4-Stage Bardenpho Configuration

A pair of new Post-Aeration tanks (2 X 120 m^3) could be added to the process following the existing stabilization chambers (Post-Anoxic Zones). A pair of new Secondary Clarifiers, a new tertiary Disk Filter system, and a UV disinfection system could be added in the upgraded plant to meet the required reuse water quality criteria. Phosphorus removal could be achieved by chemical precipitation with metal salt added at the upstream of the new secondary clarifiers. **Figure H** illustrates how the existing plant components can be repurposed.

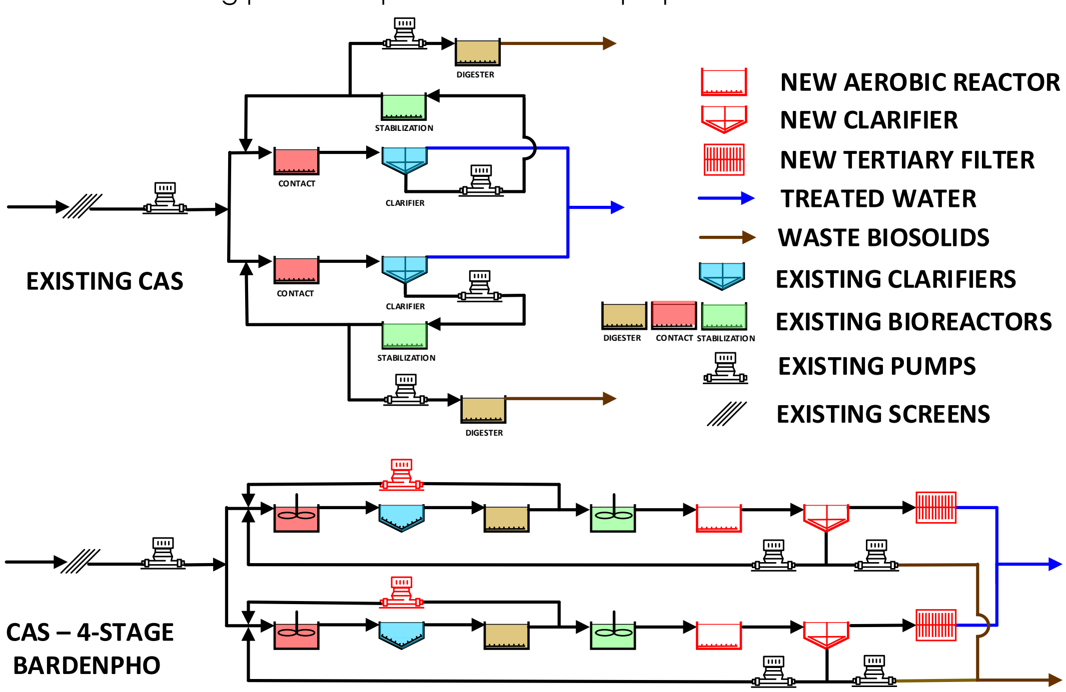


Figure H. Option 1Process Schematic – CAS 4-Stage Bardenpho Configuration

Figure I further illustrates the four stages of the CAS 4-Stage Bardenpho configuration and how nitrogen is removed through the upgraded process

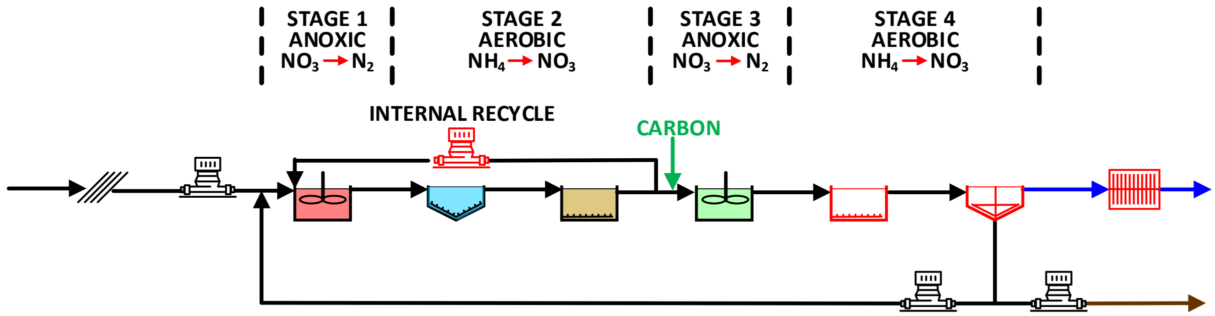


Figure I. CAS 4-Stage Bardenpho Configuration - Nitrogen Removal

With the aforementioned modifications to the existing CAS treatment process the modified CAS configuration would be able to meet the reuse water quality and increase the design capacity of the system from existing 9,000 m³/d to 15,000 m³/d. In fact, the system could be designed for a phased expansion where it could potentially be designed to initially treat only 2,500 m³/d, then be expanded to treat 5,000 m³/d and then upgraded to treat 9,000 m³/d in a future phase. The simulation water quality predictions are summarized in **Table F**.

Table F. BioWin Predicated Potential Treatment Capacity and Effluent Quality for Option 1: CAS 4-Stage Bardenpho Configuration Upgrade

CAPACITY (m^3/d)	$sBOD_5$ (mg/L)	TSS (mg/L)	NH_3-N (mg-N/L)	T-N (mg-N/L)	T-P (mg-P/L)
15,000	3.5	< 10	0.5	3.7	< 1.0

3.3.2 Option 2: MBBR - MLE

Figure J illustrates the BioWin process diagram for the conversion of the existing CAS Stabilization-Contact process (in its current secondary treatment configuration) to a MBBR system configured as a MLE process. The two existing circular clarifiers (2 X 904 m³) could be modified to become Pre-Anoxic Zones and the existing clarifier mechanisms will be removed. MBBR media could then be placed into the two Pre-Anoxic Zone reactors with a fill-level of 50%, based on the media having a specific surface area of 500 m²/m³. Submersible mechanical mixers could also be installed along with screens to keep the media within the tanks. The two existing Stabilization chambers (2 X 665 m³) could be re-purposed as the first Aeration Zones and could follow the Pre-Anoxic Zones. The same MBBR media could also be place in this tank with the same fill percentage as the Pre-Anoxic Zone and submersible mixers could be installed and the existing fine-bubble aeration diffuser grid could be maintained to ensure adequate mixing in the reactors. The same modification could be applied to the two existing Aerobic Digesters (about 2 X 974 m³) and the two existing contact chambers (2 X 365 m³) to form the second and last stages of the aeration zone. A pair of new Secondary Clarifiers, a new tertiary disk filter system and a UV disinfection system could be added to meet the required reuse water quality criteria. Phosphorus removal could be carried out using chemical precipitation with metal salts added at the upstream of the new secondary clarifiers.

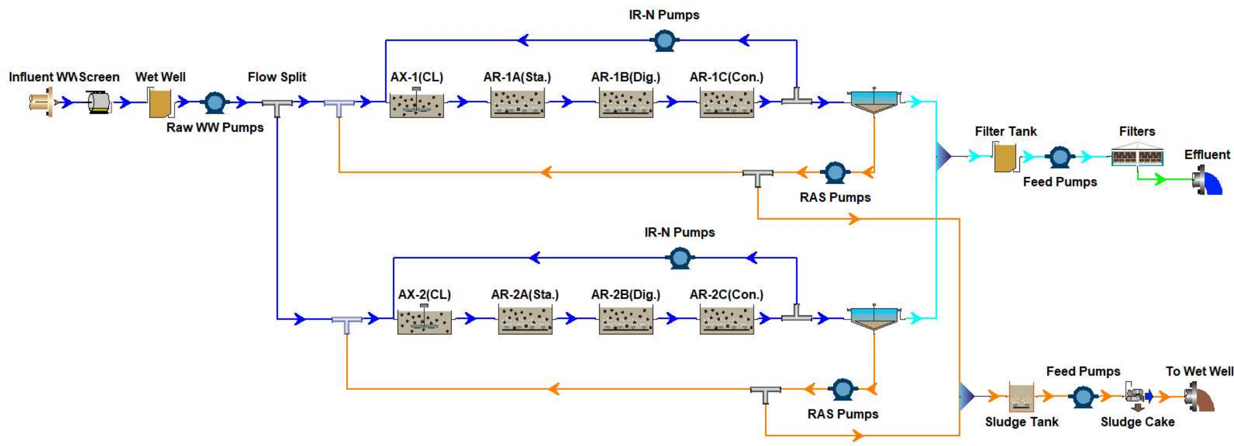


Figure J. Process Schematics for Option 2 – MBBR-MLE Process Configuration

With the aforementioned modifications to the existing treatment system and the addition of the new treatment components Option 2 could be able to meet the reuse criteria and the design capacity of the system would increase from the existing 9,000 m³/d to 20,000 m³/d, as projected by the BioWin simulation. The simulation results were summarized in **Table G**.

Table G. BioWin Predicated Effluent Quality for Option 2 - MBBR-MLE Process Configuration

CAPACITY (m³/d)	$sBOD_5$ (mg/L)	TSS (mg/L)	NH_3-N (mg-N/L)	T-N (mg-N/L)	T-P (mg-P/L)
20,000	4.0	< 10	0.35	4.0	< 1.0

3.3.3 Option 3: MBR - UCT

A major process difference between Option 3 and the other two options is that no new secondary clarifiers and tertiary disc filters are required for Option 3. Instead, a CIP membrane tank housing submersible UF membrane module could be provided for solids-liquid separation and tertiary filtration. The MBR-UCT configuration also achieves enhanced biological phosphors removal, rather than relying on chemical phosphorus precipitation as is the case for the other two options.

Figure K illustrates the BioWin process layout. The two existing contact chambers (2 X 365 m³) could be converted to an Anaerobic Zones to facilitate phosphate release and VFA uptake, and the exiting fine-bubble diffuser aeration grid could be decommissioned, and submersible mechanical mixers installed. The two existing circular clarifiers (2 X 904 m³) could be modified to become Anoxic Zones (for denitrification) and their clarifier mechanisms could be removed and submersible mechanical mixers installed. The two existing Stabilization chambers (2 X 665 m³) and two existing Aerobic Digesters (about 2 X 974 m³) could be re-purposed to be the first and second Aeration Zones, respectively. A new Membrane Tank could be added to house multiple submersible UF membrane modules after the last aeration zone for solids-liquid separation and tertiary filtration. Additional pumps, blowers for membrane air scouring and chemical membrane clean-in-place systems could also be added. A new UV disinfection system could follow the UF membranes. Although biological phosphorus is incorporated into the process, the required phosphorus removal could be achieved by biological means without the use of chemicals.

With the indicated changes to the existing treatment system and the addition of the new treatment components, Option 3 would be able to meet the reuse criteria, while could increase the design capacity of the system to 28,000 m³/d, as projected by the BioWin simulation and summarized in **Table H.**

3.4 CAPEX, OPEX and Life Cycle Costs

Financing upgrading improvements to wastewater infrastructure and services is a major challenge given the scale of investment required and the limited capacity constraints. The implementation of innovative financing mechanism will need to consider and empower the involvement of the private sector, including legislative change to allow non-state actors to play a role.

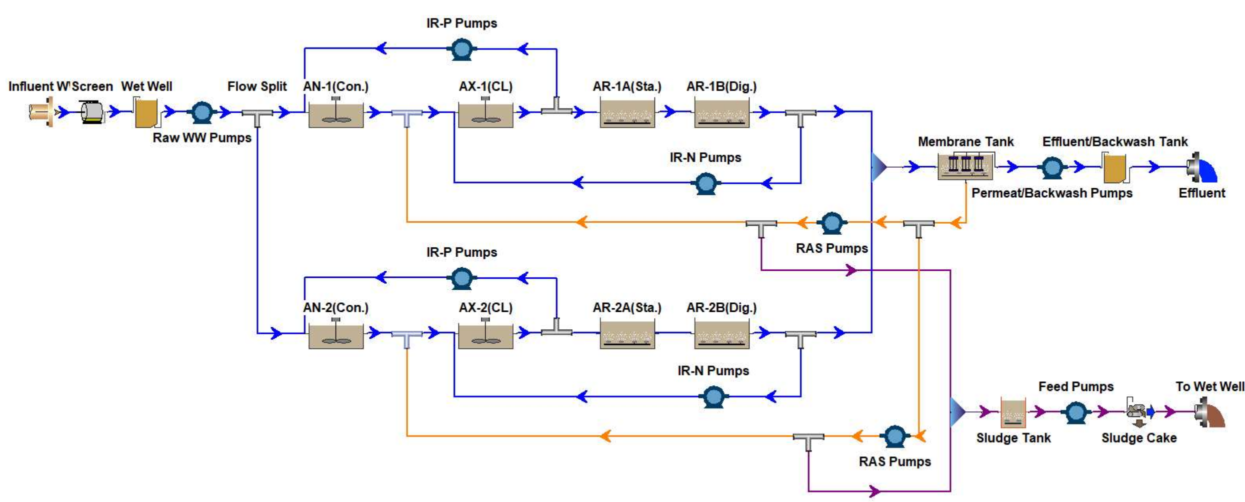


Figure K. Process Schematics for Option 3 – MBR-UCT Process

Table H. BioWin Predicated Effluent Quality for Option 3 - MBR-UCT Process Configuration

PDWF (m³/d)	$sBOD_5$ (mg/L)	TSS (mg/L)	NH_3-N (mg-N/L)	T-N (mg-N/L)	T-P (mg-P/L)
28,000	2.0	< 5	0.42	4.6	<1.0

3.4.1 CAPEX

Class 5 cost estimates, as defined by America Association of Cost Engineers International, have been prepared for all three options to establish CAPEX projections to serve all of Bridgetown (56,100 m³/d), as summarized in **Table I,** taking into consideration that construction costs highly depend on local market conditions. The cost estimate presented are sufficient for comparison purposes but will need to be revised during preliminary design once more local cost information is available. Further details related to **Table I** are provided in the Appendix for your reference.

Table I. CAPEX Estimate

PROCESS	CAPACITY (m^3/d)	CAPEX $US
CAS-4 Stage Bardenpho	9,000	$28,683,000
MBBR-MLE	9,000	$30,066,257
MBR-UCT	9,000	$33,755,906

3.4.2 OPEX

A comparative estimate of electrical consumption for the three BSTP upgrade options is presented in **Table J,** illustrating the aeration, pumping and total energy consumption for the three process configurations for the current service area and flow. The energy required for pumping is relatively similar for Options 1 and 2 as nitrogen removal requires a similar amount of recirculation, with the greatest difference for aeration due to the energy required for media mixing and membrane scouring. As Barbados produces most of its power from diesel generators the power differential also has an impact on GHG emissions consideration.

Table J. Electrical Power Consumption for Optional BSTP Upgrade Configurations

PROCESS	Aeration Nm^3/h	AR Power kW	Pumping kW	Total kW	Total kWh/y	Electrical Cost @ US$0.29/kWh
CAS (4-Stage Bardenpho)	5,201	73	135	198	1,734,480	$ 503,000
MBBR-MLE	24,524	346	160	506	4,432,560	$ 1,285,442
MBR-UCT	9,232	130	172	302	2,645,520	$ 767,200

Note: The values in Table J have been calculated based on a flow rate of 9,000 m^3/d.

The estimated electrical power demand for Option 2 (MBBR-MLE) was based on the assumption that fine bubble diffusers, instead of coarse bubble diffusers, will be used for the aeration system. This is because the Standard Oxygen Transfer efficiency of a fine bubble diffuser could be three times of that for a coarse bubble diffuser normally used for MBBR process. Moreover, reducing power consumption and improving energy efficiency is of paramount importance for this project from both high energy cost and addressing climate change considerations with respect to GHG emissions related to energy consumption. Submersible mechanical mixers will be provided working with fine bubble diffusers to compensate the weak mixing power from fine bubble diffusers for aerated MBBR reactors. The downside of this design approach is the potential diffuser maintenance difficulties as compared with coarse diffusers, fine bubble diffusers are more susceptible to clogging and need more frequent service and maintenance. With MBBR media in the reactors, this maintenance and service work would be more difficult, labour intensive and time consuming.

Table K presents the annual OPEX amounts, estimated based on calibrating the BioWin model with known electrical consumption information from utility bills provided by BWA that indicate a unit charge of US$0.29/kWh. Chemical costs used for phosphorus precipitation for Option 1 and Option 2 was estimated at US$0.15/L of chemical used, and the average plant staff comparison, including salary and other payments, was estimated at US$1,500/Month. The summary of the OPEXs for the three options are presented in **Table H**. The detailed breakdown of the OPEXs can be found in **Appendix 4**. It should note that the OPEX for AD and CHP systems were not included in **Table K**. Further details related to **Table K** are provided in the Appendix for your reference.

Table K. Annual OPEX Estimate

PROCESS	DESIGN CAPACITY (m^3/d)	Annual OPEX ($US)
CAS-4 Stage Bardenpho	9,000	$918,000
MBBR-MLE	9,000	$1,957,442
MBR-UCT	9,000	$1,270,200

3.4.3 Energy Recovery Potential

The Conceptual Design Report indicates the CAS and MBR-UCT are expected to produce similar quantities of volatile sludge per cubic metre of wastewater treated (i.e. the same bioenergy recovery potential through anaerobic digestion) and the MBBR-UCT is expected to produce about 25 percent more than the other two configurations.

The amount of bioenergy extracted from the wastewater could be significantly increased for all configurations by adding primary clarification into the design, potentially tripling the electricity and heat energy potential.

A quantitative estimate of the methane generation potential of the upgrade BSTP treatment process using BioWin for the current BSTP 9,000 m^3/d design capacity, assuming mesophilic digestion, without and with primary clarification is presented in **Table L.** The table presents a comparison of the methane production noting that without primary clarification 47 Standard cubic metres per day (Sm^3/d) of methane would be produced, and with primary clarification the amount of methane produced almost doubles to 88 Sm^3/d. The energy production from anaerobic digestion shown in Table L is based on the Low Heating Value (LHV) of methane at the Standard Condition (15 ^{o}C at 1 atm), which is 33,906 KJ/Sm^3.

Table L. Projected Biogas and Methane Production

Primary Clarifier	AD Feed TS Kg/d-dry	AD Feed VS/TS %	Biogas Sm3/d-dry	CH_4 Content %	CH_4 Produced Sm^3/d-dry	Energy kW
No	13,500	76	67	70	47	309
Yes	16,000	82	139	70	88	523

3.4.4 Anaerobic Digestion

The most logical choice for an anaerobic digestor configuration for Barbados and this scale of operation would be a mesophilic anaerobic digester with an operating temperature of between

30 to 40 ^{O}C. A thermophilic digester operating at a higher temperature has some advantages with respect to improved biosolids pathogen reduction, potentially higher gas yields and a smaller footprint; however, the added operational complexity likely offsets those advantages. Consideration between mesophilic and thermophilic mode of operation can be considered as part of preliminary design once the characteristics of the feedstock are determined.

The biogas produced through anaerobic digestion can be used directly (with simple H_2S removal) as a fuel for a boiler system to produce steam or hot water for plant use. While this option is simple and less expensive than alternatives, it will only recover a relatively small portion of the bioenergy available.

The two most practiced energy recovery methods using biogas generated from WWTPs are Co-generation of Combined Heat and Power, and Renewable Natural Gas. For CHP, depending on the quantity of the biogas produced, micro-turbines or combustible engines may be employed to produce electricity and heat using processed biogas as the fuel. For this application, the raw biogas must be processed to remove particles, H_2S, and Siloxane etc. to protect micro-turbines and combustible engines from damaging. The total energy recovery for a CHP system is expected to be approximately 60 - 65% (about 25 – 30% as electricity) for micro-turbines and 70 – 75% (35 – 40% as electricity) for combustible engines, all of which can be used to power the plant operation.

If CHP is employed to utilize recovery energy from biogas to produce electricity and heating power, assuming a 40% of the electrical fuel efficiency and 35% fuel heating efficiency for the CHP system, the expected electricity and heating power are shown in **Table M**, with and without primary clarification. To put the amount of electricity produced into economic perspective the maximum electricity produced with primary clarification of 209 kW is valued at US$1,455 per day (US$530,000 per year based on US$0.29/kWh). The incremental value of including primary clarification in the process design has an estimated electricity value of US$226,000 per year.

Table M. Estimated CHP Power Output for Energy Recovery at BSTP

PROCESS	No Primary Clarification		With Primary Clarification	
	Electricity (kW)	Heat (kW)	Electricity (kW)	Heat (kW)
CHP	124	108	209	183

A much more intensive biogas purification process is required for RNG use to remove not only particles, H_2S, and Siloxane, but also CO_2 (which comprises 25 – 45% of the total biogas volume produced), moisture, and VOCs. The major advantage for RNG is its energy recovery is more than 90%. The disadvantages are that the biogas purification processes are complicated and expensive. An established natural gas infrastructure that store and distribute the RNG will also be required.

Recently, Hydrogen Fuel Cell technology has been developed to use methane in biogas as the feed stock to generate and store electricity. Limited full-scale operation of this technology has been reported, but the technology is still considered under development and very limited full scale operating data and experiences are available.

As summary of the advantages and disadvantages of the above technologies is presented in **Table N.**

3.4.1 Upgrade Component Comparison

The major treatment components for the three BSTP upgrade options are summarized in **Table O**. It should be note that the volumes shown are the total volumes for two treatment trains. The table illustrates Option 1 (CAS 4-Stage Bardenpho) requires the largest total reactor volume, followed by Option 2 (MBBR-MLE) that is 69% of the volume of Option 1, and Option 3 (MBR-UCT) that is 58% of the volume of Option 1. The difference is due to the mass of bacteria that is retained within the treatment process by each technology and the difference in total reactor volumes also translates to a proportional difference in the footprint requirement for each upgrade configuration. Based on the premise there are no plans to expand the capacity and the intent is to repurpose the existing infrastructure, the difference in total reactor volume and associated footprint is not a significant consideration in comparing options.

Table N. Advantages & Disadvantages of Biogas Energy Recovery Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Plant Boiler Fuel	- Proven technology - Simple and lowest cost - Easy to implement and operate - Relatively low maintenance	- Low energy recovery limited by the plant heating demand - Excess biogas needs to be flared - Not cost effective considering with AD
CHP	- Proven technology - Recover 60 – 75% biogas energy - Biogas processing is less complicated than RNG - No additional infrastructure necessary - Flexible	- High capital cost for micro turbine or combustible engine system - Requires high level of operating skills - Increased maintenance level and operator's attention
RNG	- Proven technology - Recover > 90% biogas energy - Not limited to the plant energy requirement limitation	- Requires an established infrastructure to deliver the RNG to end users - Requires extensive biogas purification - High capital and operating costs for biogas purification systems - Increased maintenance level and operator attention
HFC	- Reported high energy efficiency - No additional infrastructure necessary - Reported as most environmentally friendly	- Still under development - Limited full-scale operation - Limited technical data available

Table O. Treatment Process Component Comparison for the Three Upgrade Options

PROCESS	AN (m^3)	Pre-AX (m^3)	AR (m^3)	Post-AX (m^3)	Post-AR (m^3)	Clarifier (m^3)	Total Vol (m^3)
CAS-4 Stage Bardenpho	0	2,400	14,400	1,800	900	4,800	24,300
MBBR-MLE	0	2,400	9,600	0	0	4,800	16,800
MBR-UCT	2,400	4,000	7,200	0	0	400*	14,000

*This is for a MBR ultrafiltration membrane modules housing, not a clarifier.

3.5 Effluent Reuse Options

3.5.1 Distribution

As noted earlier, one of the key economic challenges in making reclaimed water available for a wide range of reuse applications is the cost of distributing the reclaimed water to those uses. The alternative is to identify a few large-scale reuse applications to reduce the conveyance costs. Large-scale, or large capacity, reclaimed water reuse applications are typically related to satisfying irrigation demands or indirect potable reuse through groundwater recharge.

3.5.2 Agricultural Irrigation

Agricultural irrigation could greatly benefit from increased availability of water, and the application of reuse water for agricultural applications is likely the most common reuse application world-wide. However, the Ministry of Agriculture and Food Security has determined the TDS content for agricultural irrigation use must be less than 450 mg/L. Municipal wastewater typically has TDS concentrations in excess of 1,000 mg/L, often as high as 2,000 mg/L, depending on the TDS concentration in the potable water supply (e.g. groundwater) and commercial and industrial wastewater sources within the collection system. This means the reuse water will need to be further treated using a desalination technology, the most common of which is reverse osmosis.

Reverse Osmosis Treatment

Reverse Osmosis filtration involves applying a high degree of pressure to one side of a permeable membrane to force water through the membrane and rejecting most of the soluble molecules including salts. The rejected dissolved solids and salts are released within a reject brine stream and effectively resulting in a loss of from 25 to 40 percent of the water being treated, which then requires disposal. Typical disposal methods of brine use ocean outfalls, making it more difficult to dispose of brine if a RO treatment facility is situated more inland, where most of the agricultural lands are situated.

While RO can remove most of the TDS in the reuse water, the complete or near complete removal of TDS is not required to meet the 450 mg/L target value for irrigation. To minimize the capital and operating cost for RO treatment it would be reasonable to treat only a portion of the reuse water to an RO water quality standard, and then blend it with reuse water that has not been treated with RO to achieve the target TDS concentration. **Figure L** illustrates the relationship between the RO treatment capacity, the amount of reuse water available, and the reuse water TDS concentration. For example, assuming a TDS concentration of 1,500 mg/L, and 9,000 m^3/d of reuse water is produced by the upgraded BSTP treatment facility, an RO treatment process with a processing capacity of 6,845 m^3/d is required to produce 5,030 m^3/d of filtered permeate, which when blended with 2,155 m^3/d of reuse water (not treated by RO) will produce a total flow of 7,186 m^3/d of water for use in irrigation (representing 80% of the total reuse water available by blending). Similarly, if 5,500 m^3/d or reuse water is available with a TDS of 1,500 mg/L, 4,200 m^3/d of water processed by RO will produce a blended 4,400 m^3/d of water for irrigation use (80%) and resulting in 1,110 m^3/d of (20%) brine.

Taking the above into consideration, it should be noted the BWA recently obtained effluent TDS concentration analyses (August 2021) for the BSTP plant ranging from about 2,100 to 4,200 mg/L.

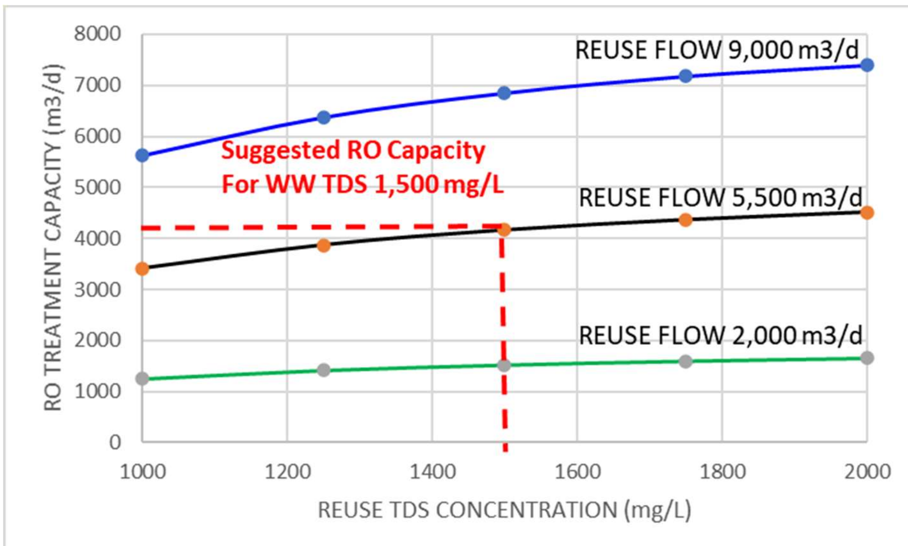


Figure L. Reverse Osmosis Treatment and Permeate Recovery Diagram

3.5.3 Groundwater Augmentation

Another challenge of using reuse water for agricultural irrigation is the seasonal requirements for irrigation water varies over the year, whereas the production of reuse water is year-round. Therefore, using the reuse water to augment groundwater (aquifer recharge) resources is another large-scale reuse application that would have value for Barbados.

There are an increasing number of communities globally that use reuse water for indirect potable water reuse. Indirect Potable Reuse involves augmenting surface or groundwater to increase the availability to recover and treat the water for potable use. The indirect aspect is the water must flow through an environmental buffer to be part of the potable water resource.

The Spring Garden BWRO desalination plant in Bridgetown presents an opportunity to convert the reuse water produced at the BSTP facility into potable water and increase the availability of potable water supplies. The reclaimed water from the BSTP could be piped and discharged to ground in the vicinity of the Spring Garden BWRO desalination plant, thereby increasing the availability of groundwater in the area for potable water production, with a relatively low cost to convey the water from the BSTP to Spring Garden roughly 3 km by road, at a cost of about US$3M.

This strategy would eliminate the need to install a RO system at the BSTP and present further cost savings (as illustrated in **Appendix 3**).

3.5.4 Reclaimed Water Pipeline Route Options

The BWA, and MAFS, have proposed three reclaimed water pipe route options, noted as Options 1, 2 and 3 in **Table P** and **Figure M**. The pipelines would deliver reclaimed water from the BSTP for both agricultural irrigation and aquifer recharge, requiring the BSTP to be upgraded to tertiary treatment as well as add a RO treatment process to meet the MAFS TDS requirement of 450 mg/L.

A fourth 3 km pipeline route (Option-4) is also illustrated in **Figure N** and provides reuse for aquifer injection to the Spring Garden BWRO plant. It does not require RO treatment and the pipeline is only 3 km long. This option utilizes the existing water distribution network to distribute potable water, with potential irrigation use and avoids the cost of RO and a dedicated pipeline to transmit reclaimed water.

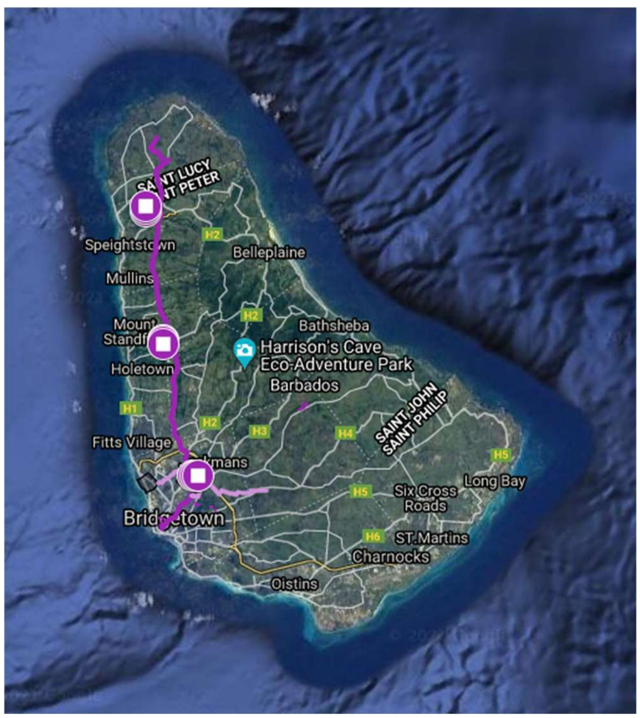


Figure M. BWA Reclaimed Water Pipeline Route Options

3.5.1 Required Changes to the Building Code

To take full advantage of reclaimed water alternative reuse applications beside irrigation should be considered including building applications such as toilet flushing, fire suppression and water features. A dual plumbing water distribution system is required for these reuse applications (non-potable plumbing in parallel with potable water plumbing) which can be a considerable cost to install if existing buildings are to be retrofitted. The most cost-effective means to include this dual plumbing would be during new construction projects.

Table P. Reclaimed Water Pipeline Route Options

Option	Irrigation Route	Aquifer Recharge	Pipeline Length	Capital [1] Cost (US$)
1	BSTP to Waterford (Botanical Gardens) then northwards to recharge point at Trents (Greenwich) (find points or take-offs along the way). Assume 6 injection wells will be included in this option.	Trents and Waterford (to be modelled for impact on nitrates and where the water goes). Treatment using RO is also required to meet irrigation TDS requirements)	13 kms	$6.7M[1]
2	Extend option 1 all the way to Spring Hall Land Lease, St. Lucy – all other points remain the same. Assume 9 injection wells will be included in this option	Trents and Waterford (to be modelled for impact on nitrates and where the water goes). Treatment using RO is also required to meet irrigation TDS requirements)	27 kms	$13.8M
3	BSTP to Waterford (Botanical Gardens) with take-off at Hothersal roundabout to Friendship plantation the turn south along ABC H'way And Then Turn North Along Belle Road up to Lears (Roberts Manufacturing) – irrigation can be done for lands on east and west of that road. Also take in Neil's Plantation, Salters, Constant and Valley Plantation. Assume 6 injection wells will be included in this option	Waterford (to be modelled for impact on nitrates and where the water goes). Treatment using RO is also required to meet irrigation TDS requirements)	9 kms	$4.7M
4	BSTP to Spring Garden BWRO desalination plant. Assume 3 injection wells will be included in this option	Spring Garden using reclaimed water with reuse water quality. No RO treatment cost is required.	3 kms	$1.6M [2]
RO	Reverse Osmosis Treatment Facility [(3)]	Required for agricultural irrigation use. CAPEX includes additional PV panel costs to offset additional energy requirements. **Does not apply to Option 4**	NA	$10.9M

Notes:

[1] – *Pipeline capital costs are based on US$500,000 per km of pipeline installed plus US$100,000 to drill and install a set of 3 injection wells. Cost does not include required RO treatment facility or engineering design costs.*

[2] – *Reverse Osmosis (RO) treatment costs only apply to Options 1, 2, and 3. RO treatment required to meet Ministry of Agriculture and Food Safety requirement to reduce TDS to maximum 450 mg/L. Option 4 avoids the capital cost for RO treatment and associated annual O&M costs (estimated to be US$10/m^3) that are not reflected in this table but are included in the Financial Assessment (see Appendix 4).*

Figure N. Potential 4th Option Route to be Considered between the BTSP and the Spring Garden BWRO WTP

3.6 Nutrient Resource Recovery

The amount of wastewater that is treated at the BSTP contains about 22 kg-P/d of phosphorus, or 8 tonnes per year. If a biological phosphorus removal process were constructed it could conceivably recover approximately 50% (4 tonnes per year) with 50% remaining in the residual waste biomass that could benefit the land it was applied to. The value of diammonium phosphate [$(NH_4)2PO_4$] was about US$390 per tonne in 2020 and contains about 24% phosphorus by weight (i.e. could conceivably produce 16 tonnes of diammonium phosphate), the potential value of the recovered phosphorus content would be about US$6,200, which would not justify the costs of implementing a more complex and expensive biological phosphorus removal process.

As a consequence, biological phosphorus removal and phosphorus recovery is not considered economically viable and is not recommended. A more sustainable approach would be to apply the residual waste biosolids to land in a manner that would benefit from the phosphorus content of the biosolids.

Anaerobically digested sludge would be dewatered and transported for land spreading and nutrient benefit.

3.7 Upgrade Options Comparison

As noted in the Conceptual Design report, all three options are able to produce a tertiary reuse water quality meeting the legislated water quality requirements including nearly complete ammonia nitrification, while producing about 6,000 kg/d of waste biosolids, of which 77% is volatile.

The effluent quality projections for total nitrogen removal presented in the Conceptual Design Report have been modified by including increased recirculation pump rate capacity and tank modifications to improve the level of denitrification to achieve a total nitrogen concentration of 5 mg-N/L.

The Conceptual Design Report also shows the aeration and associated power requirements for the three process configuration upgrades. The CAS process has a significantly lower operating costs than the other two technologies; about one-half the power requirement of the MBR-UCT process and about one-quarter the unit power requirement for the MBBR-MLE process. As previously noted, a long solids retention time is required for all three configurations in order to establish the necessary biomass to achieve the target nitrogen removal and effluent total nitrogen concentration of 5 mg-N/L. Accordingly, both the CAS and MBBR-MLE configurations are projected to produce similar amounts of biosolids (750 kg/d) with a volatile solid's percentage of about 75 percent. The MBR-UCT is expected to produce about 690 kg/d of waste biosolids with a slightly lower volatile content of about 70%. This difference in potential biomass is not considered to be significant with respect to bioenergy recovery.

Table Q provides a qualitative comparison of the three process configurations based on retrofitting components as discussed above. As all three configurations can achieve the same reuse water quality and can treat the same existing estimated flow of 9,000 m^3/d and can fit on the same site, the principle remaining factors for consideration are capital expenditure, operating expenditure, and process complexity. The CAS upgrade configuration has an advantage over the other two process configurations for all three factors, indicating it is the preferred option.

Table Q. Overall Relative Comparison of Upgrade Options

Parameter	Option 1- CAS	Option 2 - MBBR	Option 3 - MBR
CAPEX, US$	**$28,297,000**	**$34,705,071**	**$35,967,471**
OPEX, US$/y	**$999,156**	**$2,215,592**	**$1,781,358**
Capacity, m^3/d	**9,000**	**9,000**	**9,000**
Effluent T-N	**3.7**	**4.0**	**4.6**
Phosphorus Removal	**Chemical**	**Chemical**	**Biological**
Process Complicity	**Low**	**Moderate**	**Highest**
Level of Modification	**Moderate**	**Moderate**	**Moderate**
Energy Consumption	**Lowest**	**Highest**	**Moderate**
Footprint	**Largest**	**Moderate**	**Smallest**
Bioenergy Recovery	**Moderate**	**Moderate**	**Moderate**

3.8 Solar Energy Considerations

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

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

Barbados has favourable solar energy conditions due to its location in the tropics. Therefore, the installation of PV for electricity generation and solar thermal energy for hot water production is advantageous. The total number of hours of sunlight in Barbados is about 3,030 hours per year (or an average of about 8.3 hours per day). The BSTP currently has approximately 3,000 m^2 of solar panels that were installed between early 2017 and mid-2019, collectively located on the wastewater treatment plant roof, and to the west and north of the treatment facility, as shown in **Figure O.** The BWA has only recently received authorization to tie the PV system to the grid (August 2021), so there is no electical production information available. However, in reference to another solar PV system operating on the island with a similar area of 2,300 m^2 and a metered output of 370 kW (i.e. 160 W/m^2) , it is expected the solar PV installation at the BSTP would produce about 480 kW of electricity , or about 1,454,000 kWh/y based on an average of 8.3 hours os sunlight per day.

The principally diesel generated electricity distributed through the power network in Barbados has an average GHG emission of 0.66 $kgCO_2e/kWh$. In comparison, when using natural gas for generating power, the emissions decrease to 0.4 $kgCO_2/kWh$, indicating the potential to reduce the GHG emissions by almost 40% when using natural gas instead of diesel. **Table R** shows the calculations used for deriving the average power emissions factor when using diesel and natural gas, excluding any emissions resulted from transportation of diesel or natural gas to the Island.

Figure O. BSTP Site and Potential Areas for Solar Panels

Table R. Diesel and Natural Gas Power CO2 Emissions

Item	Unit	Value
Power Generated from Diesel		
Diesel Emissions Factor[1]	kg CO_2 e/kWh	0.25
Power Conversion Efficiency[2]	%	38
Barbados Power Grid Emissions Factor	Kg CO_2 e/kWh	0.66
Power Generated from Natural Gas		
Natural Gas Emissions Factor[1]	kgCO_2 e/kWh	0.18
Power Conversion Efficiency[2]	%	45
Power Emissions Factor	kgCO^2 e/kWh	0.40

[1] https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

[2]Power conversion efficiency based on typical generator performance

The available open space and roof surface area that could be used for additional for solar panels, and the corresponding power generation potential, is shown in **Table S** along with the estimated GHG offset potential. The solar power generation potential can not only greatly offset the additional power demands of the BSTP upgrade to tertiary treatment, and associate indirect GHG emissions, but also generate extra power to supply the country's power grid with clean power.

Table S. Additional Solar Power Generation Potential

Area #	Available Surface Area (m^2)	Solar Power Potentials		GHG Offset Potential (tCO_2e/yr) [3]
		(kW) [1]	(kWh/yr) [2]	
1	1,300	208	630,136	416
2	4,400	704	2,132,768	1,408
3	2,100	336	1,017,912	672
4	1,200	192	581,664	384
Total	**9,000**	**1,440**	**4,362,480**	**2,880**

Table Notes:
1. *Solar irradiation potential is based on 160 W/m² based on assumptions described in Section 3.8.*
2. *Based on average of 8.3 hours of sunshine per day, with no efficiency loss.*
3. *GHG CO_2 offset based on 660 kg-CO_2/1,000 kWh.*

3.9 GHG Emissions

3.10 Direct GHG Emissions

The general wastewater load on the existing BSTP facility compared with the proposed upgrades is assumed to be 9,000 m^3/d and the net direct GHG emissions (i.e. direct emissions from the treatment process) are expected to remain the same as may be released by the existing CAS process. Therefore, no direct GHG credit is assumed for any of the upgrades.

3.11 Indirect GHG Emissions

Table T illustrates the power consumption at the existing BSTP infrastructure and the expected consumption for the three-upgrade configuration being considered. The existing treatment facility at BSTP has smaller indirect GHG emissions compared with the proposed new upgrades mainly due to having a lower power consumption. However, the tertiary reuse effluent quality for all three options offsets the negative impact associated with the indirect GHG emissions. **Table T** provides a summary of the power produced by the existing PV panels and the estimated additional PV panels required to offset the extra power demands for the upgrade options.

Renewable sources of energy should be considered to mitigate the impact of the upgrades on GHG emissions. In addition to providing additional PV panels, anaerobic digestion of the biosolids to produce methane can also be considered.

3.12 Onsite Wastewater System Improvements

Other government and BWA wastewater initiatives that are outside the scope of this project, include the Roof to Reefs Programme that incorporates several projects, such as the current BWA tender for "*Design Build Services for Sewage Disposal Solutions to Specific Districts: RFP # BWA-21/06/13-1,*" that could also fall under the R2RP, and compliments the current Design-Build tender, by proposing other similar wastewater collection and treatment systems in other Zone A areas along the west coast of Barbados.

The concept is to construct smaller-scale cluster wastewater collection system within Zone A areas where the existing onsite wastewater disposal systems are of concern with respect to contributing to groundwater contamination within aquifers used for drinking water extraction. The collected wastewater would be treated to a reuse standard and either post treated using RO to remove TDS for agricultural irrigation use or used for other non-potable water applications in the immediate vicinity of the treatment facility. Our project team believes this concept has merit in addressing problem onsite ground dispersal systems, particularly in highly sensitive groundwater areas, and is a more economical and sustainable approach than attempting to implement individual onsite package wastewater treatment systems or provide centralized sewage collection and treatment systems for the entire country.

Table T. Power Consumption and Indirect GHG Emissions for BSTP Upgrade Options

Treatment Infrastructure	Unit	Value
BSTP - Existing Facility		
Design Capacity	m^3/day	9,000
Energy Consumption	kWh/year	1,245,867
Available Solar Energy[1]	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	0
Indirect GHG Emissions	tCO_2e/year	822
Total additional Solar Power Required[1]	kW	0
BSTP - CAS 4-Stage Bardenpho Upgrade		
Design Capacity	m^3/day	9,000
Power Consumption	kWh/year	1,734,480
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	289,320
Total Additional Solar Power Required	kW	95
Indirect GHG Emissions for Additional Power	tCO_2e/year	191
BSTP - MBBR Upgrade		
Design Capacity	m^3/day	9,000
Power Consumption	kWh/year	4,432,560
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	2,987,400
Total Additional Solar Power Required	kW	986
Indirect GHG Emissions	tCO_2e/year	1,972
BSTP - MBR Upgrade		
Design Capacity	m^3/day	9,000
Power Consumption	kWh/year	2,645,520
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	1,200,360
Total Additional Solar Power Required	kW	396
Indirect GHG Emissions	tCO_2e/year	792

[1]Based on a total covered area of 3,000 m^2 by solar panels at the site, with assumed power density of 160 W/m^2

4 OPERATIONAL & MAINTENANCE AND LEGISLATIVE CONSIDERATIONS

Both the Baseline Study and the Conceptual Design report comment on the BWA's O&M status. The information provided in section 4.1 is meant to provide an overview of this previous information and to underline recommendations moving forward.

4.1 Operation and Maintenance Programme

4.1.1 Overview

Over the years, the maintenance focus at BWA has shifted from Preventative Maintenance towards emergency breakdown maintenance. PM extends the life cycle of equipment and helps to reduce breakdown maintenance and associated high financial and environmental costs. The Conceptual Design Report indicates the shift from PM activities is a lack of staff resources dedicated to preventative maintenance and available finances for maintenance in general and too few staff, funds and work scheduling assigned to maintenance.

There is also a major problem in getting replacement parts for aging equipment. To improve this situation, staff are trying to standardise equipment to make it easier to source replacement components and parts.

4.1.2 Computer Maintenance Management System

The BSTP process upgrades are expected to exacerbate the operations and maintenance problems unless improvements are made. The Conceptual Design Report provides recommendations for initiating a robust maintenance programme, including:

- Review and update training programmes to ensure all BWA operations staff have a basic knowledge of equipment troubleshooting of equipment and ability to recognize the level of maintenance expertise and knowledge required, and that maintenance staff have a similar level of basic operator training and process knowledge.
- Review staffing levels and restructuring plans to shift personnel resources from operational roles to maintenance roles;
- Provide financial support for a maintenance programme as well as the purchase and installation of critical pieces of equipment; and
- Develop a robust Computer Maintenance Management System prior to any process upgrades to create a smooth transition of the new equipment into an established system, allowing the new equipment and components to be entered into the PM cycle from its installation forward.

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

A pilot program is suggested to be carried out to establish the core programme focussed on a subset of equipment which can then be expanded by migrating any other existing equipment into the system later once the system is refined.

Future equipment replacement and expansion can be added to the existing system through requirements written into future contracts to ensure that specifics of the equipment, required PM tasks and scheduling are provided on BWA established templates. This process can be linked to the acceptance of equipment. Similarly, any new upgrades or replacement equipment must be incorporated into existing operations and maintenance manuals and any drawings related to the equipment in a timely fashion.

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

4.1.3 Computer Maintenance Management System Content

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

- Establishment of a CMMS team including members from Finance and champions from the front-line maintenance staff;
- Review and selection of third-party software system, or decision to develop in-house if the skill sets exist. Once this is selected the provider should offer staff training to ensure understanding and ability to use effectively;
- BWA senior management and Human Resource support is needed to ensure required resources are available to drive the initiative at all levels in the utility;
- Conduct an inventory of all equipment and specifications using a standardized template. This inventory should focus not only on operational equipment but supporting equipment related to the building envelope and grounds. This must address health and safety related items like eye washes, showers and gas monitoring equipment as well;
- All the data should be entered into the CMMS system including a link from every entity to an owner. This owner would be a staff position such as a supervisor or foreman who would be responsible for the assignment of work related to the entity. It is important to note that this CMMS system often offers an application that can be used on an Operators smart phone or tablet. When introducing a new data collection system, it is important that the new system is easy to use, otherwise most people will not try it and continue to implement it;
- Each entity must then be reviewed to establish what tasks must be scheduled under PM. Any new equipment should be scheduled based on a review of manufacturers guidelines and industry practices. For existing equipment, experience may drive the scheduling;
- For each scheduled task, a documented work instruction or SOP should be developed, with input from field staff, and attached to the entity within the CMMS system. A work instruction, or SOP, should be written using an agreed upon standard template;

- Once tasks have been developed, a scheduled triggering system needs to be created among staff to ensure that when PM is due on a piece of equipment the Supervisor assigned to the equipment is alerted so they may assign the work to a staff member, or other team member;
- Details of the completed tasks must be entered into the CMMS system to create a history of maintenance performed on the equipment that is available to all staff. This history should also include breakdown maintenance;
- Before launching the CMMS, all staff must be educated and trained on the system. Depending on the complexity of the CMMS system chosen, most offer add-on modules that can be used for time and financial tracking as well as parts inventory. This information is often utilized by others outside of the Maintenance department; and
- Finally, the system must be periodically audited to ensure PM tasks are being completed and that the tasks themselves are adjusted if required. Often manufacturers suggested maintenance schedules require shortening or lengthening due to actual field performance conditions.

4.1.4 Computer Maintenance Management System Pilot

For the establishment of a pilot CMMS, it is suggested the focus be on the lift stations and the collection systems. From there it can be expanded to the treatment plants. A similar process can be adopted for documenting operational procedures and establishing manuals for the lift stations while collecting maintenance information. Once a CMMS has been established, and tested for the equipment in the collection systems, it can then be expanded into the treatment plants and other areas using the existing hierarchy and BWA templates developed.

Records and documentation should be electronically available within the facilities such that any staff member who requires operational information to be able to access it electronically for the location it is required. Central electronic databases of the procedures and records, supported by paper copies, if necessary, will achieve this goal.

4.1.5 Operator Safety

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

4.1.6 Document Updates

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

4.1.7 External Training Opportunities

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

4.1.8 In-House Laboratory Support

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

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

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

4.2 Legislation and Policy Reform Considerations

The National Environmental Survey (2010), and the Barbados National Assessment Report (2010) have pointed to outdated and inadequate legislation, overlapping and contradictory roles and responsibilities, conflicts of interest and poor enforcement as hampering the efficient and effective management of water resources and, provision of water and wastewater services. At present the BWA is responsible for both the regulation of the country's water resources as well as the delivery of water and wastewater services. The water sector has long recognised that this is a conflict of interest, and the roles should be separate; regulatory functions should not be mixed with service delivery. It has long been acknowledged that the governance of the sector needs an overall to improve its transparency and accountability[2] [3] and the introduction of participatory mechanisms in decision-making. Regulatory roles and requirements are in some cases overlapping and contradictory.

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

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

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

- Outdated legislation:
  - Three Houses Spring Act (1713) and Porey Spring Act (1864) have contradictions and it has been recommended that they should be either reviewed or repealed.[4]
- Failure to develop and implement legislation as well as resolve conflicting legal provisions:
  - Draft Environmental Management Act;
  - Draft Water Reuse Act and regulations[5]; and
  - Conflict between Groundwater Zoning Policy requirements and the provisions of the Marine Pollution Control Act, chapter 392A, particularly with respect to the coastal strip.
- A lack of a comprehensive regulatory framework, including inter alia;
  - Private sector participation in the provision of wastewater services[6];
  - Improved effluent discharge standards;
  - Standards for the control of agricultural run-off;
  - Policy provisions and codes of practice regarding wastewater infrastructure and design standards, septic tank design, soak-aways, appropriate technology and, EIA and waste management provisions; [7]
  - Performance standards for wastewater services;
  - The Barbados National Standard's Code of Practice CP 16 (Part 1): 1981 UDC 691.1:628.15/.3 August 1981. Although there has been new development on this, it should be reviewed and updated to include provisions for wastewater reuse (reclaimed water) as well as rainwater harvesting in the interest of public health[8]; and
  - Complaints regarding the control of nuisance arising from odours and air quality.
- An absence of national medium-term management master plan:
  - Develop a master plan for the management of the country's water resources and, water and wastewater services that takes into account the National Physical Development Plan and national economic development priorities; and
  - Require the water and wastewater service provider (currently the BWA) to draw up and publish, every 5 years, its asset development and financial management plan.
- An absence of independent economic and service performance regulation to;
  - Develop, set, and periodically revise tariffs for the abstraction, supply and use of water and, for wastewater services; [9]
  - Require the provision of acceptable standards of service and impose penalties when these are not met; and

---

[4] CEHI (2008)

[5] CEP TEC Rep 66

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

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

[8] IDB mission report

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

   - Require the development and submission of business plans for service provision.

Other challenges include the limited human and financial resources which limit the ability to monitor and enforce compliance with legal and regulatory requirements. Lastly, there needs to be better policy coordination across sectors particularly with respect to economic development planning; tourism and agricultural development planning need to consider water availability and wastewater management issues.

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

- Provide support to the Water and Wastewater Master Plan with the updating of a Policy Framework for Water Sector Development and Management, incorporating gender considerations, public participation, climate change, wastewater, and stormwater:
   - Diagnostic analysis of existing policy framework, legislation and regulations including recommended reforms;
   - Integration of climate change, ecosystems management, blue-green circular economy and, sustainability policies;
   - Outline improvements and conditions for effective regulation and enforcement; and
   - Outline formal/statutory requirements for a national medium term management master plan.
- Water Reuse strategy and programme;
   - Regulations governing reuse and effluent discharge standards; and
   - Identification of uses and markets for treated reclaimed water.
- Strategy and programme for low-income communities addressing water and wastewater services, including;
   - Water conservation;
   - Water reuse; and
   - Decentralised treatment.
- Establish national reclaimed water reuse and plumbing standards including;
   - Codes of Practice;
   - Training and certification; and
   - Registration requirements.

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

5 ECONOMIC AND FINANCIAL ANALYSIS

An economic and financial analysis, examining the various design considerations related to this project has been prepared and was required in the context of the Barbados economy showing how this project can advance Barbados into the growth of a green economy model that can be sustained over the long term.

5.1 Capital Expenditure Forecasts

The need for and timing of all works have been reviewed in developing the capital expenditure forecasts in this economic and financial analysis. **Table V** provides a summary of the capital expenditure forecast for the first 10 years, the subsequent two 10-year periods and the 30-year total. The forecasts are broken down by business areas and strategic drivers. **Table P** provided a brief analysis of the options for the treated water noted in **Table V**. Key Capital Expenditure Assumptions are shown in **Exhibit 1 in Appendix 4**.

This economic and financial analysis is focused on the CAS plant. In addition to the financial advantages illustrated in **Table U,** it has several process and operating advantages including:

- Lowest capital cost;
- Lowest power consumption & least GHG associated emissions;
- Lowest expected operator staff time (operating cost);
- Most familiar technology for operations staff;
- Ability to meet the Barbados government's proposed reuse water quality standard; and
- Simplest use of existing process components for the upgrade to the BSTP.

5.2 Asset Renewal Strategy

The degradation of infrastructural assets over time results in a decline in the performance to the point of asset failure. Asset failures have the potential to cause loss of service and may pose a risk to public health and safety. Asset replacement and rehabilitation programmes are developed to monitor the condition and performance of assets in order to assess the end of their useful life. Asset renewal decisions are based a risk assessment of the likelihood and consequence of failure taking into consideration the asset age and life expectancy, asset condition, asset performance, system resilience and asset criticality. For the purpose of this economic and financial analysis, we have estimated that the useful life of the asset and the replacement and programmes are in accordance with the manufacture's recommendation, or unless otherwise stated.

INTEGRATED SUSTAINABILITY

Table U. BSTP Treatment Upgrading Options - Capital & Operating Comparison

Description	ELECTRICAL USE (kWh/y)	ELECTRICAL COST @ US$0.29/kWh (US$/y)	ANNUAL OTHER O&M COST ($US/y)	ADDITIONAL SOLAR PANELS (#)	ADDITIONAL SOLAR COST ($US)	UPGRADE COST (US$)	UPGRADE & SOLAR CAPEX (US$)	ANNUAL OPEX (US$/y)
Existing **CAS** Secondary Treatment Process	1,245,867	$361,301	$496,157	0	$0	$0	$0	$857,458
Upgrade to **CAS with 4-Stage Bardenpho** Configuration	1,734,480	$502,999	$496,157	300	$240,000	$28,057,000	$28,297,000	$999,156
Upgrade using **MBBR** Treatment Technology	4,432,560	$1,285,442	$930,150	3,100	$2,480,000	$32,588,707	$34,705,071	$2,215,592
Upgrade Using **MBR** Treatment Technology	2,645,520	$767,201	$1,014,157	1,245	$996,364	$35,189,289	$35,967,471	$1,781,358
RO Treatment (4,5)	2,303,880	$668,125	$1,300,000	2390	$1,912,727	$9,000,000	$10,913,000	$1,968,125

Table Notes:

1. *RO Costs based on upgrading the BSTP to produce 9,000 m³/d for reuse water, treating 7,100 m³/d with RO and blending 5,350 m³/d of RO permeate with 1,900 of reuse water (i.e. not treated with RO), to produce 7,200 m³/d or irrigation water with a capital cost of US$1,250/m³/d for brackish water RO treatment. Capital cost ranges from US$690 to US$4,067/m³ of the capacity depending on the feedwater quality, corrected for inflation to 2020. (Pearson, J.L. et al. 2021. Economics and Energy Consumption of Brackish Water Reverse Osmosis Desalination: Innovations and Impacts of Feedwater Quality. Membranes, 11, 616.).*
2. *Other RO assumptions include: 80% recovery, influent TDS = 1,500 mg/L; blend product water to produce TDS of 450 mg/L; 0.7 kWh/m³, 6-yr membrane life, Membrane cost = 50% total capital cost; US$314,000/yr for chemicals, no additional labour cost to operate RO (I.e. use existing labour),*
3. *PV requirement is not reduced by existing 1,500 panels (i.e. offset is only taken into account for treatment upgrades).*
4. *Solar cost assumptions include: 1,500 panels currently deployed; 320 Watts per panel; 8 hr/d sunlight; US$800/panel installed (Note: Additional Solar Panels are those required in addition to the existing panels currently deployed at the BSTP.*
5. *Other costs include labour and an allowance for MBBR media and MBR UF membrane replacement every 6 years.*
6. *No RO cost allowance for brine treatment, contingency, engineering, or disposal (assumed EPD will permit brine discharge through existing outfall)*
7. *Further details related to this table are provided in Appendix 3.*

Table V. Capital Expenditure Forecasts – US$million

Business Area	Contributing Driver	Year 1 - 10	Year 11- 20	Year 21- 30	30-year Total
Conventional Activated Sludge (CAS)					
WASTEWATER	Wastewater Networks and Transmission	47.0	-	4.7	51.7
	Wastewater Treatment	30.0	3.0	5.1	38.1
	Energy and Control Systems	0.6	0.1	0.1	0.8
	CMMS	0.1	-	0.1	0.3
Grand Total		**77.7**	**3.1**	**10.1**	**90.8**
Treated Water - Option 1					
	Water Network Transmission	6.5	-	0.7	7.2
	Wastewater Reverse Osmosis (RO) Treatment	9.7	2.4	2.4	14.6
	Injection Wells (6)	0.2	0.0	0.0	0.2
Grand Total		**16.4**	**2.4**	**3.1**	**21.9**
Treated Water - Option 2					
	Water Network Transmission	13.5	-	1.4	14.9
	Wastewater Reverse Osmosis (RO) Treatment	9.7	2.4	2.4	14.6
	Injection Wells (9)	0.3	0.0	0.0	0.3
Grand Total		**23.5**	**2.4**	**3.8**	**29.7**
Treated Water - Option 3					
	Water Network Transmission	4.5	-	0.5	5.0
	Wastewater Reverse Osmosis (RO) Treatment	9.7	2.4	2.4	14.6
	Injection Wells (6)	0.2	0.0	0.0	0.2
Grand Total		**14.4**	**2.4**	**2.9**	**19.7**
Treated Water - Option 4					
	Water Network Transmission	1.5	-	0.2	1.7
	Wastewater Reverse Osmosis (RO) Treatment	-	-	-	-
	Injection Wells (3)	0.1	0.0	0.0	0.1
Grand Total		**1.6**	**0.0**	**0.2**	**1.8**

Detailed annual capital expenditure costs are shown in **Exhibit 2 in Appendix 4**.

5.2.1 Critical Facilities and Assets

Critical facilities and assets are those that should not be allowed to fail because the consequences of a failure are too high. Criteria to identify which facilities and assetsare critical include:

- Health and safety risk;
- Number, type and duration of customers affected;
- Environmental consequence of the asset failure;
- Size and location of the asset; and
- Complexity of repair and outage duration.

5.3 Plant Assets

Plant assets include wastewater treatment plants, pump stations and reservoirs. These are generally accessible and have inspections and planned maintenance programmes. Dual process streams are incorporated within plants to provide redundancy and resilience, where feasible. Mechanical and electrical assets within these facilities have duty and standby assets to reduce the criticality ofindividual assets. Renewal of plant assets are planned based on the performance ofthe asset and condition assessments outlined above.

5.4 Transmission Assets

The transmission assets convey significant quantities of wastewater across the Bridgetown region. The failure of these assets can have a significant impact on many customers, the environment or public health and safety. All transmission assets are classed as critical assets and are scheduled for renewal based on age and condition assessments.

5.5 Network Assets

The network assets generally comprise smaller diameter pipes. The impact of a failure of these assets is typically much lower than a transmission asset failure due to the limited number of customers affected and reduced environmental or public health and safety impacts associated with a failure. For this reason, most network assets are considered to be non-critical assets and are allowed to fail a number of times before they are replaced. The consequence of failures is managed via the maintenance contracts' response performance indicators. A subset of network assets could be regarded as critical based on their location and the type of customers serviced.

5.6 Pipe Asset Age Profiles

Pipe assets make up some of the infrastructure assets of the BWA and therefore a renewal strategy that addresses the uncertainty surrounding these buried assets is important.

5.7 Revenue and Financing Policy Assumptions

In this economic and financial analysis, we have assumed the following principles regarding revenue and financing:

- Paying for Benefits Received - In general, if a service mainly benefits a particular person or group, then that person or group should contribute to the cost of the service;
- Intergenerational Equity - The spread of benefits over time from an item of expenditure should be reflected in a spread of cost to users over time;
- Paying for Costs Imposed - As far as practicable, cost should be recovered from the people who have caused the cost to be incurred i.e., User pay;
- Transparency and Accountability - Where the principles of paying for benefits and paying for costs suggest that a particular person or group should contribute towards the cost of a service, then that service should be funded separately from other services, if it is practicable to do so;

- Financial Prudence and Sustainability - Revenue, expenditure, assets, liabilities, investments, and general financial dealings should be managed in a prudent and sustainable manner;
- Efficiency and Effectiveness - Revenue and financing policies should have regard to the costs of carrying them out, and how effective they will be in achieving their objectives;
- Affordability - revenue and financing policies need to reflect consideration of people's ability to pay and the desire to provide broad access for people to fundamental services; and
- Overall Social, Economic, Environmental and Cultural Impacts - Revenue decisions should consider the impact of the decision on the current and future social, economic, environmental, and cultural well-being of the community.

5.7.1 Willingness to Pay

As part of this project, a very limited Willingness to Pay public survey was undertaken and the result of that survey is shown in **Exhibit 3 in Appendix 4**. The limited results of that survey would not generally be representative of the view of the wider public but could be indicative of a trend.

The principal goal of the "Willingness to Pay" study was 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.

However, due to the current economic downturn, associated with a significant reduction in tourism due to the Covid pandemic, the GoB decided to cancel the circulation of the Willingness to Pay study to the population shortly after it was released in local newspapers. As such, only a small amount of information was collected before the study was recalled.

From the information collected and provided in **Exhibit 3 in Appendix 4**, the sample was collected on the high end of the income and education spectrum, and it is notable that the willingness to pay results suggest quite clearly that people are willing to pay for the improvements. The two approaches that the study used to elicit willingness to pay (dichotomous choice with different fee levels and the "payment card" approach) produced nearly the same estimates of mean willingness to pay (around $15/month), which represent what the publics willing to pay in addition to what they are currently paying monthly.

5.7.2 Funding Operational Expenditure

In this economic and financial analysis, we have assumed that the projected operating revenue will be sufficient to cover the cost of regular, on-going operating activities. A combination of fees and charges are used to fund operating expenditure.

5.7.3 Funding Capital Expenditure

In this economic and financial analysis, we have made assumptions about how the BWA will fund and finance the projects;

- Funding is how the project will ultimately be paid for (fees and charges); and

- Financing is the way in which the money is raised to undertake the project (usually debt).

The principle of intergenerational equity suggests that assets with a long-life span should initially be financed by borrowings. In that way, repayments are spread over a longer period, instead of users paying for the entire cost of an asset in the year that it is acquired / built. This general principle, however, needs to be balanced by consideration of the nature of the capital expenditure and other relevant funding principles. It should be noted that aspects of the project could be funded by grant funding.

A potential source of funding for this project woold be the GCF. The GCF provides grants, loans, equity or guarantees towards the implementation of qualifying projects and programmes. It does not implement projects directly but rather, works through Accredited Entities (AE) which meet the standards of the Fund. AEs execute various activities including the development of funding proposals, management, and monitoring of projects.

The CCCCC became fully functional in 2004 and is also a registered AE for the GCF. The mandate of CCCCC is to coordinate the region's response to climate change, and its early work laid the framework for successful projects utilizing the GCF. A key programme of the CCCCC was the implementation of the SPACC which aided in the development and implementation of pilot projects aimed at developing resilience and mitigating the negative effects of climate variability and change

5.7.4 Growth Related Capital Expenditure

New residential and commercial developments, such as planned for in and around the Bridgetown area, can increase the demand on the wastewater network and require the upgrade and/or the construction of new infrastructure. Existing infrastructure needs to be enhanced or expanded to cater for this increase in demand. In addition, to cater for growth within the areas not currently serviced by the BSTP, new infrastructure needs to be provided.

The most significant assumptions are based on forecast increases in population and estimate of the daily per capita wastewater demand. The BWA applies a levy which is applicable to all BWA customers at a rate of US$3.88/month/customer (or US$4.7 million per annum), based on an estimated 100,000 residential and non-residential customers. The average capacity of the upgraded plant is estimated to be 7,200 m^3/day (26.2 million m^3/years) of treated water[10].

The principles of paying for benefits received and paying for costs imposed require that such growth-related capital expenditure should be primarily funded by the associated 'growth community', i.e., those that cause the need for, and benefit from, the new or improved infrastructure. It is appropriate that charges to these users be used to partially fund such capital expenditure which may be, partially of fully, financed by borrowings or grant funding.

5.8 Long-life Service Improvement Related Capital Expenditure

Borrowings are appropriate when the service improvement asset has a long life andwill provide a benefit over a long period. By financing over a long period, current and future users both pay for

[10] Conceptual Design Report

the benefit they receive. This project is expected to be financed by Government and we have projected that the financing would be through an IFI (such as the CDB, EIB IDB, etc.), or similar financial institutions, or through the GCF, at applicable rates. Long-life Service Improvement Related Capital Expenditure could also be finance by grants provided by the GCF.

5.9 Renewal Capital Expenditure

The BWA has an on-going obligation to maintain the long-term integrity of its assets and as a result an annual requirement to fund a substantial level of renewal capital expenditure. Since this annual programme of work is required to replace ageing infrastructure rather than add service capacity or cater for new growth, it is appropriate that fees and charges to current users fund this capital expenditure.

5.10 Short Life Service Improvement Related Capital Expenditure

BWA has an on-going programme of capital expenditure that relates to short life service improvements, such as information system's capital expenditure. It is appropriate that fees and charges to current users fund this capital expenditure. It should be noted that the supply of potable water and the disposal of wastewater by the BWA is regulated by the FTC.

5.11 Funding Interest and Principal Repayments on Borrowings Raised to Fund Capital Expenditure

Fees and charges are appropriate to fund the on-going servicing cost and repayment of borrowings raised to finance growth and service improvement capital expenditure. This is consistent with both intergenerational equity and financial prudence and sustainability principles.

5.12 Financial Strategy - Debt or Grant Funding

We have assumed that the BWA will be either raising debt, from IFIs noted earlier in this economic and financial analysis, or through grant funding from the GCF, to finance a level of the new capital expenditure and will be generating fees and charges to repay any debt obtained. Given the long life of the BWA's debt financed assets, fees and charges projections should achieve a level sufficient to repay new debt within the life period of the asset for which the debt was raised, if the project is debt funded.

5.13 Operational Expenditure Forecasts

The operational expenditure forecast for the period is presented in nominal dollars (including inflation) in **Table W**. This economic and financial analysis provides a summary of the operational expenditure forecast for the first 10 years, the subsequent two 10-year periods and the 30-year total. As noted earlier in the economic and financial analysis, Option 1, Options 2, and Option 3 (as outlined in **Table P**) require an RO Plant, so we have modelled operating expenditure forecasts of the CAS system with and without the RO Plant.

Operational expenditure (excluding depreciation and interest) includes allocations of shared services expenditure. For each activity operating expenditure is split into employee benefit expenses (labour), maintenance and asset operating costs and other expenses including chemicals (coagulant and disinfection). Electricity being a significant component of the operational expenditure is separately shown. Detailed annual operating costs are shown in **Exhibit 4 in Appendix 4**.

The total forecast operational expenditure for the first 10-year period (excluding depreciation and interest) is estimated to be US$19.72 million with the RO Plant and US$17.46 without the RO Plant.

Table W. Operating Expenditure Forecasts – US$million

		Year 1 - 10	Year 11- 20	Year 21- 30	30-year Total
Conventional Activated Sludge (CAS) with Waste Water Treatment RO Plant					
WASTEWATER	Asset operating Costs	5.12	6.14	7.37	18.63
	Maintenance Costs	3.84	4.61	5.53	13.97
	Electricity Expenses	12.82	15.39	18.47	46.68
	Employee Expenses	14.07	16.89	20.26	51.22
	Other Expenses	2.56	3.07	3.68	9.31
Grand Total		**38.41**	**46.09**	**55.31**	**139.81**

Conventional Activated Sludge (CAS) without Waste Water Treatment RO Plant					
WASTEWATER	Asset operating Costs	2.19	2.63	3.15	7.97
	Maintenance Costs	1.64	1.97	2.37	5.98
	Electricity Expenses	5.51	6.62	7.94	20.07
	Employee Expenses	6.02	7.23	8.67	21.92
	Other Expenses	1.10	1.31	1.58	3.99
Grand Total		**16.46**	**19.76**	**23.71**	**59.93**

For the CAS with the RO Plant, over the first 10-year period, employee costs make up approximately 37% of the total operating costs, electricity costs make up about 33%, asset operating costs contributes 13% while maintenance contributes on average 10%, and the remaining 7% is attributable to other expenses.

For the CAS without the RO Plant, over the first 10-year period, employee costs make up approximately 36% of the total operating costs, electricity costs make up about 33%, asset operating costs contributes 13% while maintenance contributes on average 10%, and the remaining 7% is attributable to other expenses.

Over the 30-year period, the operational expenditure in wastewater (in real dollar terms) range is estimated to be between US$59.93 million without the RO Plant and US$139.81 million with the RO Plant.

5.14 Significant Assumptions and Risks

5.14.1 Efficiency/Value for Money Savings

In general, the capital investment planning process produces project cost and implementation timing estimates with varying degrees of precision. Uncertainty of estimates is implicit in forecasting capital expenditure programmes. Actual project costs can be more or less than initially estimated due to new technologies, materials, method of construction, processes, and supply constraints.

5.14.2 Cost Adjusters

The following Cost Price Index and Capital Goods Price Index adjusters shown in **Table X** have beenapplied to the long-term financial projections. The cost price index is applied to real operating expenditure to derive nominaloperating expenditure as well as to real capital expenditure to derive nominalcapital expenditure.

Table X. Cost Adjusters - Inflations

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11- 20	Year 21- 30
Inflation Estimate	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	20.00%	20.00%

5.14.3 Key Assumptions in Projections

The detailed operating expenses are outlined in the projected statement of operations and are based on the key assumptions that are included in **Exhibit 1 in Appendix 4**. In these projections, it is assumed that operating expenses will increase at a consistent rate throughout the 30-year plan.

5.14.4 Capital Asset Management

The BWA has long term planning studies, which address the wastewater treatment and distribution facilities and water distribution linear assets, providing rehabilitation and replacement recommendations used for forecasting capital requirements and ongoing maintenance. The Engineering Division schedules capital replacement for its linear assets based on prioritization calculated using the following characteristics: break history, soil condition, age, material type, criticality as well as theintegration with road resurfacing, road reconstruction work and other utilities' underground efforts.

Over the projected period, as shown in **Table V**, approximately US$51.7 million in capital infrastructure will be spent to upgrade the wastewater treatment plant, while the capital infrastructure on the options for the treated water distribution network are be between US$1.8 million and US$21.9 million between year 1 - 30.

5.15 Cost Benefit Analysis

We have undertaken a CBA using an incremental approach to compare the net incremental cost with the net incremental benefit of the options outlined in this economic and financial analysis. Depreciation and interest expenses were excluded from the CBA.

In this economic and financial analysis, we have assumed that there is no existing benefit from the wastewater from the current BSTP as this water is disposed at sea. With secondary treatment, this reclaimed water is added to the existing aquifers, creating a greater amount of potable water, or used for agricultural irrigation. We have assumed that there is a financial benefit for the project that a percentage of this reclaimed water eventually contributes to the potable water which is able to be sold by the BWA at residential or commercial rates or used for agricultural irrigation.

For this economic and financial analysis, if the reclaimed water is distributed for aquifer recharge and irrigation purposes (as reflected in the first 3 options of **Table P**) we have assumed that 48% of this reclaimed water from the BSTP is converted into potable water (**see Figure P**). In this example, we have estimated that 60% of the reclaimed water would go towards replenishing the aquifers, with 40% of the reclaimed water being directed towards agricultural irrigation. Of the 60% of the reclaimed water going towards the aquifers, we estimate that approximately 20% of this amount would be carried to the ocean and the remaining would be used by water pump stations. With respect to the reclaimed water allocated for agricultural irrigation, it is expected that some of this water would be absorbed by the plants and the remaining water would eventually go towards aquifer replenishment. The incremental benefit would be the benefit derived from the new plant compared to the existing benefit of the existing plant. In the case of option 4 (in **Table P**), considering all the water is used for aquifer recharge adjacent to the Spring Garden BWRO WTP, we estimated that 80% of the water would be used by the WTP and converted to potable water, while 20% would travel to the adjacent ocean and be lost.

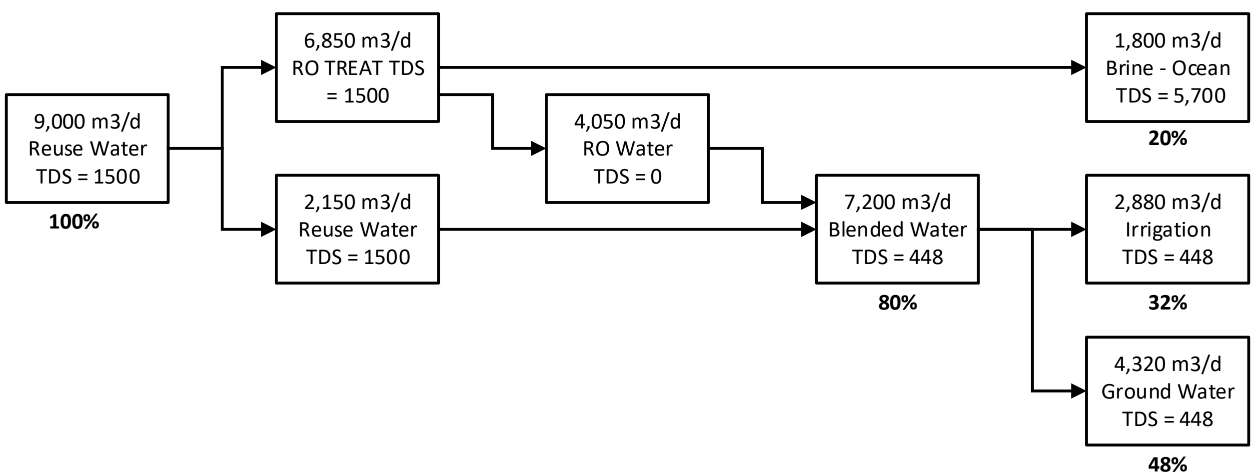


Figure P. Reclaimed Water Use Assumptions

Exhibit 5 in Appendix 4 shows the potential financial benefit derived from the implementation of this project.

In addition, the use of reclaimed water would provide an additional benefit, resulting in increased potable water for residential and commercial purposes and for agricultural irrigation, particularly during the dry season. Reclaimed water for aquifer replenishment could potentially reduce the need for the BWA to implement water rationing during the dry season The use of reclaimed water for irrigation purposes provides an option that would not only be beneficial to the environment, but also provides an added benefit to the farming community[11]. Also as noted in the Conceptual Design Report, agricultural water reuse reduces demands on fresh water sources and is a means of nutrient management and recovery. It also results in greater crop production reliability due to more constant yields.

With respect to the existing costs for the current BSTP, we have assumed that without this project, that the cost of the operation of this plant will remain. For this economic and financial analysis, we have assumed that the cost of operating this exiting plant, due to its age, would be approximately 85% of the cost of the upgraded plant. The costs of the new plant includes both capital and operating costs. These costs are reflected for each of the options noted. The incremental cost is the difference between the costs of the new plant compared to the costs of the existing BSTP.

As noted earlier in this economic and financial analysis, Option 1, Option 2, and Option 3 (as per **Table P**) requires the construction of an RO plant in additional to the upgraded tertiary treatment CAS technology, as noted in the Conceptual Design Report. Option 4 (in **Table P**) does not require a new RO plant, as this option utilizes the existing Spring Garden BWRO desalination plant. For each of these options, we have considered both capital costs and O&M costs for purposes of the CBA.

The Options considered also allow for injections wells as various locations. We have considered both capital costs and O&M costs for the injection wells for each of these options for purposes of the CBA.

For purposes of this analysis, we have estimated that PV modules would be installed on building rooftops, as well as open spaces within the property, to the extent of approximately 3.91 MW of PV to supplement the existing power provided to the BSTP, as well as the power requirement for the proposed RO Plant identified for Option 1, Option 2, and Option 3. Our estimate for the size of the PV system is to make the BSTP electricity neutral, as the proposed new PV system, along with existing PV systems at the BSTP are used to off-set plant electrical power costs used by the BSTP. It should be noted that in accordance with the FTC, the electricity generated by PV systems is connected into the grid and sold to the local electricity company. We have considered both capital costs and O&M costs for the PV system for each of the options for purposes of the CBA.

Table Y provides an illustration of the derivation of the incremental costs and incremental benefits using Year 1 of Option 1 as shown in **Exhibit 6 in Appendix 4** as an example.

Detailed annual costs and benefits of all the options are also shown in **Exhibit 6** to **Exhibit 9 in Appendix 4**.

As shown in **Table Y**, the CAS with Option 4 provides the highest Gross Project Flow over the 30-year forecast period, while the CAS with Option 2 provides the lowest Gross Project Flow over this same period.

Table Z shows the overall CBA for the project considering all the options.

[11] Source: Cost Benefit Analysis – Provision of Reclaimed Water for Irrigation Purposes – Ministry of Agriculture and Food Security – March 03, 2021

Table Y. Illustration of the Cost Benefit Analysis for Option 1 – Year 1(US$million)

Benefits		Year 1	
	Gross Project Inflows with project		
	Proceeds from Treated Water	5.47	= 7,200 M3/day X 365 X 80% X $2.60 M3 (water to acqifer replenishment)
	Electricity Generated	0.06	=315,900 KWh x $0.1813/KWh
	Sale of phosphorus	0.07	= 61 Tonne X $1,200/Tonne
	Gross Project Inflows with project	**5.60**	

	Gross Project Inflows without project		
	Proceeds from Treated Water	-	= 7,200 M3/day X 365 X 80% X $0.00 M3 (water discarded in ocean)
	Gross Project Inflows without project	**-**	

Costs			
	Gross Project Outflows with project		
	Total Operating Costs	3.57	= Operating Cost (Exhibit 4 - Year 1 CAS with RO Plant $3.51) + (6 wells x US$10k/well)
	Total Capital Costs	40.53	= Capital Cost (Exhibit 2 - Year 1 - Wastewater $31.3 + Capital Cost (Treated Water - Option 1 - Year 1 $9.3)
	Gross Project Inflows with project	**44.10**	

Costs			
	Gross Project Outflows without project		
	Total Operating Costs	2.98	= Operating Cost (Exhibit 4 - Year 1 CAS with RO Plant $) X 85%
	Gross Project Inflows without project	**2.98**	

Table Z. Cost Benefit Analysis of the Options (in US$million)

Summary	Option 1	Option 2	Option 3	Option 4
Benefits				
Inflows with Project	202.59	202.59	202.59	202.59
Inflows without Project	-	-	-	-
Net Incremental Inflows	202.59	202.59	202.59	202.59
Costs				
Total Operating Costs	142.07	143.21	142.07	61.06
Total Capital Costs	112.76	120.58	110.56	92.59
Outflows with Project	254.82	263.78	252.63	153.66
Outflows without Project	118.84	118.84	118.84	118.84
Net Incremental Outflows	135.99	144.95	133.79	34.82
Gross Project Flows	**66.60**	**57.64**	**68.80**	**167.77**

6 MANAGING RISK

6.1 Risk Assessment

A risk assessment was included in the Conceptual Design report (and certain section repeated in Section 7.3) that intended to identify internal risks, exposure to cumulative effects, and external factors that may affect the availability and reliability of wastewater management for wastewater treatment and sewage collection systems framed within the context of climate change. Recommended risk mitigation strategies are intended to minimize the potential for operational disruption and create an adaptable strategy, resilience to changes in baseline conditions, and under the expectation that future conditions will be strongly influenced by climate change.

In the context of this assessment, security is defined as having access to suitable wastewater management infrastructure that is capable of managing wastewater for beneficial reuse for supplying water for agricultural irrigation and aquifer recharge, while ensuring safe, and sustainable management of residuals. Reliability is defined as the assurance that the wastewater collection, treatment, and effluent supply functions will not change significantly with time, with adaptable plans in place to avoid interruptions in critical functions of the infrastructure as a result of climate change events.

6.2 Risk Assessment Objectives

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

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

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

6.3 Risk Assessment Approach

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

The risk assessment is divided into two stages: 1) Conceptual: risk formulation and characterization; and 2) Feasibility: risk and opportunities analysis. The conceptual phase identifies characterizes and provides context and professional advice on current risks to climate resiliency in wastewater systems. The Feasibility stage is intended to affirm the context, determine the likelihood, and expected effects on the economic and technical viability of proposed wastewater management strategies, with potential mitigating solutions to current and future risk valuations. The overall purpose is to develop strategies to manage through potential risk realizations and provide a management approach to address future challenges.

Figure Q. Process Flow for Water Security Assessment

6.4 Assessment Criteria

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

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

6.5 Risk Identification

Several key risks and associated opportunities have been identified that may influence the security of wastewater management and water supply and disposal. Some of the potential environmental and social impacts related to the construction and implementation of this project were described in the Baseline Study. Environmental and social risks mentioned here will be further identified within the concurrent ESIA and ESMP project (by others).

6.5.1 Climate Risks

Climate change is expected to exert a significant effect in the hydrologic cycle for Barbados. This includes variations in the intensity and duration of rainfall events with the potential for both drought and flooding impacts and damage to infrastructure. The interactions between wastewater management, aquifer recharge, as well as groundwater extraction and loss of fresh groundwater to the ocean in island nations such as Barbados will become more complex and challenging under a more variable climate. The major risks associated with climate change associated impacts on wastewater and water management include:

- Flooding due to changes in precipitation characteristics and surface runoff deficiencies as well as sea-level rise and/or storm surges impacting centralized wastewater collection and treatment ion, that strain the wastewater collection and treatment infrastructure;
- Droughts affecting groundwater/potable-water availability, resulting in a more pronounced incursion of salt water into near-coast aquifers and an overall increase in salinity in most of the ground water wells along the coastline; and
- Increase in intensity of storm events resulting in significant damage to wastewater infrastructure and the need for changes in engineering specifications to meet reliability needs under future conditions.

6.5.2 Technical Risks

The technical risks associated with building and maintaining centralized wastewater collection and treatment infrastructure and decentralized onsite wastewater disposal systems are manageable are but numerous and vary in cause and effect. The augmentation of groundwater resources using reuse water also has technical challenges including complex subsurface interactions which may vary with climate change and subject to physical complexities which are difficult to characterize.

Technical risks associated with the proposed infrastructure upgrade and adaptation options include:

- Design complexity of new wastewater treatment infrastructure to produce effluent of sufficient quality for agricultural irrigation use and groundwater augmentation;
- Capability of existing process management, data collection and analysis systems to adequately maintain required system performance;
- Economic feasibility of bioenergy recovery based on centralized wastewater biosolids production;
- Aquifer pressure build-up within confined aquifers (local, and regional);
- Formation or well plugging due to chemical or biological fouling;
- Cumulative effects on groundwater quality from other commercial activities (such as farming);
- Anisotropic injection rates; and
- Reuse water injected into the ground may not diffuse in a predictable manner.

6.5.3 Environmental Risks

Environmental risks include the impact of increased rainfall on soil saturation on the infiltration and natural process remediation received by the wastewater disposed to ground from the many decentralized onsite wastewater disposal systems that serve most of the population. There is evidence that current practices are having an impact on groundwater quality and coastal shoreline marine environments and further soil saturation could impair pathogen removal and pose a potential public health risk.

The key environmental risks identified include:

- Excess reuse water irrigation surface runoff and impacts on sensitive surface water courses and marine environment;
- Inability to controlled stormwater inflow and infiltration to the collection system, infrastructure integrity, monitoring and remediation capacity;
- Management of wastewater treatment residuals;
- Increased nitrogen loading to groundwater; and
- Construction impacts.

6.5.4 Public Health Risks

All wastewater collection and treatment infrastructure pose potential public health risks if not operated and maintained properly. Inadequate treatment combined with inadequate monitoring and water quality analyses could place the environment and public at risk.

The key potential public health risks identified include:

- illness from ingesting pathogens as a result of exposure to inadequately treated wastewater and not meeting reuse water quality requirements;
- hydrogen sulphide (H_2S) generation and release resulting in odour problems in surrounding residential areas; and
- unauthorized access to sewers.

6.5.5 Baseline Data Risks

There is a lack of continuous and reliable wastewater information that would otherwise be of use to inform operations personnel of changes that are or could affect wastewater collection, treatment, and environmental protection. The existing wastewater characterization and treatment operating datasets are small and incomplete. Similarly, there is a lack of data pertaining to aquifer characteristics and hydrological conditions.

Baseline data risks identified include:

- lack of wastewater flow and quality data;
- baseline assumptions on wastewater flows and quality may result in underestimating upgrading capital and operating costs;
- the sewage collection system may have a greater amount of inflow and infiltration than estimated;
- the capacity of the existing sewage collection system may be insufficient to transfer future flows;
- there may be insufficient land for the BSTP upgrade components;
- the current impact of rainfall on wastewater flows, and capacity to transfer and treat wastewater may be over-estimated;

- the upgrade capacity and associated capital and operating costs could be underestimated;
- performance of existing BSTP may be overestimated and upgrading costs may be underestimated;
- the BSTP is over 40 years old and there is no information available on the existing structural (such as concrete and building components) and equipment condition.
- the salvage and repurposing value of the existing BSTP infrastructure may be over-estimated;
- no information is available on the performance of onsite wastewater disposal systems;
- onsite system failures could be impacting public health and the environment; and
- limited data is available regarding formation characteristics.

Given the lack of hydro-geotechnical data throughout Barbados, there is uncertainty regarding the long-term implementation of aquifer recharge measures.

6.5.6 Stakeholder Risks

Stakeholder engagement is critical to developing public consensus for regional infrastructure projects and ensuring that the social performance aligns with community needs. As such, a Stakeholder Analysis report was prepared separately and is available for review. The key stakeholder risks identified include:

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

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

6.5.7 Institutional Risks

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

The institutional risks identified include:

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

6.6 Risk Mitigation

6.6.1 Adaptive Management and Regional Planning Initiatives

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

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

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

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

6.6.2 Risk and Water Security

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

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

7 LOGICAL FRAMEWORK

7.1 Introduction

This study has determined that the most significant potential climate change impact on the wastewater infrastructure in Barbados is related to drought. The island relies on precipitation to replenish limited groundwater supplies, and changes in precipitation characteristics can severely reduce potable water resources, as has been confirmed recently. The majority of the population (95 percent) disposes wastewater directly to ground, contributing dissolved wastewater constituents to the aquifer and impairing groundwater quality for potable water use. Most of the remaining 5 percent of the population is served by two sewage collection and treatment systems: 1) the SCSTP and 2) the BSTP. Both plants discharge the processed wastewater to the ocean; whereas many parts of the world consider the wastewater as a potential water resource asset either through reclamation and reuse to satisfy water demands or, in some cases, used to augment groundwater resources that subsequently serve as an indirect potable water resource.

The Feasibility Study recommends the BSTP be upgraded to a tertiary water standard suitable for reuse applications, and the water either by piped to the nearby Spring Garden Brackish Water Reverse Osmosis facility to supplement and augment groundwater resources used for producing potable water, as well as consideration for further treatment of the reuse water using Reverse Osmosis treatment to reduce total dissolved solids and then, in concert with the Barbados government's plan to construct a pipeline to supply reclaimed water to St. Lucy for agricultural use. While it is economically impractical to consider constructing sewage collection and treatment systems for all of Barbados, the study supports another Government of Barbados proposed plan to construct small-scale cluster wastewater collection and treatment systems for implementation in Zone A groundwater extraction areas where onsite disposal systems are believed to be contaminating the local potable water aquifer.

To enable this wastewater reuse concept, and upgrade the BSTP to improve the treated water quality to achieve a reuse water quality standard for use in groundwater augmentation and/or supply water for agricultural irrigation, it is necessary to also consider what needs to be done to operate and maintain the collection and treatment infrastructure including developing training resources for operations and maintenance; public and stakeholder information and educational materials; and establish enabling legislation and guidance materials.

A Logical Framework was developed during the Conceptual Design stage to consider the various potential activities that could be carried out to achieve the climate change adaptation goals being developed. Also called a Logframe, the Logical Framework is used as a planning tool in the form of a spreadsheet matrix that provides a structure to interrelate the project components and activities of a project in a manner that illustrates the relationship between them and identifies key outcomes.

Since first presented in the Conceptual Design Report, the LogFrame now consists of four Components that reflect the recommendations within this Feasibility Report which have received general acceptance by the BWA and government stakeholders.

7.2 Components

Component 1: Supplement potable water resources by: 1) upgrade the centralized wastewater treatment facilities to achieve a minimum tertiary water quality standard suitable for agricultural irrigation and groundwater augmentation reuse applications; 2) implement cluster wastewater collection and reclamation treatment for sensitive Zone A aquifer areas impacted by decentralized onsite wastewater disposal practices; and 3) intercept and treat groundwater in coastal areas served by onsite wastewater ground disposal and produce potable water using reverse osmosis for the overall purpose of improving the water sector resiliency to climate change.

Component 2: Implement renewable energy measures, improve energy efficiencies, and reduce air emissions consistent with national Zero Emissions objectives for the BSTP facility.

Component 3: Improve technical personnel capabilities to operate, maintain and monitor wastewater and related renewable energy systems (water treatment and PV systems) through improved training opportunities and operations data availability and increase public awareness of water reuse safety measures and water availability benefits.

Component 4: Enhance the existing policy and regulatory framework and improved climate resilient development planning and decision making for the water sector and wastewater systems.

7.3 Risks, Barriers, and Benefits

7.3.1 Component 1 – Water Reuse Strategies.

SITUATION: Barbados is almost entirely dependent (approximately 90%) on groundwater supplies, which is directly impacted by the weather and climate. Groundwater supplies are replenished by annual rainfall, through groundwater aquifer recharge, and are impacted by saltwater intrusion (brackish water) as a result of rising sea levels and excess groundwater extraction due to increased frequency and severity of droughts, which climate models suggest may intensify in the future in the Caribbean region (Vichot-Llano et al., 2020) and impact agriculture and water resources. Climate change is expected to worsen these conditions. The Barbados-based CIMH climate change modelling predicts a decline in annual precipitation for 2080-2099 from 10% to 27%. A drop of 27% would be critical for Barbados, which already experiences drought and increasing groundwater salinity. The BWA has reported decreases in groundwater levels at most groundwater wells located across the country. Potable water production has been reduced by as much as 3 million gallons per day during severe drought events that have occurred to date. These restrictions on potable water use have drastic implications for water and food security as well as an economic impact to the island's industries and tourism. Recent trends towards longer periods of drought can significantly impact the water balance resulting in interruptions in water supply, diminishing water supply resources, and increasing strain on current water availability of potable water during drought conditions. Agriculture is also vulnerable to climate change as droughts can cause pre-mature death of livestock and poultry and reduce crop yields (CCCCC, 2019). Efforts to produce potable water from brackish groundwater along the coast have been effective; however, even this water source has limited availability. Reclaimed wastewater has significant value in application to satisfy water demands that do not require potable water, and reclaimed water can be injected into the ground to replenish groundwater resources in the immediate vicinity of reverse osmosis water treatment facilities, like Spring Gardens, or augment groundwater resources as a means of indirect potable reuse.

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

- Social Risks/Barriers:
  - Although technically feasible, the treatment, reclamation, and reuse of wastewater effluent for non-potable water applications to offset potable water demands may not be readily accepted by the public. A willingness to pay study that was initiated as part of this study indicated some acceptance, however, further study is required;
  - Routine wastewater flow measurement, effluent water quality analyses, and have not been carried out for a very long time. Measuring influent wastewater flows and collecting influent and effluent water samples. In addition, there exists an inability to enforce inadequate influent and effluent wastewater quality testing and reporting;
  - Only a small percentage of Barbadians are currently able to access the BSTP wastewater collection and treatment facilities; and
  - There is an absence of mechanisms to foster greater stakeholder participation in the design, implementation, monitoring and evaluation of project activities.
- Gender Risks/Barriers: Water shortages as a result of drought conditions, resulting from climate change, can pose great challenges for women who are primarily care givers for children and the elderly (as identified in the Gender Analysis and Gender Action Plan);
- Financial Risks/Barriers: The cost of distributing the reclaimed water into the community for non-potable use may be a major drawback, as dual plumbing systems need to be constructed to safely distribute and use the reclaimed water within buildings. In addition, the O&M costs for tertiary wastewater treatment, and especially specially RO treatment, system can be significant.
- Regulatory Risk/Barriers:
  - Currently there is no adequate policy in place to support and encourage the use of reclaimed water. The EPD currently restricts the use wastewater effluent for irrigation purposes to only ornamental plants and lawns; and
  - The current indication is the Government would prefer to use all reclaimed water for agricultural irrigation purposes; However, the Ministry of Agriculture has determined that reuse water for use in agriculture must have a total dissolved solids concentration no greater than 450 mg/L. To achieve this requirement the

reuse water musty be treated using reverse osmosis (RO), requiring high pressures and energy use, as well as capital cost.

- Technological Risks/Barriers: None. Several treatment technologies were considered (refer to Section 2.6 of the Conceptual Design Report) and ultimately, the BWA has expressed a preference in the CAS treatment type. There is little risk associated with this CAS technology as the BWA is already operating the existing BSTP using this technology; and
- Ecological Risks/Barriers: The continued discharge of partially treated (primary and secondary treatment) effluent into the ocean negatively impacts the marine environment (eg. nutrient loading can be detrimental to coral reefs and the near shore environment (W.F. Baird, 2019)). Elevated levels of nitrates in certain production wells that sample water discharged into the ocean have raised concerns over the quality of water.

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

7.3.2 Component 2 - Energy Recovery, Efficiency and GHG Emissions.

SITUATION: Centralized wastewater management relies on expensive high-emission electricity supplied from conventional power plants that use fossil resources. The

Barbados National Energy Policy sets a goal of achieving 100% renewable energy and carbon neutrality by 2030 including: the provision of reliable, safe, affordable, sustainable, modern and climate friendly energy services to all residents and visitors; zero domestic consumption of fossil fuels economy wide; export of all hydrocarbons produced both on land and offshore; maximising local participation (individual and corporate) in distributed renewable energy (RE) generation and storage (democratisation of energy); and creating a regional centre of excellence in RE research and development[12]. Upgrading the SCSTP and BSTP can be done in such a way as to produce waste biosolids with high potential for bioenergy recovery through anaerobic co-digestion with other organic solid waste, and power consumption can be offset through the deployment of large solar panel arrays at the treatment plant sites. The existing BTSTP facility can generate approximately 17,200 CO_2e of direct GHG emissions from the treatment process (at an average flow of 4,100 m^3/day) to approximately 238,000 CO_2e (at an average flow of 56,700 m^3/day).

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

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

- Social Risks/Barriers: None found associated with this Component;
- Gender Risks/Barriers: None found associated with this Component;
- Financial Risks/Barriers:
  - The costs associated with investing in proposed solar infrastructure could be high, especially if battery storage is deemed to be necessary. If ground-mounted solar is preferred, land would need to be allocated by the government;
  - Switching to natural gas generators, that emit less GHG than diesel generators, will also be costly. Supporting the private sector to develop a biogas facility could require allocating land to a facility; and
  - The establishment of an anaerobic digester to convert waste biosolids from the two treatment facilities to methane is unlikely to be economically justifiable.
- Regulatory Risks/Barriers: Some new legislation is required to support the renewable energy sector to develop, including signing Power Purchase Agreements. As anaerobic digestion applied solely to waste biosolids produced at the SCSTP and

[12] https://energy.gov.bb/publications/barbados-national-energy-policy-bnep/

BSTP is unlikely to generate enough methane to be sustainable, co-digestion with other high energy organic solid waste would be required;

- Technological Risks/Barriers: Solar PV is a mature technology, therefore there is little risk associated with it, however, the panels will need to be removed and safely stored during major storm events such as hurricanes. It is also not yet known what exact technology will be chosen by the private sector to develop a biogas facility; and
- Ecological Risks/Barriers: Regarding the biogas facility, collecting methane and other related gases may pose an explosion concern. As such, an explosion development radius may need to be considered. Odour control is also another factor that needs to be considered when choosing a land location to house this facility.

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

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

7.3.3 Component 3 - Operations Support.

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

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

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

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

7.3.4 Component 4 - Policy & Regulatory Framework and Public & Stakeholder Engagement.

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

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

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

- High degree of transparency is required; however, there may be capacity constraints and an inability of the BWA to routinely and consistently publish flow and water quality results on their website.

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

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

7.4 Outputs & Activities

The four Components described in Sections 7.2 and 7.3 were carefully reviewed the Caribbean Community Climate Change Centre and considered from a sustainability perspective considering financial costs, environmental benefits and social values, along and the associated risks, barriers and benefits, resulting in the refined Logical Framework that includes the Component Outputs and Activities described in this section.

7.4.1 Component 1: Improve the water sector's resilience to climate change by enhancing availability, management and use of tertiary level treated wastewater

- **Output 1.1:** The Bridgetown Sewage Treatment Plant (BSTP) is upgraded to treat wastewater to a tertiary water-quality standard.
  - **Activity 1.1.1**: Design, procure and convert/upgrade the existing conventional activated sludge (CAS) biological treatment process at the Bridgetown Sewage Treatment Plant to tertiary filtration and disinfection for achieving national reclaimed water-quality standards.
- **Output 1.2:** Tertiary wastewater is available to supplement non-potable use.
  - **Activity 1.2.1:** Install reverse osmosis (RO) membrane filtration systems to reduce the total dissolved solids concentration of the reclaimed water produced at BSTP
  - **Activity 1.2.2:** I Install a 9Km pipeline and 6 aquifer recharge wells going from the BSTP for irrigation and aquifer recharge.

- **Output 1.3:** Decision-support tools and infrastructure implemented to mitigate potential climate change risks to the wastewater collection and treatment systems.
  - **Activity 1.3.1**: Implement a sewer monitoring programme that will include the installation of flow measurement and rain-gauging equipment at the BSTP to identify and address sources of inflow and infiltration to the sewer. Mechanisms that identify and reduce or mitigate vulnerabilities in the wastewater collection systems will also be investigated.
  - **Activity 1.3.2**: : Establish on-site laboratory facilities and personnel at the BSTP to generate influent and effluent water quality data to inform operations control strategies that optimize operations and reduce energy consumption and GHG emissions.
  - **Activity 1.3.3**: Implement process simulation and Computerized Real-time Management System (CMMS) software at the BSTP to inform decision making and climate resilient building.
- **Output 1.4:** Decentralized treatment plants or cluster treatment systems installed.
  - **Activity 1.4.1**: Construct two small (cluster) decentralized wastewater collection and treatment systems in Zone A locations to produce reuse quality water for domestic/commercial non-potable water applications.

7.4.2 Component 2 – Achieve climate resilient net zero carbon operations at BSTP

- **Output 2.1:** Energy efficiency and renewable energy technologies implemented.
  - **Activity 2.1.1**: Install a grid-tied Photovoltaic (PV) Renewable Energy Systems to offset increased power consumption associated with the centralized treatment plant process upgrades using Category 3 hurricane resistant solar panels.
  - **Activity 2.1.2**: Implement automated controls and energy efficiency measured within the upgraded centralized treatment processes to reduce the overall energy footprint and reduce GHG emissions.
  - **Activity 2.1.3**: Install sludge dewatering equipment to improve energy efficiency and reduce the overall GHG and CO_2 emissions associated with the biosolids

7.4.3 Component 3: Enhance capacity and capability of the BSTP through preventative maintenance (PM) and climate resiliency programmes

- **Output 3.1:** Improved capabilities of waste water technical personnel to operate, maintain and monitor and implement climate change adaptation planning strategies for wastewater management.
  - **Activity 3.1.1**: Develop and provide specialized and customized training to support the operations and maintenance of wastewater collection and treatment facilities including photovoltaic equipment.
  - **Activity 3.1.2**: Update Standard Operating Procedures (SOP) and Operational Manual that addresses the requirements of the upgrades, preventative maintenance, operator safety, and environmental monitoring, including specific

risks posed by to climate change and gender and social inclusion considerations adaptation and preventative maintenance.
- **Activity 3.1.3**: Develop and implement a risk management framework to support the sustainable management of BWA's operations.

- **Output 3.2:** A strategic plan is developed to guide the replication of the brackish water RO treatment plant along the west coast corridor.
    - **Activity 3.2.1**: Investigate and develop a strategic plan for the installation of water treatment facilities along the west coast corridor for augmenting water supply and protecting the west coast ecosystem.

7.4.4 Component 4: Create an enabling environment for wastewater technologies and reuse in the public and private sectors

- **Output 4.1:** Governance and planning roadmaps developed to enable wastewater reuse in the public and private sectors.
    - **Activity 4.1.1**: Undertake a legislative review to promote the Planning and Development Act, Wastewater Reuse Bill and other related legislations for enhancing wastewater effluent quality, treatment options and re-use requirements and applications. The review will also include recommendations for strengthening - private sector engagement, public-private partnerships, building codes, resiliency to climate change and equal opportunities and access to males and females.
    - **Activity 4.1.2**: Develop a water and sanitation master plan that includes an optimal combination of decentralized, cluster and centralized water reclamation and reuse applications, with the centralized reclaimed water being transmitted and used for agricultural irrigation or industrial use (such as lower cost of reclaimed water transmission). This strategy will also take into consideration the social, gender-related and climate risks in the design and prioritizing of water reuse strategies.
- **Output 4.2:** Mechanisms developed/expanded to encourage the adoption of wastewater treatment and reuse applications by private individuals and businesses.
    - **Activity 4.2.1**: Develop a strategy and action plan to engage the private sector in the provision and adoption of wastewater treatment technology and the utilization of wastewater by-products such as activated sludge. This includes conducting an assessment to identify opportunities for public-private partnership in the water and wastewater sector, especially for the expansion of the decentralized onsite cluster wastewater systems. The strategy will also promote gender equality and women empowerment.
    - **Activity 4.2.2**: Undertake a review and identify recommendations for a gender sensitive and socially inclusive incentive programme to encourage conservation, recycle, re-use.
    - **Activity 4.2.3**: Expand the Revolving Adaptation Fund Facility (RAFF) to provide resources for the adoption of decentralized onsite wastewater systems.

- **Output 4.3:** Gender Sensitive Public Education and Awareness Campaign Implemented.
  - **Activity 4.3.1**: Re-educate communities, teachers, students, farmers and businesses about the impact of climate change on water resources and their impact on water quality and quantity (availability as well as the importance of water reuse activities and indirect potable reuse (IPR)) to building climate resilience in the Water Sector.
  - **Activity 4.3.2:** Develop and implement a Gender Sensitive Public Awareness Campaign for community and visitors (tourists) through workshops, videos, community town hall meetings, site tours (demonstration of the plant technology and by-product reuse) and consultations. Emphasis will be placed on assuring the general public about food safety to ensure there is public acceptance and trust in the agriculture produce from local farms using the treated wastewater as well as the improved resilience of the water sector and the direct and indirect benefits on ecosystem services and ecotourism. Share lessons learnt to spur greater public and entrepreneurial involvement.
  - **Activity 4.3.3:** Develop a 3R-CReWS Project Page and social media accounts, which is dedicated to transparent measures of reporting, knowledge products, identify/host a link to the Redress Mechanism and provide update to all stakeholders on the project activities.

8 CLOSURE

Integrated Sustainability would like to thank the Caribbean Community Climate Change Centre for the opportunity to work on this project. If there are any questions regarding this report, please contact the Project Manager, Mr. Nick St-Georges.

Sincerely,

Integrated Sustainability

Troy D. Vassos, Ph.D. FEC P.Eng.
Sr. Lead Consultant / Wastewater Treatment

Nick St-Georges, P.Eng.
Project Manager / Sr. Civil Engineer

INTEGRATED SUSTAINABILITY

Appendix 1 – Preliminary Geotechnical Investigation

Final

GEOTECHNICAL INVESTIGATION

Bridgetown Sewage Plant (BTSTP)
Lakes Folly, St Michael, Barbados

PREPARED FOR:

Integrated Sustainability Consultants Ltd.

#47 Franklin House

St James, Barbados, W.I.

PREPARED BY:

CENTURY ENGINEERING

10710 GILROY ROAD
HUNT VALLEY, MARYLAND 21031

JULY 2021

CEI Project No. 211164.00

Table of Contents

LIST OF TABLES & APPENDICES

APPENDIX A

APPENDIX B

APPENDIX C

Geotechnical Bearing Capacity, Settlement, and Seismic Evaluation and Design Parameters

APPENDIX D

Laboratory Analyses Results

1.0 INTRODUCTION

In accordance with our proposal, Century Engineering, Inc. (CEI) has completed the Geotechnical Evaluation for the proposed Bridgetown Sewage Plant Project, located in Bridgetown, St. Michael Parrish, Barbados (Figure A-1).

The purpose of this study was to conduct a general evaluation of subsurface conditions at the project site and evaluate those conditions with respect to geotechnical engineering considerations for the proposed construction. The specific scope of our services on this project consisted of the following.

- A review and description of the field and laboratory test procedures conducted and their results;
- A review of area and site geologic conditions, including geological hazards at the site, such as sinkholes, swelling soils, collapsing soils, coral features, liquefaction, etc.;
- A review of subsurface conditions encountered with available physical properties;
- Potential excavation difficulties;
- Estimated value for angle of internal friction (if appropriate);
- Unit weights of soils/rock;
- Lateral earth pressures (active, at rest, and passive) for design of below grade structures (if any);
- Subgrade modulus;
- Recommendations for shallow foundations (Net allowable bearing pressure and applied safety factor and recommended bearing depth, resistance to sliding, resistance to uplift, estimated settlement and modulus of subgrade reaction);
- Subsurface drainage and potential difficulties with ground water;
- Seismic site classification, liquefaction potential, and recommendations;
- Depth to bedrock, rippability, and other rock-related recommendations.
- Site preparation, subgrade preparation, and construction and testing compacted fills;
- and, other geotechnical concerns that may affect the planned construction.

2.0 SITE AND PROJECT DESCRIPTION

In this section, details of the areas explored are described based on the limited information available at the time of this report. Currently, there are no conceptual design site plans or specifications or any other information, indicating the location of the structures and site boundaries.

2.1. SITE DESCRIPTION

The site is located at the Bridgetown Sewage Plant close to the southwest coast of Barbados, a ½-mile south of the cricket stadium and a ½-mile northeast of the Caribbean Sea (see Figure A-1). The survey area is a flat, grassy area adjacent to several rows of solar panels and is just north of two clarifiers with elevations ranging between 18 feet and 22 feet above sea level (see Figure A-2).

2.2. PROJECT DESCRIPTION

There is no information regarding the proposed construction at this time. Typical sewage treatment plant structures include tanks, clarifiers, digesters, bioreactors, filters, and control buildings. Typical foundations for these types of structures could range from shallow to deep foundations, depending upon size and loading and soil strength.

3.0 GEOLOGIC SETTING

3.1. REGIONAL GEOLOGY

Barbados is a relatively flat island, compared to other Caribbean islands. The island was formed from the upthrust seabed of the Caribbean Plate, unlike most of its Caribbean neighbors, which were formed from volcanic activity related to subduction zone processes. Primary rock types include Quaternary and Tertiary marine limestone, sandstone, and shale; Tertiary marine strata; and Eocene and Paleocene marine strata. Soils are typically residual clays with some sand. Overlying these soils in much of the island is coral, which can be as much as 100 meters thick, except in the northeastern region known as the Scotland District. The project site is located on the southwestern edge of the island in St Michael.

3.2. SITE GEOLOGY

Based upon the Geologic Map of Barbados (Poole and Barker, 1983), the proposed development will be sited within Middle Reef Terrace Coral Rock Deposits, close to the interface with Lower Reef Terrace Coral Rock Deposits. The geology of the site is presented in Figure A-3 in Appendix A. This unit can be made up of several different types of coralline formations. These formations include massive coral rock within a matrix of calcareous sand and mud formed within the former reef-crest and upper reef-front; a mélange of limestone breccia, coral debris, sand and mud formed within the lower reef-front; and back-reef deposits of lime mud and sand formed within lagoonal zones, shallow-water corals formed in patch-reef, and former beach zones of well washed and graded calcarenites.

Bridgetown is located approximately 14 miles southeast of a northwest-southeast trending normal fault and 9 miles east of a blind thrust fault (Taylor and Mann, 1991). There do not appear to be any major faults close to the site, although any structural features of the basement rock underlying the site are hidden by coral rock formations. Structural features such as faults are present in the Scotland District which is comprised primarily of limestones, sandstones, and shales. These formations underlie the coral rock at the project site. Based upon the Geologic Map of Barbados, the depth to this basement rock is approximately 50 meters (160 feet) below ground surface.

3.3. SITE HYDROGEOLOGY

The hydrogeology of the site is dominated primarily by the flow of fresh water, resulting from precipitation and infiltration within the island interior, through the underlying coral rock formations and sea level tidal fluctuations. The resulting groundwater table is made up of three distinct zones, a freshwater zone and a salt water zone, with a variable width brackish zone in between. The porosity of the overlying alluvial deposits is high for sands and gravels and very low for clayey deposits. The underlying coral rock has very high porosity, mainly derived from the many pores and interstices within the coral skeletons and algal secretions and from the intergranular voids within cemented coral sands. The primary porosity of coral rock varies between 0.9% and 14.9% (average 5.7%). The macro-porosity, however, is much higher and is due to the growth patterns of coral which tend to grow vertically. Secondary porosity occurs from dissolution of the calcium carbonate. As acidic rainwater passes through coral, the rock is dissolved creating cavities which significantly increase the overall permeability of the coral rock mass. The groundwater table at this site is likely located within the underlying coral rock, moving along the top of the Oceanic clay deposits. Groundwater was not found within any of the borings during the exploration at this site.

3.4. CORALLINE MATERIAL CLASSIFICATION

Coral reefs are massive calcareous rock structures secreted by reef-building organisms, which live on a thin layer on the surface of the rock. They continually build new coral rock on top of old extending the reef seaward and upward toward the surface. Reef-building corals require clear water; therefore, heavy siltation can kill these organisms. Coral reefs do, however, produce calcareous sediments; from calcareous algae secretions, wave and current action pulverizing the coral into sand-size particles, and the shells of other animals such as mollusks and sea urchins. This material can eventually become cemented into coralline rock. Any remaining voids become filled as calcium carbonate is dissolved and precipitated as water passes through the rock. With time, the calcium carbonate of the coral changes from a weak and unstable form called aragonite into a stronger and more stable form called calcite.

Three distinct types of coralline materials are typically found during subsurface explorations; coralline rock, detrital coralline gravel and sand, and fine coralline sand. Coralline rock is a relatively low strength rock, as compared to other rocks. Detrital coralline gravel and sand consist of fragmented pieces of coralline rock and loose pieces of coral and other organic carbonate material such as shells. Fine coralline sands are coralline material which has been broken down by currents and waves or by weathering into fine sand and silt. This material tends to be gap-graded with organic fines and coarse materials such as shells.

3.5. SITE SEISMIC HAZARDS

Barbados is located on the Caribbean Plate, a small lithographic plate over-riding the North American and South American plates to the east and being subducted by the Cosos Plate to the west. The subduction of the North American plate has resulted in the formation of a volcanic arc extending between Anguilla and Grenada. Bozzoni et al, (2011) describe the seismotectonic setting where Barbados is located approximately 130 miles west of the surface convergence of the North American and Caribbean Plates (where the Caribbean Plate is over-riding the North American Plate at a relatively shallow angle) and 105 miles east of the island arc (where the North American Plate is subducted under the Caribbean Plate at a steeper angle). The southern Caribbean plate boundary is located approximately 200 miles to the south and is characterized by the complex interaction of many fault-bounded blocks and by east-west striking faulting (El Pilar fault).

Forces from these major tectonic interfaces can result in the development of smaller faults which develop to relieve stress within the plates (intraplate). Locally, Bridgetown is located approximately 14 miles southeast of a northwest-southeast trending normal fault and 9 miles east of a blind thrust fault (Taylor and Mann, 1991). Barbados is primarily composed of coral reef, and lightweight sedimentary rocks, and resulting residual soils in a seismically active area. The project site is located within the city of Bridgetown in a topographically flat-lying area bounded by parking lots and the existing hospital. The site is approximately 1 km from the sea.

Historical seismicity within the Eastern Caribbean indicates that over the past 300 years, there have been a number of significant seismological events of both tectonic and volcanic origin. Between 1690 and 1900, empirical evidence shows that the region has been subject to earthquakes with magnitudes ranging up to greater than 8.0 on the Richter Scale. From 1900 to the present, with the onset of more accurate recording devices, earthquakes ranging from less than 4.0 to 7.75 on the Richter Scale were recorded. The hypocenters or foci of these earthquakes typically ranged from less than 15 km to roughly 200 km below the seabed. These events occurred along the island arc from Trinidad to Antigua, however, only a few relatively shallow earthquakes occurred close to Barbados (UWI, 2005). Based upon review of a geology map of Barbados, there are no known faults on or near the site (UK, 1981). Fault zones are depicted to the east of the site within the Scotland District, however. It is unknown whether these faults are active.

Most methods for determining seismic soil response are based upon the assumption that upward propagation of horizontally polarized shear waves from the underlying rock formation governs the response of the soil deposit. Two independent design response spectra are typically developed, one to define the horizontal component of ground motion, and the second to define the vertical component. The vertical component of ground motion usually contains much higher frequency content than the horizontal component; therefore, the spectral shape is different than that of the horizontal component. The peak ground acceleration (PGA) associated with the vertical component will also be different than the PGA of the horizontal component. Both values of PGA are dependent on the distance from the source.

The type of soil affects the response to dynamic loading. The most significant factors include grain size distribution, clay fraction, and degree of saturation. For coralline limestone rock with interlayered sands and gravels above the groundwater table, such as the deposits that exists at the site, liquefaction and lateral spreading is likely not an issue.

4.0 FIELD WORK

4.1. FIELD EXPLORATION

The field exploration was conducted by Subsurface Imaging and consisted of drilling four (4) standard penetration test (SPT) borings. Boring locations BH-1 to BH-4 were drilled on March 4, 2021. Subsurface Imaging completed the borings using a CME 45C trailer-mounted drill rig using hollow stem auger. Subsurface Imaging personnel logged the borings and developed the boring logs. The boring locations were dictated by the client, as shown in Figure A-2, located in Appendix A. Boreholes BH-1 to BH-4 were all drilled to 51.5 feet below ground surface.

Samples were obtained at 0.6-meter (2-feet) intervals. In general, the SPT consists of advancing a sampling spoon (50.8 mm or 2-inch outside diameter) 0.45 m (1.5-feet) by driving it with a 140-pound hammer falling 76.2 cm (30-inches). The values reported on the boring logs are the blows required to advance three successive increments. The first 15.24 cm (6-inch) increment is considered as seating. The sum of the number of blows for the second and third increments is the "N" value. The soils were classified in general accordance with the Unified Soil Classification System.

4.2. LABORATORY ANALYSES

The laboratory testing consisted of performing classification and index testing, including natural moisture content, grain-size distribution, and Atterberg limits (Table 4-1).

Table 4-1. Laboratory Testing

Laboratory Analysis	ASTM Standard	Purpose
Atterberg Limits	D4318	Determine soil plasticity
Sieve Analysis	D422	Determine soil grain size distribution
Natural Moisture Content	D2216	Determine soil moisture content

Results of classification testing are summarized in Table 4-2. Natural Moisture Content results are shown on Test Boring Logs in Appendix B and all other test results in Appendix C.

Table 4-2. Laboratory Classification Results

Sample	Depth (ft)	Description	LL%	PL%	NMC	% Clay/Fines	USCS
		TBD					

USCS: Unified Soil Classification System **PL:** Plastic Limit **LL:** Liquid Limit **NMC:** Natural Moisture Content

5.0 SUBSURFACE CONDITIONS

5.1. SUBSURFACE CONDITIONS

The test boring logs in Appendix B depict details related to the subsurface conditions. In situ, strata changes could occur gradually or at slightly different levels at other locations on site. Also, the boring depicts conditions at the particular time indicated. Some conditions, particularly groundwater conditions could vary from the conditions encountered at the particular boring locations. The following three (3) distinct strata were encountered (see Figure A-4).

Stratum I: Clayey GRAVEL FILL: This stratum was encountered at ground surface in all borings to depths ranging from 0.5 (1.5 ft) to 1.4 meter (4.5 feet) below ground surface. The stratum generally consisted of dark brown to black, moist, medium to very dense, Clayey GRAVEL (gc) with varying amounts of organic material (peat) and coral rock fragments. ranged from 15 to 100 blows per 0.3 meter or blows per foot (bpf), averaging 33 blows per 0.3 meter (bpf).

Stratum I: Silty Lean CLAY: This stratum was encountered from below FILL material in borings BH-1 and BH-2 only to a depth of 2 meters (6.5 feet) below ground surface. The stratum generally consisted of dark brown to brown to gray, moist, soft to stiff, Silty Lean CLAY (cl) with varying amounts of organic materials. The SPT N-values ranged from 3 to 9 blows per 0.3 meter or blows per foot (bpf), averaging 6 blows per 0.3 meter (bpf).

Stratum II: Coralline Sands and Gravels: This stratum was encountered below Stratum I or Stratum II soils in all borings to the boring completion depth. Soils within this layer can be generally classified as tan to white, moist to wet, very loose to dense, Poorly-graded SAND with Silt and Gravel (SP-SM) to Silty GRAVEL (GM) with Sand and Poorly-Graded GRAVEL with Sand and Silt (gp-gm) with varying amounts of shell fragments. The SPT-N values varied from weight-of-hammer (WOH) over 12” to 44 blows per 0.3 meter (bpf), averaging 16 blows per 0.3 meter (bpf), indicating a wide range of density for this layer.

5.2. GROUNDWATER

Groundwater was encountered in all borings from 1.1 meters (3.5 feet) to 1.7 meters (5.5 feet) below ground surface, averaging 1.2 meters (4 feet). during the field exploration. The cave-in depths were recorded to be from 1.5 meters (5 feet) to 9.8 meters (32.1 feet) below ground surface, averaging 4.5 meters (14.7 feet). In granular silicate soils, cave-in depths may be due to the presence of saturated soil conditions arising from groundwater and/or perched-water conditions. In coralline sandy soils, cave-in depths may be much deeper due to cementation effects. A more accurate determination of the hydrostatic water table would require the installation of monitoring wells or piezometers. It should be noted that the actual level of the hydrostatic water table and the amount and level of perched water should be anticipated to fluctuate throughout the year, depending upon variations in precipitation, surface run-off, infiltration, site topography, and drainage.

6.0 SEISMIC EVALUATION

CEI conducted a seismic review of the proposed pump house site. This review was conducted in general accordance with the 2009 International Building Code (IBC) (ICC, 2009). Where referenced in the IBC, the American Society of Civil Engineers (ASCE) 7-05 (2005) "Minimum Design Loads for Buildings and Other Structures" was utilized. In addition, the National Earthquake Hazard Reduction Program "(NEHRP) Recommended Seismic Provisions for New and Other Structures" (FEMA P-1050-1) (2015) and published journal articles were used to supplement and define the methodologies. In some cases, such as the requirement for a global slope stability analysis for seismic design category D structures in the IBC, the identified requirements were outside the scope of CEI's services. These services have been identified and the owner may wish to perform them to meet a strict interpretation of the identified code.

6.1. SUMMARY OF SITE-SPECIFIC CONDITIONS RELATED TO SEISMIC EVALUATION

Blow counts were corrected for hammer efficiency and overburden pressure using methods from McGregor and Duncan (1998). Factors accounting for the overburden pressure at sample depth, the length of the rods, sampler liner, hammer type, anvil type, and the frequency of the blow counts were used to normalize the N-values to $N_{1,60}$ values, which relate to a hammer that is 60% efficient driving a sampler through soil with 1 ton per square foot of overburden pressure. There was no indication of sand heave on the borehole logs that might impact the recorded penetration resistance. The borehole logs indicate the presence of gravel. The gravel is anticipated to increase the reported penetration resistance and may not reflect the density of the soil.

The soils at the site consist of man-made fill consisting of clayey sand and gravel overlying alluvial deposits of coralline sands and gravels and clays. The fill was reported to depths of 2 to 4 feet. The corrected blow counts in the top 4 feet was 54.8 bpf. The fines content of these samples is likely not above 30 percent. The fines content likely is not large enough to control the behavior of the soil, the clayey sands and gravels would be considered to be liquefiable, however this stratum is well above the groundwater table.

Below 4 feet depth, the predominant materials are described as coral sands and gravels. Fourteen (14) samples tested from depths of 6 feet and greater averaged 39.5% gravel; 40.8% sand; and

19.8% fines; and were classified as clayey sand with gravel, silty sand with gravel, well-graded sand with silt and gravel, poorly-graded sand with gravel, well-graded gravel with silt and sand, clayey gravel with sand, and silty gravel with sand. Soil samples recovered below 4 feet depth were characterized as both plastic and non-plastic. Below 4 feet depth, the corrected blow counts ranged from 5.8 to 92.8, with the average corrected blow count being 26.7. Two (2) samples within this zone were predominately clay with 19.7% gravel, 18.0% sand, and 62.3% fine, and were classified as lean clay and fat clay. The corrected blow counts ranged from 7.4 to 7.9, with the average corrected blow count being 7.6.

Granular soils (non-plastic silts, sand, and gravel) and cohesive soils (plastic silts and clays) behave differently. During an earthquake, the shaking can result in the soil particles reorganizing into a denser form in granular soils. However, depending on the soil, it may take a period of time for the porewater to dissipate, resulting in an increase in the pore water pressure. During this time, the effective stress in the soil and the corresponding shear strength is reduced. This process is referred to as liquefaction. The associated stress-strain behavior in a granular material is strongly dependent on the initial relative density and the intensity of ground motion.

In cohesive (clayey) soils, the cyclic loading can also cause an increase in porewater pressure. However, the strength behavior of clays (the cyclic and monotonic undrained shear strength are closely related, and their history is dependent on the stress history (over-consolidation ratios)) is different than the granular material. The susceptibility of the cohesive soils can be somewhat quantified by the sensitivity ratio, or the ratio of peak undrained shear strength to the remolded (residual) strength and the liquidity index. The liquidity index is the ratio of the difference between the moisture content and the liquid limit and the difference between the liquid limit and the plastic limit. Soils with high liquidity index values generally are weaker soils that are more sensitive (Boulanger and Idriss, 2006). The impact of cyclic loading on a cohesive soil is generally laboratory determined.

Boulanger and Idriss (2006) developed guidance for choosing between sand-like (granular) and clay-like (cohesive) behavior under earthquake loads based on laboratory testing. Based on their research, they determined that fine-grained soils can be expected to exhibit clay-like behavior if they have a plasticity index (PI) (liquid limit-plastic limit) equal to or greater than 7. Fine-grained soils with a PI of 3 to 6 may be transitionary, and laboratory cyclic loading testing may prove to be valuable. If the PI is less than 3, the fine-grained material will act as a granular material.

The boreholes at the site were drilled in March of 2021. The water level was reported to be at depths ranging between 3.5 feet to 5.5 feet. The elevation of the groundwater table is estimated to be on the order of 15.0 to 16.0+ feet above mean sea level. Depths were measured from the ground surface during drilling. The analysis in this seismic review assumes the ground water levels reported on the logs is consistent with the groundwater table throughout the year. The groundwater table may fluctuate throughout the year, which could have a limited impact on the results of the liquefaction analysis.

6.2. RECOMMENDED SITE-SPECIFIC GROUND MOTIONS

Earthquake magnitude is used to 'normalize' the design event to the standard magnitude 7.5 event that is the basis of many of the empirical relationships developed to quantify the potential for soil liquefaction. A magnitude scaling factor (MSF) is applied directly to the cyclic resisting ratio ($CRR_{7.5}$) for a magnitude 7.5 event. The factor of safety against liquefaction is defined as the ratio of the $CRR_{7.5}$/cyclic stress ratio (CSR) multiplied by the MSF.

The MSF recommended for liquefaction analysis is the modal value for a particular return period. Historically, the recurrence interval has generally been associated with a 2,475-year recurrence interval event (2 percent chance of occurrence in 50 years). Recently, the IBC has changed to a modified 1 percent chance of occurrence in 50 years.

A deaggregation study of the probabilistic seismic hazard was performed by Salazar et al (2013). The study identified the following Magnitude – Distance to Source (M-R) pairs associated with different return periods. The events given are identified as seismic events that dominate the analysis. However, the dominant event may not represent the appropriate design event. The following M-R pairs were identified:

- 95 year recurrence interval: M=6.8, distance to source 42.5 km,
- 475 year recurrence interval: M=7.4, distance to source 42.5 km,
- 975 year recurrence interval: M=8.6, distance to source 42.5 km, and
- 2,475 year recurrence interval: M=8.6, distance to source 42.5 km.

The recommended values for the 2,475 year event are based on the 975 year event, which is assumed to represent 2/3 of the actual value.

Based on the presence of primarily very loose to medium dense coralline sands and gravels and in accordance with American Society of Civil Engineers (ASCE) 7-05 (Table 20.3-1), the recommended site classification is Site Class E. The values presented below are based on 1613.3.3 of the IBC (2009). The mapped spectral acceleration values were estimated from the University of the West Indies (http://www.uwiseismic.com/Maps.aspx). The ASCE 7-05 approximation for peak ground acceleration is equal to the short-period spectral acceleration multiplied by a factor of 0.4.

Table 6-1. Recommended Seismic Design Parameters

Parameter	Mapped Spectral Acceleration (g)	Site Coefficient (F_a, F_v)	Adjusted Site Parameters (S_{MS}, S_{M1}) (g)	Design Spectral Response Parameters (S_{DS}, S_{D1}) (g)
PGA	0.439	-	—	—
T=0.2 sec	1.060	0.90	0.954	0.636
T=1 sec	0.338	2.65	0.895	0.597

For a structure with an assumed Risk Category of II (as defined by Table 1604.5 (IBC, 2009), the seismic design category of the structure is anticipated to be seismic design category D. Due to a very shallow groundwater table and the site being primarily very loose to medium dense coralline sands and gravels, seismic hazards such as slope instability, liquefaction, total and differential seismic settlement, surface displacement due to faulting or lateral spreading, dynamic lateral earth pressures, and strength loss in soils due to liquefaction are possible.

In accordance with 1803.5.11 and 1803.5.12 of IBC (2014), a structure identified as assigned to a seismic design category E, the geotechnical investigation shall include an evaluation of all of the following potential seismic hazards:

- Slope instability,
- Liquefaction,
- Total and differential settlement,
- Surface displacement due to faulting or lateral spreading,

- Determination of dynamic lateral earth pressures on foundation walls and retaining walls supporting more than 6 feet of soil,
- The potential for strength loss in soils due to liquefaction in accordance with ASCE 7-10,
- An assessment of potential consequences of liquefaction and soil strength loss, including but not limited to:
  - Total and differential settlement,
  - Lateral soils movement,
  - Lateral soil loads on foundations,
  - Reduction in foundation soil-bearing capacity and lateral soil action,
  - Soil downdrag and reduction of axial and lateral soil reactions for pile foundations,
  - Increases in soil lateral pressures on retaining walls, and
  - Floatation of buried structures.
- Discussion of mitigation measures, such as, but not limited to the following:
  - Selection of appropriate foundation types and depth,
  - Selection of appropriate structural systems to accommodate anticipated displacement and forces,
  - Ground stabilization, and any combination of these measures and how they shall be considered in the design of the structure.

6.3. SITE SEIMIC EVALUATION

The performance of the site soils under seismic load was evaluated. Calculations based on assumed magnitude 6.8 and 8.7 earthquakes indicate that liquefaction is a potential concern for the stability of the structure. In particular, the potential impact of dynamic settlement, loss of strength under the footing, and lateral spreading may result in displacement and possible damage to the structure.

Global Stability. An evaluation of global stability is outside the scope of the current investigation. Given the generally flat-lying topography at the site, global stability is not anticipated to be a significant mode of seismic failure. However, with the potential for a large seismic event, it is recommended that a global stability analysis be performed to verify the overall stability of the site according to a strict interpretation of the building code.

Liquefaction. Liquefaction may occur within the coral sands and gravels below the groundwater table. The normalized penetration resistance in the borehole logs ($N_{1(60)}$) is variable with this layer. In general, liquefaction is not anticipated to occur in soils with a ($N_{1(60)}$) of more than 30 blows per foot (Youd et al 2001), although there are other factors affecting liquefaction potential including fines content, groundwater elevation, seismic energy, overburden stress, and similar factors.

The factor of safety for a soil to liquefy under a magnitude 6.8 and 8.7 event was calculated in general accordance with Youd et al (2001). The fines content of the soil was approximated based on the available grain size distribution curves. Based on the calculations, approximately 62 percent of the saturated samples are calculated to have a factor of safety less than 1.0 for the magnitude 6.8 event (Figure 6-1) and 67 percent of the saturated samples are calculated to have a factor of safety less than one based on an 8.7 magnitude event (Figure 6-2).

Lateral Spreading. Lateral spreading is the most pervasive type of liquefaction-induced ground failure. Lateral spreading occurs where blocks of mostly intact, surficial soil displace downslope or towards a free face along a shear zone that forms within the liquefied sediment (Bartlett and Youd, 1995). Given the generally flat-lying topography in the project area, only the downslope condition was considered.

Calculations were performed in general accordance with the process described in Youd, Hansen, and Bartlett (2002). In this calculation, the paired magnitude and distance to source are major data components. In accordance with Dickenson (2005), liquefaction calculations should be performed on the modal magnitude-distance to source (M-R) pair based on a probabilistic seismic hazard assessment. A probabilistic seismic hazard assessment for Bridgetown, Barbados was reviewed (Salazar et al, 2013). The modal pair was not identified as part of the analysis. However, the study identified that the dominant seismic event for intraplate subduction corresponding with the 2,475-year recurrence interval was an M-R pair with 8.6 magnitude at a distance of 42.5-kilometers. In addition, the dominant M-R pair with a 95-year recurrence interval was identified as a magnitude 6.8 event at a distance of 42.5-kilometers. These two events were used for the site lateral spread analysis.

Figure 6-1. Calculated Factor of Safety Against Liquefaction of Saturated Clean Sand Samples with a ($N_{1(60)cs}$) Normalized Penetration Resistance <30 Blows per Foot, Magnitude 6.8 Event.

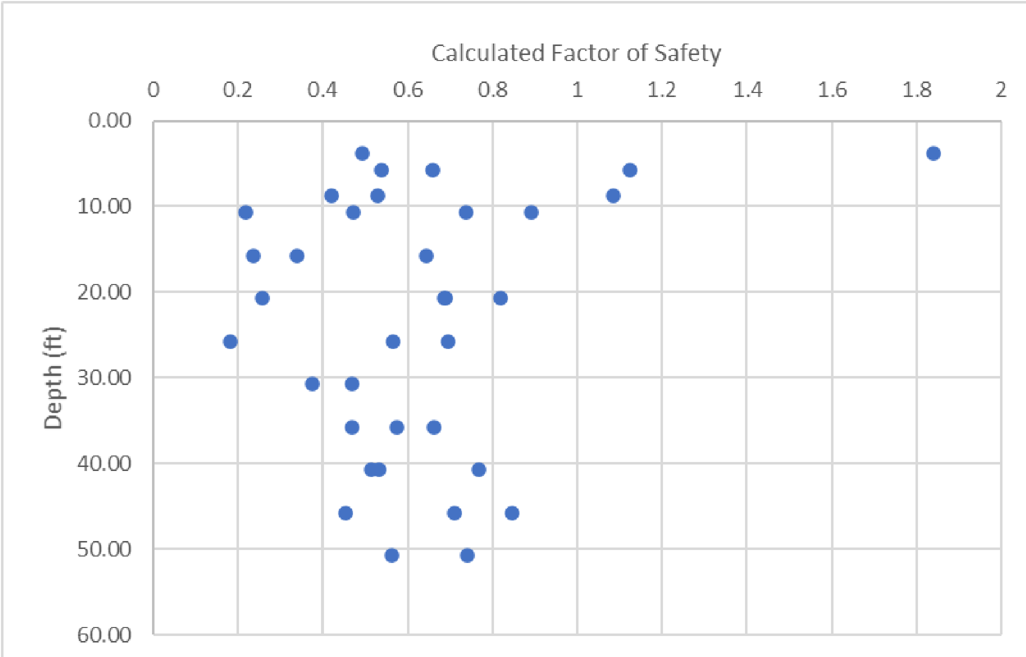
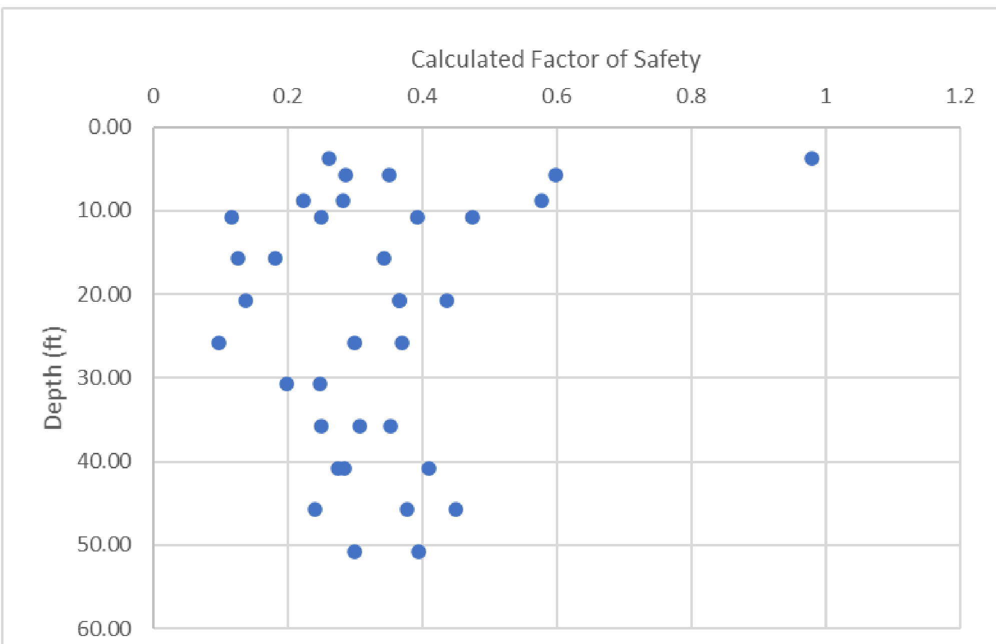


Figure 6-2. Calculated Factor of Safety Against Liquefaction of Saturated Clean Sand Samples with a ($N_{1(60)cs}$) Normalized Penetration Resistance <30 Blows per Foot, Magnitude 8.7 Event



The calculations indicated that there is a limited potential for lateral spreading associated with the 6.8 magnitude event. The displacements associated with lateral spreading range between 0 to 0.02 feet for a 1 percent slope and 0.01 to 0.03 feet for a 10 percent slope. Significant lateral spreading was calculated to be associated with a magnitude 8.6 seismic event. The calculated displacement ranged between 1.7 to 6.3 feet for a 1 percent slope and 3.7 to 13.6 feet for a 10 percent slope. The estimated horizontal displacements indicate that sufficient lateral movement could occur during an 8.6 magnitude earthquake to induce full lateral spreading earth pressures on structural components, such as pile foundations. These seismically induced lateral loads are further discussed in the Deep Foundations section of this report.

Dynamic Settlement. Dynamic settlement refers to the potential settlement of the soil as it densifies under after a seismic event. For this analysis, the procedures identified in Ishihara and Yoshimine (1992) were utilized to calculate the potential strain in soils. This method relates the volumetric strain to the factor of safety against liquefaction and the relative density of the soil as estimated by the clean sands penetration resistance ($N_{1(60)cs}$). The results of the calculations show that dynamic settlement is expected to range from 5.5 inches (BH-3) to 15.0 inches (BH-1) for the boreholes drilled. Differential settlement on the order of 10 inches across the length of a structure may be anticipated.

Loss of Shear Strength. The potential for soil to lose shear strength during liquefaction was evaluated according to the techniques of Olson and Stark (2001). For this method, only soils having a normalized penetration resistance ($N_{1(60)}$) of 12 blows per foot or less are anticipated to experience significant strength loss. The samples that are anticipated to experience loss of strength are presented in Table 6-2. The rotational and punching shear bearing pressure capacity of the footings under the structure should be checked to evaluate their performance under liquefied conditions. For shallow foundations, zones of liquefaction below 15 or 20 feet below the ground surface may not impact the footing, depending on the design and loading of the foundation.

Table 6-2. Shear Strength Loss during Liquefaction

Borehole	Depth (ft)	Reduced Friction Angle (º)
BH-1	3.75	3.5
	5.75	6.0
	8.75	5.7
	10.75	6.1
	15.75	2.9

Table 6-2. Shear Strength Loss during Liquefaction

Borehole	Depth (ft)	Reduced Friction Angle (º)
	30.75	5.2
	40.75	6.7
	45.75	5.2
	50.75	5.9
BH-2	5.75	3.8
	8.75	6.1
	15.75	4.6
	25.75	1.7
	40.75	6.1
BH-3	20.75	3.9
BH-4	10.75	2.8
	30.75	6.5
	35.75	6.3

Utility Buoyancy. Given that the soils within 3 to 5 feet of the ground surface are above the groundwater table, buoyancy during liquefaction should not be a concern. Deeper utilities will need to analyzed, if necessary.

Lateral Forces on Walls. The active and passive soil pressure acting on a below-grade wall will change due to seismic loading. The use of the Mononobe-Okabe equation should be used to calculate the forces on the wall utilizing the soil parameters developed for retaining walls and foundations as required.

7.0 EVALUATIONS AND RECOMMENDATIONS

7.1. GENERAL RECOMMENDATIONS

Our findings indicate the site may be developed for any proposed structures using deep foundations or shallow foundations if compaction grouting, or some other form of ground improvement, is performed to remediate the liquefiable soils below the site. The proposed structure will overlie primarily clayey gravel FILL soils, coral sands and gravels, and thin deposits of alluvial clays with moderately good SPT N-values. However, there are indications of weaker materials within the borings, where the N-values were generally below 10 blows per 0.3 meter (blow per foot). Based upon these N-values, the soil within this zone has lower shear strength and, therefore a higher potential for liquefaction.

The following recommendations have been developed on the basis of the previously described project characteristics and subsurface conditions. If there are any significant changes to the project characteristics or if significantly different subsurface conditions are encountered during construction, CEI should be consulted so that our recommendations can be reviewed.

7.2. EARTHWORK RECOMMENDATIONS

The initial step in the development of this site should be to remove topsoil, root matter and other deleterious materials from the areas to be developed. Typically, deeper undercutting on the order of 0.6+/- meter (2+/- feet) to 1.0+/- meter (3+/- feet) will be required where trees must be removed but, otherwise stripping will be limited to the upper 0.15+/- meter (0.5+/- feet) to 0.3 meter (1+/- feet) in grassy areas. These stripping operations should be performed in a manner consistent with good erosion and sediment control practices.

After stripping, areas to be filled or where pavements or structures will be placed should be compacted to the maximum dry density by using a smooth vibratory roller. The purpose of the proof rolling is to provide surficial densification and to locate any isolated areas of soft or loose soils. Unsuitable areas should be undercut and replaced with controlled compacted fill as described in Section 7.4. A licensed geotechnical engineer or engineering technician under the supervision of such an engineer should witness the stripping and proof rolling operations. All earthwork activities should be performed in a manner consistent with good erosion and sediment control practices.

7.3. FILL SELECTION, PLACEMENT AND COMPACTION

Satisfactory materials shall comprise any materials classified by ASTM D 2487 as GW, GP, GM, GP-GM, GW-GM, GC, GP-GC, GM-GC, SW, SP, SM, SW-SM, SC, SW-SC, SP-SM, or SP-SC. Satisfactory materials for grading shall be comprised of stones less than 20 cm (8 inches), except for fill material for pavements which shall be comprised of stones less than 8 cm (3 inches) in any dimension.

In general, existing on-site soils free from environmental contamination, building debris, organic or wet materials, having liquid limits less than 40 and plastic indices less than 10, with a Unified Soils Classification, as defined previously, can be reused as compacted fill. Imported materials, if required, should have a Unified Soils Classification of SM, or more granular and less plastic, and free of organic material.

In building areas, the fill should extend a minimum of 1.5 meters (5 feet) beyond the building limits and fill slopes no steeper than 2(H):1(V) should be used. Fill in structural and pavement areas should be placed in horizontal, eight-inch maximum loose lifts and compacted to at least 95 percent of the Modified Proctor maximum dry density (ASTM D-1557). In areas to support floor slabs and pavements, the uppermost one-foot (after compaction) should be compacted to 100-percent of the maximum dry density.

The moisture content of the fill should be properly controlled during placement. Moisture content of fill materials should be within plus or minus 2% of the optimum moisture content as determined by the Modified Proctor moisture-density test procedure. In-place density tests should be performed by an engineering technician on a full-time basis under the supervision of a licensed geotechnical engineer to verify that the proper degree of compaction is being obtained.

7.4. BASEMENT AND OTHER BELOW-GRADE WALLS

If basements will be constructed for any proposed structures, basement walls must be designed to withstand lateral soil and water pressure. Due to the shallow groundwater table, basements are not recommended, unless significant waterproofing is included in the design.

7.5. FLOOR SLABS

Slabs-on-grade should be cast on a minimum 15 cm (6-inch) thick free-draining crushed stone or clean sand-gravel layer over compacted granular fill following removal of unsuitable existing soils and surficial soils. The slab base course will provide a level bearing surface and permit lateral drainage beneath the slab. We recommend that an impermeable membrane be placed over the slab base course to provide a vapor barrier and prevent clogging of the gravel drainage blanket during concrete placement. A modulus of subgrade reaction of 67.86 MN/m^3 (250 pci) may be used. Additional recommendations are as follows:

- Keep the washed stone moist, but not wet, immediately prior to slab concrete placement to minimize curling of the slab due to differential curing conditions between the top and bottom of the slab.
- Provide isolation joints between the slab and columns and along footing supported walls.

Use interior construction joints containing dowels or keys to permit rotation between parts of the slab while reducing sharp vertical displacements. This detail does not apply to joints at foundation elements.

7.6. SHALLOW FOUNDATIONS

If ground improvement is conducted to address liquefaction, shallow building foundations may be designed for an allowable bearing pressure of 120.0 kPa (2,500-psf), using a factor of safety of 3.0. A coefficient of friction against sliding of 0.5 may be used for lateral loads. Total settlement will be dependent upon loading to be provided by the designer but is not expected to exceed one (1) inch. It is difficult to predict differential settlement in coralline materials, however, the boring results indicate relatively good uniformity between borings, therefore, differential settlement should not exceed 0.005 L, respectively, where L is the distance between adjacent columns.

Soil parameters that may be used for design include:

Angle of Internal Friction (ϕ') = 32 degrees
Rankine Coefficient of Active Earth Pressure (K_a) = 0.31

Coefficient of At-Rest Passive Earth Pressure (K_p) = 0.47
Rankine Coefficient of Passive Earth Pressure (K_p) = 3.25
Unit Weight = 120 pcf
Coefficient of friction - concrete against soil (μ) = 0.5

Proper construction procedures should be used to maintain the bearing qualities of the footing excavations. Footings and excavations should be protected from the detrimental effects of precipitation, seepage, or surface run off. Before placing concrete, the subgrade should be reviewed and tested by an engineering technician acting under the guidance of a licensed engineer. The size, position, and amount of reinforcing steel should be checked for conformance with the construction documents. If material is judged unsuitable in the field, it should be undercut to firm material. The undercut excavation may be backfilled as described in Section 7.3 of this report.

7.7. DEEP FOUNDATIONS

Deep foundations may be required depending upon proposed structure type and load. Due to the potential for liquefaction and weak materials between approximately 1 meter (3.3 feet) to 15.7 meters (51.5 feet) bgs, driven piles, continuous flight auger (CFA) piles, or drilled shafts set below these depths may be necessary. Since piles would have to be drilled below 50 feet, an additional SPT boring should be drilled prior to construction to determine soil properties below 50 feet. General recommendations for coral soils are included below.

Coralline Sands and Gravels. In areas with uncemented coralline sands and gravels, the unit skin friction and end bearing should be estimated using the appropriate method for coralline soils as follows. For driven piles in coralline sands and gravels, the skin friction, f_s, is given by:

$$f_s = K_s \tan\phi_a' \, \sigma_v' \ (< f_{s1}),$$

where K_s is the coefficient of lateral earth pressure, ϕ_a' is the angle of friction between the pile and soil, σ_v' is the effective overburden pressure, and f_{s1} is the limiting value of skin friction. The end bearing capacity, f_b, is given by:

$$f_b = N_q \, \sigma_{vb}' \ (< f_{b1}),$$

where N_q is the end bearing capacity factor, σ_{vb}' is the effective overburden pressure at the pile tip, and f_{b1} is the limiting value of end bearing. Typical design parameters for driven piles in uncemented calcareous sands and silicate sands (Poulos, 1985; Poulos, 1989; Murff, 1987) are shown in the table below:

Table 7-1. Typical Design Parameters for Driven Piles in Coralline Sands

Soil Type	Skin Friction			End Bearing	
	K_s	ϕ_a'	f_{s1} (kPa)	N_q	f_{b1} (MPa)
Calcareous sands	0.5	20	15	20	3
Silicate Sands	0.7-1.0	25	100	40	10

For grouted piles, significantly higher values of skin friction are developed than for driven piles in coralline sands. Average values of skin friction ranging from 72 kPa to 96 kPa in uncemented coralline sands and up to 700 kPa in cemented calcarenite have been reported (Poulos, 1988). Laboratory tests on grouted piles in uncemented coralline sands have resulted in skin frictions reported to be 3 to 5 times higher than skin frictions developed for driven piles. There is also evidence of strain-softening beyond the peak to a residual value substantially less than the peak value of skin friction, therefore, load testing is usually warranted to determine the load deformation behavior of the pile-soil system and the ultimate load capacity. Typical ranges of design values for static resistance for both driven and grouted piles are presented in the table below, including peak and residual skin friction values as well as the lateral pile displacement necessary to reduce the skin friction from the peak to the residual condition.

Table 7-2. Typical Ranges of Design Values for Static Resistance of Piles in Coralline Sands

Soil Condition	Driven Pile			Drilled and Grouted Pile		
	f_s (kPa)	f_r (kPa)	ρ_{pp} (mm)	f_s (kPa)	f_r (kPa)	ρ_{pp} (mm)
Uncemented	10-20	5-10	30-100	60-100	30-40	50-100
Weakly-cemented	10-40	5-20	30-70	100-200	40-60	40-60
Well-cemented	10-100	-	-	200-500	60-150	30-100

f_s: Peak skin friction **f_r:** Residual skin friction **ρ_{pp}:** Displacement from peak to residual condition

The factor of safety applied to the ultimate pile capacity is based upon the method of pile construction control in accordance with Table 7-3 below. Based on similar projects in the area, it is assumed that pile load tests will be conducted, therefore a factor of safety of 2.0 could be utilized. For seismic conditions we recommend a factor of safety of 1.0.

Spacing closer than 2.5 pile diameters should not be used. The efficiency of a pile group, η_g, is calculated using,

$$\eta_g = \frac{R_{ug}}{\sum_{i=1}^{n} R_{u,i}}$$

where R_{ug} is the ultimate resistance of the pile group and $R_{u,i}$ is the ultimate resistance of a single pile "i" in the pile group with a total of n piles in the group.

Table 7-3. Recommended Factor of Safety Based on Construction Control

Construction Control Method	Factor of Safety
Static Load Test (ASTM D-1143)	2.0
Dynamic Measurements (ASTM D-4945) and Signal Matching Analysis coupled with Wave Equation Analysis	2.25
Indicator Piles coupled with Wave Equation Analysis	2.50
Wave Equation Analysis	2.75
Modified Gates Dynamic Formula	3.50

Seismic axial and lateral capacity should also be checked when more pile-related information is available.

7.8. SEISMIC DESIGN CONSIDERATIONS

Based on the current field-testing information and laboratory test results, there is the potential for the sand and gravel soils at the site to experience liquefaction under an earthquake with a moment magnitude of M_w = 6.8 and higher and a horizontal peak ground acceleration of 0.439. In particular, the potential impact of dynamic settlement, loss of strength under footings, downdrag on piles, and lateral spreading may result in displacement and possible damage to the structure. An alternative to using published seismic hazard maps and related literature is to conduct a more site-specific seismic hazard analysis and site response analysis. This effort may result in less stringent seismic design criteria.

Even though the factor of safety against initial liquefaction is unsatisfactory, a liquefaction impact analysis and seismic settlement evaluation can be performed to evaluate whether the foundations will still perform as intended. Potential impacts of liquefaction include bearing capacity failure, loss of lateral support for piles, lateral spreading, seismic settlement of unsaturated sand, and post-liquefaction settlement, all phenomena associated with large soil strains and ground deformations. Relatively dense soils which liquefy may subsequently harden at small deformations and thus have minimal impact on overlying structures. Conversely, relatively loose soils that liquefy will tend to collapse resulting in a much greater potential for post-liquefaction deformation. Methods for assessing the impact of liquefaction generally are based upon evaluation of the strain or deformation potential of the liquefiable soil.

If the aforementioned evaluations still yield unacceptable deformations, a more sophisticated liquefaction potential assessment may be performed to evaluate potential liquefaction mitigation measures. Other options include designing the structure to resist the potential anticipated deformations, performing ground modification/stabilization, or selecting another site with better soil characteristics.

There is the potential that a targeted compaction grouting or jet grouting program could be implemented to "stiffen" these zones of weakness. Specifically, the following depth zones within the areas around the borings could be grouted to address seismic issues. The grout holes would be drilled in a grid pattern (see Section 7.9) over the building area, especially around foundation locations.

7.9. COMPACTION GROUTING

Based upon the results of the drilling program, it is recommended that compaction grouting with low mobility (low slump) grout by staged injection be performed in potentially liquefaction-prone areas between 10 feet and 50+ feet below ground surface. Compaction injection grouting is a grouting technique that densifies and stabilizes loose granular soil, by the staged injection of low-slump, low mobility, aggregate grout. Typically, an injection pipe is first advanced to the maximum treatment depth. The low mobility grout is then injected as the pipe is slowly extracted in lifts, creating a column of overlapping grout bulbs or filling voids. The expansion of the low mobility grout bulbs also displaces loose materials.

Primary and secondary (if needed) grout holes should be patterned at 20 feet (and 10 feet intervals for secondary holes) spacing intervals around and within proposed footer locations. Grout should be injected at two-foot intervals (vertically) until an injection pressure roughly equivalent to local effective overburden pressure is obtained from the bottom of the hole to the top (moving upward). Other criteria for termination of pumping at a given stage should also be implemented, including measurement of sustained high injection pressure, rapid changes in injection pressure (indicating a potential fracture in the soil), or prescribing a maximum quantity of grout.

Verification consisting of both quality control (QC) and quality assurance (QA) procedures should be implemented. Quality control procedures to be implemented by the contractor should include monitoring, regulating and recording grout mix consistency and injection rate and monitoring and recording injection pressure, grout quantity and surface response at each stage. Daily records of all grout constituents consumed (sand, cement and water) should be maintained. The client engineer's QA procedures should include observation of contractor procedures, verification of grout unit weight and compressive strength, and post-treatment subsurface exploration; including SPT sampling. Records of grout production and consumption should be corroborated by comparison of pump stroke counts with daily material balance and measured grout unit weight.

Measurement of ground surface uplift should be conducted to ensure that grouting-induced stresses have not exceeded local effective stress in the underlying soil. Vertical ground deflection should be limited to approximately 1 mm per stage, with a maximum cumulative uplift of 15 mm resulting from each injection location. Lateral ground deflection should also be monitored at the surface adjacent to the existing building using a grid of temporary survey monuments and a line of "poor-man" inclinometers (or similar) to provide continuous real-time monitoring during grouting operations. Lateral strain can also be monitored using measurements of injected grout quantity by comparing grout-induced ground fractures to grout quantity.

Post injection SPT testing should be conducted to evaluate the effectiveness of the grouting. The resulting SPT N-values can then be used to evaluate the soils for susceptibility to liquefaction, seismic-related settlement, differential settlement, and lateral spreading using the same procedures to evaluate the soil prior to grouting.

7.10. DEWATERING AND DRAINAGE

The borings indicated static groundwater within 1 meter (3.3 feet) below ground surface. For this depth, groundwater dewatering techniques should not be required, unless a deep basement is constructed. Adequate above-ground drainage should be provided at the site at all times, including during construction, to minimize any increase in moisture content of the foundation soils. All run-off from adjacent areas should be diverted away from the excavation to prevent ponding of water in the excavation. After construction, all areas should be sloped away from proposed structures to prevent ponding of water around the building. The site drainage should also be such that the run-off onto adjacent properties is controlled properly.

7.11. FURTHER INVESTIGATION AND ANALYSES

Based upon the findings of the initial subsurface exploration, it is our opinion that additional investigation is warranted. Our recommendations include:

- Grout testing within drilled boreholes to determine potential mixes as well as the potential grout "takes" that may be expected during a grouting program, if needed.
- An additional boring to at least 85 feet below ground surface to evaluate physical properties of soils below 51.5 feet, the deepest boring depth from the initial investigation.
- Additional laboratory testing to determine soil properties.
- Seismic Analysis and Design, including,
  - Surface rupture;
  - Potential for a deep-seated landslide or flow slide failure under seismic conditions; and
  - Evaluation of liquefaction mitigation, including compaction grouting and other methods.
- Grouting design if liquefaction mitigation is the selected method.

8.0 REFERENCES

1. Alpan, I., 1964. "Estimating the Settlements of Foundations on Sands." Civil Engineering and Public Works Review, Vol. 59, pp. 1415-1418. Morgan-Grampian Ltd., Woolwich, London, England.
2. American Society of Civil Engineers, 2005. ASCE Standard 7-05, Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, Reston, Virginia.
3. Barlett, S.F. and T.L. Youd, 1995. "Empirical prediction of liquefaction-induced lateral spread." American Society of Civil Engineers Journal of Geotechnical and Geoenvironmental Engineering, v 121, n 4, p 316-329.
4. Boulanger, R.W. and I.M. Idriss, 2006. "Liquefaction susceptibility criteria for silts and clays." American Society of Civil Engineers Journal of Geotechnical and Geoenvironmental Engineering, v 132, n 11, p 1413-1426.
5. Burland, J. B. and M. C. Burbidge, 1985. "Settlement of Foundations on Sand and Gravel." Proceedings, Institution of Civil Engineers, Part 1, Vol. 78, pp. 1325-1381. Thomas Telford Ltd., Westminster, London, England.
6. Dickenson, S., 2005. Recommended guidelines for liquefaction evaluations using ground motions from probabilistic seismic hazard analysis. Report to the Oregon Department of Transportation.
7. Federal Emergency Management Agency, 2015. NEHRP Recommended Seismic Provisions for New and Other Structures (FEMA P-1050-1). Building Seismic Safety Council, Washington, D.C.
8. Fellenius and Siegel, 2007. "Pile Design Consideration in a Liquefaction Event." ASCE Journal of Geotechnical and Environmental Engineering, 132(9), pp. 1412-1416.
9. International Code Council, 2015. "International Building Code."
10. Ishihara, K. and M. Yoshimine, 1992. "Evaluation of settlements in sand deposits following liquefaction during earthquakes." Soils and Foundations, vol 32, no 1, 173-188.
11. Janbu, N. and K. Senneset, 1981. "Settlement due to Drained, Cyclic Loads." Proceedings Tenth International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 165-170. Stockholm, Sweden. A.A. Balkema, Rotterdam, the Netherlands.
12. Kay, J. N. and R. L. Cavagnaro, 1983. "Settlement of Raft Foundations." Journal of the Geotechnical Engineering Division, Vol. 109, pp. 1367-1382. ASCE, New York, NY.
13. Olson, S.M. and T.D. Stark, 2001. "Liquefied strength ratio from liquefaction flow failure case histories." Canadian Geotechnical Journal, vol 39, p 629-647.
14. Peck, R. B. and A. Bazarra, 1969. "Discussion of Settlement of Spread Footings on Sand," by D'Appolonia, et al, Journal of the Soil Mechanics and Foundations Division, Vol. 95, pp. 905-909. ASCE, New York, NY.
15. Peck, R. B., W. F. Hanson, and T. H. Thornburn, 1974. Foundation Engineering, 2nd ed., pp. 307-314. John Wiley & Sons, New York, NY.

16. Perloff, W. H., 1975. “Pressure Distribution and Settlement.” Chapter 4, Foundation Engineering Handbook, pp. 148-196. H. F. Winterkorn and H. Y. Fang, ed. Van Nostrand Reinhold Company, New York, NY.
17. Salazar, W., L. Brown, and G. Mannette, 2013. Probabilistic Seismic Hazard Assessment for Bridgetown-Barbados, Employing Subduction Interface Characteristic Earthquakes. Journal of Civil Engineering and Architecture, Nov. 2013, Volume 7, No. 11 (Serial No. 72), pp. 1405-1422.
18. Schmertmann, J. H., J. P. Hartman, and P. R. Brown, 1978. “Improved Strain Influence Factor Diagrams.” Journal of the Geotechnical Engineering Division, Vol. 104, pp. 1131-1135. ASCE, New York, NY.
19. Schultze, E. and G. Sherif, 1973. “Predictions of Settlements from Evaluated Settlement Observations for Sand.” Proceedings Eighth International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 225-230. USSR National Society for Soil Mechanics and Foundation Engineers, Gosstray, USSR, Marx Prospect 12, Moscow K-9.
20. Taylor, F.W. and P. Mann, 1991. “Late Quaternary folding of coral reef terraces, Barbados.” Geology, vol 19, p 103-106.
21. UK, 1982. “Barbados 1:20,000 Geology of the Scotland Area.” Published by the Government of the United Kingdom, Directorate of Overseas Surveys for the Government of Barbados. Barbados Government. 1982.
22. UK, 1983. “Geology of Barbados 1:50,000.” Published by the Government of the United Kingdom, Directorate of Overseas Surveys for the Government of Barbados. Barbados Government. 1983.
23. UWI, 2010. The University of the West Indies, Seismic Research Unit. St. Augustine, Trinidad & Tobago, West Indies. Annual Report – 2009-2010.
24. UWI, 2009. The University of the West Indies, Seismic Research Unit. St. Augustine, Trinidad & Tobago, West Indies. Seismic Hazard Maps for the Eastern Caribbean at 0.2 and 1.0 second periods. http://www.uwiseismic.com. 2011.
25. Vesic, A.S., 1973. Analysis of Ultimate Loads of Shallow Foundations.” Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Vol. 99, No. SM1, January, 1973.
26. Youd, T. L., (1998). “Screening Guide for Rapid Assessment of Liquefaction Hazard at Highway Bridge Sites,” *Tech. Rep. MCEER-98-0005*, Multidisciplinary Center for Earthquake Engineering Research, Buffalo, New York
27. Youd, T. L. et al., (2001). “Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER And 1998 NCEER / NSF Workshops on Evaluation of Liquefaction Resistance Of Soils.” *Journal of Geotechnical & Geoenvironmental Engineering*, ASCE, Vol. 127, No., 10, 817-833.
28. Youd, T.L., C.M. Hansen, and S.F. Bartlett, 2002. “Revised multilinear regression equations for prediction of lateral spread displacement.” American Society of Civil Engineers Journal of Geotechnical and Geoenvironmental Engineering, v 128, n 12, p 1007-1017.

9.0 BASIS OF RECOMMENDATIONS

This report has been prepared to aid in the evaluation for the proposed construction described in this report. Adequate recommendations have been provided to serve as a basis for design and preparation of plans and specifications. The opinions, conclusions, and recommendations contained in this report are based upon our professional judgment and generally accepted principles of geotechnical engineering. Inherent to these are the assumptions that the earthwork and foundation construction should be monitored and tested by an engineering technician acting under the guidance of a licensed geotechnical engineer.

These analyses and recommendations are, of necessity, based on the information available at the time of the actual writing of the report and on the site conditions, surface and subsurface, that existed at the time the exploratory borings were drilled. Further assumption has been made that the limited exploratory borings, in relation both to lateral extent of the site and to depth, are representative of conditions across the site.

The nature and extent of variations between borings may not become evident until construction. If variations from the anticipated conditions are encountered, it may be necessary to revise the recommendations in this report. We cannot accept the responsibility for designs based on recommendations in this report unless we are engaged to make site visits during construction to: a) check that the subsurface conditions exposed during construction are in general conformance with our design assumptions and b) ascertain that, in general, the work is being performed in compliance with the contract documents.

Our professional services have been performed in accordance with generally accepted engineering principles and practices; no other warranty, expressed or implied, is made. CEI assumes no responsibility for interpretations made by others on the work performed by CEI.

We recommend that this report be made available in its entirety to contractors for informational purposes only. The boring logs and laboratory test data contained in this report represent an integral part of this report and incorrect interpretation of the data may occur if the attachments are separated from the text.

FIGURES

APPENDIX A

CENTURY ENGINEERING

Project Title
Bridgetown Sewage Plant

Project No.
211164.00

Sheet Title
Site Vicinity Map

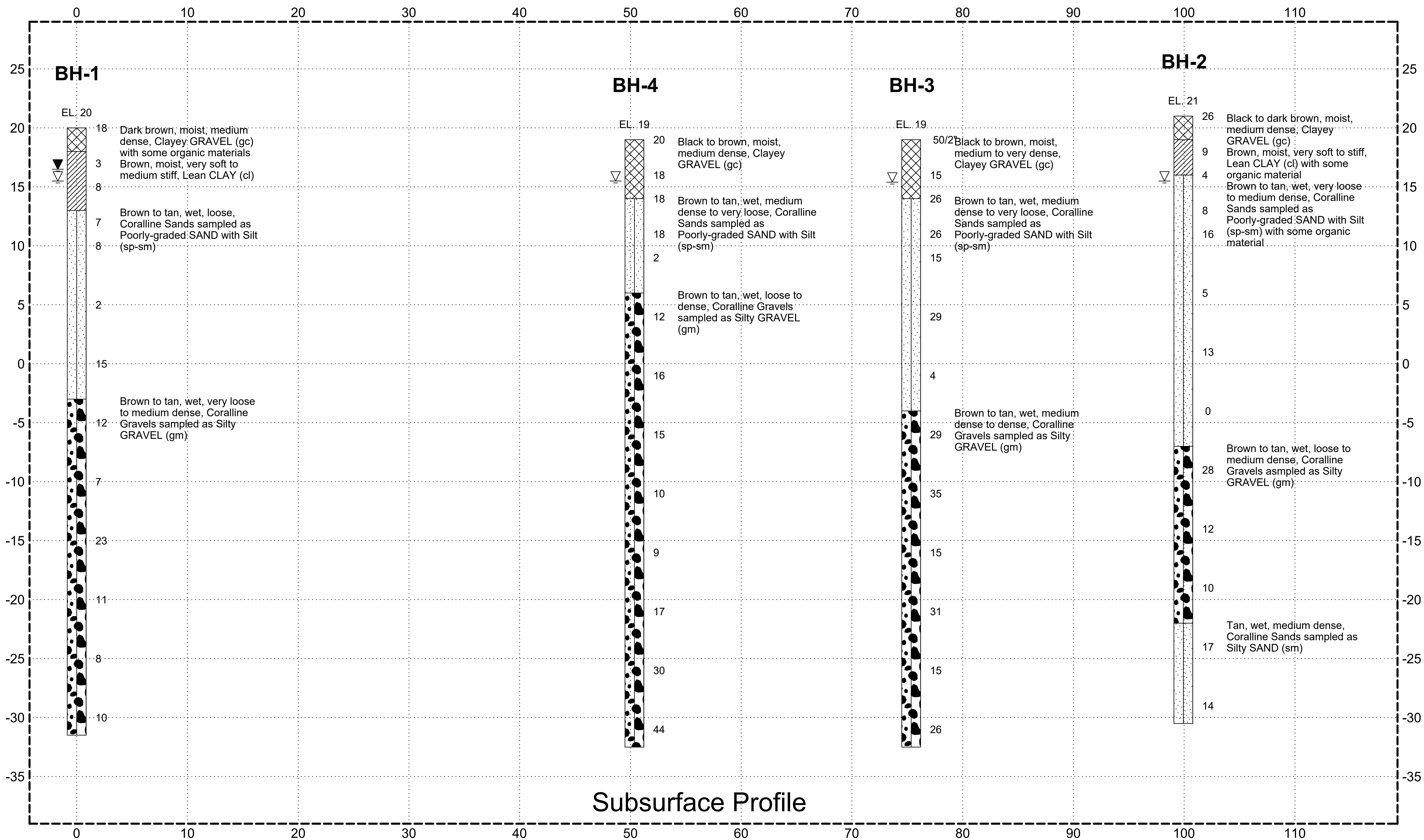
Drawing Sheet No.
A-1

Scale: NTS

Date: July 2021

CENTURY ENGINEERING	Project Title **Bridgetown Sewage Plant**	Project No. **211164.00**
	Sheet Title **Site Layout and Boring Location Plan**	Drawing Sheet No. **A-2**
	Scale: NTS / Date: July 2021	

CENTURY ENGINEERING	Project Title **Sewage Treatment Plant**	Project No. **211164.00**
	Sheet Title **Site Geology Map**	Drawing Sheet No. **A-3**
	Scale: NTS / Date: July 2021	



Subsurface Profile

CEI 11 X 17 BRIDGETOWN SEWAGE PLANT.GPJ SLHTEST2.GDT 7/19/21

CENTURY ENGINEERING
10710 Gilroy Road
Hunt Valley, MD 21031
(443) 589-2400
FAX: (443) 589-2401

PROJECT : Bridgetown Sewage Plant			FIGURE NO. A-4
DRAWN BY : TEM	APPROVED BY :	DATE : 7/19/21	CONTRACT NO. 211164.00

BORING LOGS

APPENDIX B

TEST BORING LOG

BORING BH 1

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LANES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 1 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R. ATKINSON
LOGGED BY: U. SEALE

GROUNDWATER DATA (feet)					EQUIPMENT	CASING	SAMPLER	CORE
Date	Time	Water	Inside Casing	Cave-In	TYPE	CME	45C	RIG
03/04/21	13:30	4½'		20½'	SIZE, ID	8½	SPT/SS	2"
04/04/21	15:30			15'	HAMMER WT.	140 lbs		—
08/05/21	15:03	3½'			HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S1	0 TO 1½	15"	3 6 12				0, 1', 1½			DARK BROWN CLAY + PEAT LIMESTONE PEBBLES VERY LOOSE / MEDIUM DENSE SOFT TO STIFF	
S2	3 TO 4½	8"	1 1 2				3, 4½			BROWNISH CLAY VERY LOOSE VERY SOFT	▽ WATER TABLE @ 3.5 ft. 08/05/21 @ 15:03 PM
S3	5 TO 6½	11"	140 6 3 5				6½			BROWNISH / GREYISH CLAY LOOSE / VERY LOOSE - SOFT	▽ WATER TABLE @ 4½ ft. 03/04/21
S4	8 TO 9½	20"	2 3 4				8', 9½			BROWNISH/TAN DAMP SAND VERY LOOSE - SOFT	DAMP
S5	10 TO 11½	11"	1 2 6				11½			BROWNISH TAN SANDY/GRAVELS VERY LOOSE SOFT/MEDIUM STIFF	DAMP
S6	15 TO 16½	∅	1 1 1				15, 16½			* NO SAMPLE RETRIEVED VERY LOOSE VERY SOFT	NO SAMPLE
S7	20 TO 21½	22"	7 6 9				20', 21½			BROWNISH/GREYISH SANDS SILTY-LOOSE - MEDIUM STIFF	WET
							25'				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION
- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 1

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILTY CONSULTANTS LTD.
SITE: BTSTP LANES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 2 **of** 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R ATKINSON
LOGGED BY: R. SEALE

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
03/04/21	11:30	4 1/2'		20 1/2'
04/04/21	15:30			15'
08/05/21	15:03	3 1/2'		

EQUIPMENT	CASING	SAMPLER	CORE
TYPE CME	45C	RIG	
SIZE, ID	6 1/2	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S8	25 TO 26 1/2	22"	4 2 10				25' – 26 1/2'		X	WHITISH TO GREYISH SANDY COARSE GRAVELS + LIMESTONE FRAGMENTS VERY LOOSE - LOOSE / SOFT / MEDIUM STIFF	
S9	30 TO 31 1/2	13"	6 4 3				30' – 31 1/2'		X	LIGHT GREYISH LIMESTONE GRAVELS / SANDY / SILTY LOOSE - SOFT TO MEDIUM STIFF	WET
S10	35 TO 36 1/2	21"	7 14 9				35' – 36 1/2'		X	LIGHT GREYISH LIMESTONE GRAVELS / SANDY / SILTY LOOSE TO MEDIUM DENSE MEDIUM STIFF TO STIFF	WET
S11	40 TO 41 1/2	19"	3 4 7				40' – 41 1/2'		X	LIGHT GREYISH LOOSE LIMESTONE GRAVELS + SANDS / SILTY VERY LOOSE / SOFT	WET
S12	45 TO 46 1/2	24"	4 4 4				45' – 46 1/2'		X	LIGHT GREYISH LIMESTONE GRAVELS + SANDS. VERY LOOSE SOFT.	WET
							50'				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH1

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSP LAKES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 3 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R. ATKINSON
LOGGED BY: H. SEALE

GROUNDWATER DATA (feet)					EQUIPMENT	CASING	SAMPLER	CORE
Date	Time	Water	Inside Casing	Cave-In	TYPE	CME 45 C RIG		
03/04/21	11:00	4 1/2'		20 1/2'	SIZE, ID	6 1/4"	SPT/SS	2"
04/04/21	15:30			15'	HAMMER WT.	140 lbs		—
05/05/21		3 1/2'			HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S13	50 TO 51 1/2	28"	5 5 5				50				WET
											BOREHOLE TERMINATED MONITORING WELL INSTALLED 2" DIA. SCH 40 PVC WITH UPSTAND MANHOLE COVER.

BLOWS/FT.	DENSITY	BLOWS/FT.	CONSISTENCY
0-4	VERY LOOSE	0-2	VERY SOFT
5-10	LOOSE	3-4	SOFT
11-30	MEDIUM DENSE	5-8	MEDIUM STIFF
31-50	DENSE	9-15	STIFF
OVER 50	VERY DENSE	16-30	VERY STIFF
		OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 2

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LAKES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 1 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R ATKINSON
LOGGED BY: K. SEALS

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
03/04/21	15:30	5½'		32'-2"

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME	45C	RIG
SIZE, ID	6½"	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC/ Fract Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S1	0 TO 1½	12"	8 12 14				0 – 1½'		X	BLACK DARK BROWN CLAY CORAL LIMESTONE PEBBLES LOOSE – MEDIUM DENSE MEDIUM STIFF	
S2	3 TO 4½	15"	2 6 3				3' – 4½'		X	DARK BROWN CLAY SANDY-SILTY, VERY LOOSE SOFT	
S3	5 TO 6½	18½"	2 2 2				5 – 6½		X	DARK BROWN SILTY CLAY PEATY. VERY LOOSE VERY SOFT	▽ WATER TABLE APPROX. 5½ ft.
S4	8 TO 9½	17"	3 3 5				8' – 9½		X	BROWN SANDS / DARK BROWN SILTY PEAT.	DAMP
S5	10 TO 11½	27"	2 6 10				11½		X	BROWN SANDS VERY LOOSE/LOOSE – SOFT/MEDIUM STIFF	WET
S6	15 TO 16½	25"	4 2 3				15 – 16½		X	BROWN SANDS VERY LOOSE, SOFT	WET
S7	20 TO 21½	23"	10 7 6				20' – 21½		X	BROWN SANDS LOOSE / MEDIUM STIFF TO STIFF	WET

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION
- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS	
DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LAKES FOLLY BRIDGETOWN

JOB NUMBER:
SHEET NO. 2 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R ATKINSON
LOGGED BY: M.SEALE

GROUNDWATER DATA (feet)					EQUIPMENT	CASING	SAMPLER	CORE
Date	Time	Water	Inside Casing	Cave-In	TYPE	CME45	CABLE	
03/04/21	15:30	5½'		32'2"	SIZE, ID	6¼"	SPT/SS	2"
					HAMMER WT.	140lbs		—
					HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S8	25 TO 26½		WOR 0 18				25' – 26½'		X	BROWN SANDS TO GREYISH SANDY CLAY VERY LOOSE/VERY SOFT	WET
S9	30 TO 31½	21"	9 13 15				30 – 31½		X	BROWN SANDS TO GREYISH SILTY/SANDY FRACTURE LIMESTONE LOOSE TO MEDIUM DENSE STIFF	WET
S10	35 TO 36½	26"	4 6 6				35' – 36½			GREYISH SILTY ~~CLAYEY~~ LIMESTONE FRAGMENTS LOOSE / SOFT TO MEDIUM STIFF SANDY	WET
S11	40 TO 41½	28"	3 4 6				40 – 41½			TAN/ GREYISH SILTY ~~CLAY~~ FRACTURE CORAL LIMESTONE VERY LOOSE/LOOSE SANDY SOFT	WET
S12	45 TO 46½	28"	3 6 11				45 – 46½			TAN/GREYISH SILTY ~~CLAY~~ SANDY. VERY LOOSE/LOOSE SOFT TO MEDIUM STIFF	WET
							50				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 2

PROJECT: BRIDGETOWN SEWAGE PROJECT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSP LAKES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 3 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 03/04/21
END DATE: 03/04/21
DRILLER: R. ATKINSON
LOGGED BY: M. SEALE

GROUNDWATER DATA (feet)

Date	Time	Water	Inside Casing	Cave-In
03/04/21	15:30	5½'		32'-2"

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45 RIG		
SIZE, ID	6¼"	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	LABORATORY TEST RESULTS: NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S13	50 TO 51½	24"	5 4 10				51½			TANISH/GREYISH SILTY SANDY CLAY. LOOSE MEDIUM STIFF	WET
											BOREHOLE TERMINATED

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 3.

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LANES FOLLY BRIDGETOWN

JOB NUMBER:
SHEET NO. 1 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 04/04/21
END DATE: 04/04/21
DRILLER: R. ATKINSON
LOGGED BY: N. SEALE

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
04/04/21	11:30	3'-7'		6"-7"

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45C RIG		
SIZE, ID	6½"	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	LABORATORY TEST RESULTS: NMC/ Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S1	0 TO 1½'	9½"	15 50/2				0			TOP SOIL DARK BROWN CLAY MEDIUM DENSE TO DENSE VERY STIFF TO HARD LIMESTONE FRAGMENTS	
S2	3 TO 4½'	17½"	7 8 7				1½' 3'			DARK BROWN TO BLACK CLAY LIMESTONE FRAGMENTS LOOSE MEDIUM STIFF	
S3	5 TO 6½'	19"	4 6 20				4½'			BROWN SANDS VERY LOOSE/MEDIUM DENSE MEDIUM STIFF TO VERY STIFF	DAMP
S4	8 TO 9½	24"	4 9 17				6½' 8'			BROWN SANDS VERY LOOSE TO MEDIUM DENSE/ MEDIUM TO VERY STIFF	WET
S5	10 TO 11½	22"	6 9 6				9½'			BROWN SANDS LOOSE MEDIUM STIFF	WET
S6	15 TO 16½	∅	9 16 13				11½' 15			NO RECOVERY OF SAMPLE	WET
S7	20 TO 21½	24"+	4 3 1				16½' 20'			BROWN SANDS VERY LOOSE SOFT	WET
							21½' 25'				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION
- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS	
DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 3

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LAKES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 2 **of** 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 04/04/21
END DATE: 04/04/21
DRILLER: R. ATKINSON
LOGGED BY: K. SEALE

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
04/04/21	11:30	3'-7"		6'-7"

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45C RIG		
SIZE ID	6¼"	SPT/SS	2"
HAMMER WT.	140/lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S8	25 TO 26½	17"	3 10 19				25 – 26½			GREYISH SANDY CORAL LIMESTONE FRACTURED LOOSE/MEDIUM DENSE/STIFF	WET
S9	30 TO 31½	22"	9 17 18				30 – 31½			GREYISH SANDY CORAL LIMESTONE FRACTURED + GRAVELS MEDIUM DENSE/STIFF TO VERY STIFF	WET
S10	35 TO 36½	14"	6 8 7				35 – 36½			GREYISH SANDY FRACTURED CORAL LIMESTONE GRAVELS LOOSE/MEDIUM STIFF	WET
S11	40 TO 41½	24"	7 11 20				40 – 41½			GREYISH TANISH SANDY/SILTY FRACTURED CORAL LIMESTONE LOOSE TO MEDIUM DENSE MEDIUM STIFF TO VERY STIFF	
S12	45 TO 46½	18"	7 8 7				45 – 46½			GREYISH/TAN SANDY SILTY FRACTURED CORAL LIMESTONE LOOSE/MEDIUM STIFF	
							50				

BLOWS/FT.	DENSITY	BLOWS/FT.	CONSISTENCY
0-4	VERY LOOSE	0-2	VERY SOFT
5-10	LOOSE	3-4	SOFT
11-30	MEDIUM DENSE	5-8	MEDIUM STIFF
31-50	DENSE	9-15	STIFF
OVER 50	VERY DENSE	16-30	VERY STIFF
		OVER 30	HARD

SAMPLE IDENTIFICATION
- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 3

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BT STP LANES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 3 **of** 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 04/04/21
END DATE: 04/04/21
DRILLER: R. ATKINSON
LOGGED BY: A. SEALE

GROUNDWATER DATA (feet)

Date	Time	Water	Inside Casing	Cave-In
04/04/21	11:30	3'-7"		6'-7'

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45C RIG		
SIZE, ID	6¼"	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	LABORATORY TEST RESULTS: NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
SS13	50 TO 51½	24" +	11 9 17				51½			GREYISH SANDS CORAL LIMESTONE FRAGMENTS LOOSE/MEDIUM DENSE/STIFF	WET
											BOREHOLE TERMINATED

BLOWS/FT.	DENSITY	BLOWS/FT.	CONSISTENCY
0-4	VERY LOOSE	0-2	VERY SOFT
5-10	LOOSE	3-4	SOFT
11-30	MEDIUM DENSE	5-8	MEDIUM STIFF
31-50	DENSE	9-15	STIFF
OVER 50	VERY DENSE	16-30	VERY STIFF
		OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING BH 4

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.
SITE: BTSTP LANES FOLLY, BRIDGETOWN

JOB NUMBER:
SHEET NO. 1 of 3
NORTHING:
EASTING:
ELEVATION:
START DATE: 04/04/21
END DATE: 04/04/21
DRILLER: R. ATKINSON
LOGGED BY: N. SCALE

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
04/04/21	14:20	3½'		5 ft.

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45C		MG
SIZE, ID	6¼"	SPT/SS	2"
HAMMER WT.	140 lbs		—
HAMMER FALL	30"		—

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	NMC/ Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S1	0 TO 1½	18"	14 13 7				0' – 1½'		X	TOP SOIL DARK BROWN CLAY SILTY/SANDY LOOSE/MEDIUM DENSE STIFF	
S2	3 TO 4½	16"	3 7 11				3 – 4½'		X	DARK BROWN CLAY SANDY LOOSE/MEDIUM DENSE MEDIUM STIFF/STIFF	DAMP
S3	5 TO 6½	15"	3 7 11				6½'		X	BROWN SANDS LOOSE TO MEDIUM DENSE/ SOFT MEDIUM STIFF	WET
S4	8 TO 9½	14"	3 7 11				8 – 9½'		X	BROWN SANDS LOOSE TO MEDIUM DENSE STIFF / MEDIUM STIFF	WET
S5	10 TO 11½	19"	10 1 1				11½'		X	BROWN SANDS PEAT VERY LOOSE/LOOSE VERY SOFT MEDIUM STIFF	WET
S6	15 TO 16½	24" +	6 6 6				15 – 16½'		X	GREYISH CORAL LIMESTONE FRACTURED + GRAVELS + SANDS LOOSE, MEDIUM STIFF	WET
S7	20 TO 21½	24" +	1 7 9				20 – 21½'		X	GREYISH / TAN SANDY GRAVELS CORAL LIMESTONE FRACTURED LOOSE / VERY SOFT TO MEDIUM STIFF	WET
							25				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION
- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

BORING	BH 4
PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH	**JOB NUMBER:**
CLIENT: INTEGRATED SUSTAINABILITY CONSULTANTS LTD.	**SHEET NO.** 2 of 3
SITE: BTSP LARES FOLLY, BRIDGETOWN	**NORTHING:**
	EASTING:
	ELEVATION:
	START DATE: 04/04/21
	END DATE: 04/04/21
	DRILLER: R. ATKINSON
	LOGGED BY: K. SEALE

GROUNDWATER DATA (feet)				
Date	Time	Water	Inside Casing	Cave-In
04/04/21	14:20	3½'		5 Ft

EQUIPMENT	CASING	SAMPLER	CORE
TYPE	CME 45C RIG		
SIZE, ID	6½"	SPT/SS	2"
HAMMER WT.	140 lbs		
HAMMER FALL	30"		

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	LABORATORY TEST RESULTS: NMC/ Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S8	25 TO 26½	24"+	3 5 10				26½			LIGHT GREYISH FRACTURED CORAL LIMESTONE SANDY GRAVELS - V. GRY LOOSE/LOOSE SOFT TO STIFF	WET
S9	30 TO 31½	19"	3 3 7				30, 31½			LIGHT GREYISH FRAGMENTED CORAL LIMESTONE SANDY GRAVELS - VERY LOOSE/LOOSE; SOFT TO MEDIUM STIFF	WET
S10	35 TO 36½	15½"+	4 2 7				35, 36½			LIGHT GREYISH FRACTURED CORAL LIMESTONE SANDY GRAVELS, VERY LOOSE TO LOOSE, SOFT TO MEDIUM STIFF	WET
S11	40 TO 41½	24"+	4 9 8				40, 41½			LIGHT GREYISH FRACTURED CORAL LIMESTONE, SANDY GRAVELS, LOOSE MEDIUM STIFF	WET
S12	45 TO 46½	24"+	5 13 17				45, 46½			LIGHT GREYISH FRACTURED CORAL LIMESTONE SANDY GRAVELS LOOSE TO MEDIUM DENSE, MEDIUM STIFF TO STIFF	WET
							50				

BLOWS/FT.	DENSITY
0-4	VERY LOOSE
5-10	LOOSE
11-30	MEDIUM DENSE
31-50	DENSE
OVER 50	VERY DENSE

BLOWS/FT.	CONSISTENCY
0-2	VERY SOFT
3-4	SOFT
5-8	MEDIUM STIFF
9-15	STIFF
16-30	VERY STIFF
OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS	
DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

BORING

TEST BORING LOG

PROJECT: BRIDGETOWN SEWAGE PLANT GEOTECH	**BORING** BH 4
CLIENT: INTEGRATED SUSTAINABLE CONSULTANTS LTD.	**JOB NUMBER:**
SITE: BTSP LANES FOLLY, BRIDGETOWN	**SHEET NO.** 3 of 3
	NORTHING:
	EASTING:
	ELEVATION:
	START DATE: 04/04/21
	END DATE: 04/04/21
	DRILLER: R. ATKINSON
	LOGGED BY: H. SEALE

GROUNDWATER DATA (feet)					EQUIPMENT	CASING	SAMPLER	CORE
Date	Time	Water	Inside Casing	Cave-In	TYPE	CME 45C RIG		
04/04/21	14:20	3½ ft		5 ft	SIZE, ID	6½"	SPT/SS	2"
					HAMMER WT.	140 lbs		
					HAMMER FALL	30"		

SAMPLE NUMBER	SAMPLE DEPTH	SAMPLE RECOVERY	BLOWS / 6" (%RQD)	LABORATORY TEST RESULTS: NMC / Fract. Freq.	LIQUID LIMIT	PLASTICITY INDEX	DEPTH	ELEV. / DEPTH	GRAPHICS	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
S13	50 TO 51½	24" +	15 16 28				51½		☒	BROWNISH FRACTURED CORAL LIMESTONE STIFF TO VERY STIFF	WET
											BOREHOLE TERMINATED

BLOWS/FT.	DENSITY	BLOWS/FT.	CONSISTENCY
0-4	VERY LOOSE	0-2	VERY SOFT
5-10	LOOSE	3-4	SOFT
11-30	MEDIUM DENSE	5-8	MEDIUM STIFF
31-50	DENSE	9-15	STIFF
OVER 50	VERY DENSE	16-30	VERY STIFF
		OVER 30	HARD

SAMPLE IDENTIFICATION

- S - SPLIT SPOON
- T - THIN WALL TUBE
- SS - 3in. SPLIT SPOON
- R - DIAMOND CORE
- W - WASH SAMPLE
- U - UNDISTURBED

SAMPLE PROPORTIONS

DESCRIPTIVE TERM	PERCENT
TRACE	1 TO 10
LITTLE	11 TO 20
SOME	21 TO 35
AND	35 TO 50

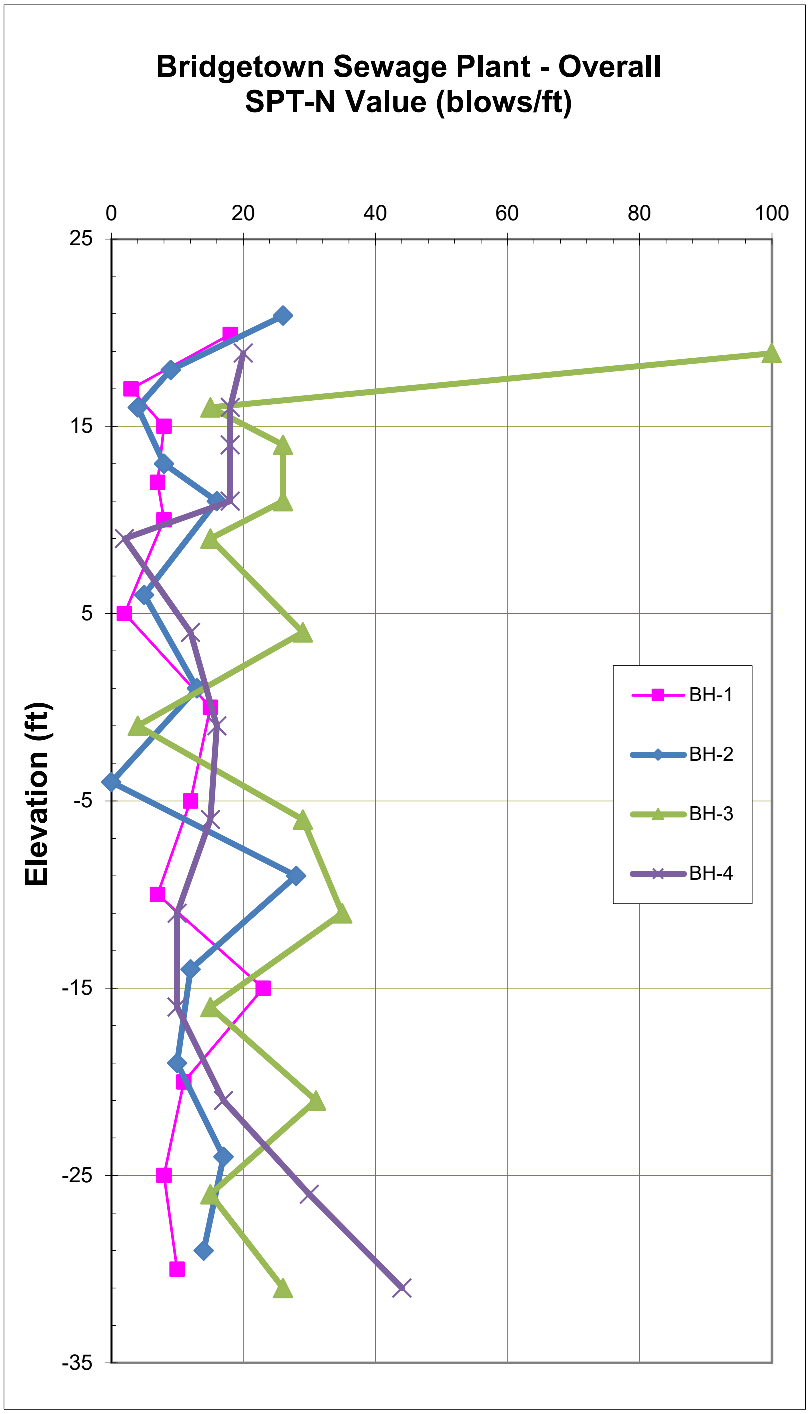
BORING

CALCULATIONS

APPENDIX C

Barbados
Bridgetown Sewage Plant
SPT Corrections

Figure 1. Summary of Uncorrected SPT Blow Counts



CENTURY ENGINEERING

Project: Bridgetown Sewage Plant - Barbados

		S.O. Number:		Sheet:	of
Subject:	Foundation Design	Computed by:	TEM	Date:	7/8/21
		Checked by:		Date:	

Note: shaded cells are data to be input

Corrections to Measured Blow Counts (McGregor & Duncan, 1998):

(1) $N_{60} = N_{field} C_E C_R C_B C_S C_A C_{BF} C_C$ — Correction for 60% of theoretical free fall energy

(2) $N_{1,60} = N_{field} C_N C_E C_R C_B C_S C_A C_{BF} C_C$ — Correction to 1 tsf of overburden pressure and for 60% of theoretical free fall energy

Note: This spreadsheet utilizes equation (2)

where

C_N = overburden correction factor

C_E = energy correction factor

C_R = rod length correction factor

C_B = borehole diameter correction factor

C_S = liner correction factor

C_A = anvil correction factor

C_{BF} = blow count frequency correction factor

C_C = hammer cushion correction factor

Overburden Correction Factor (C_N):

$$N_{corr} = \left[0.77 \log_{10}\left(\frac{1.92}{\sigma'_v}\right)\right] N$$

(AASHTO 10-7.2.3.3-4, LRFD, SI Unit, 1998))

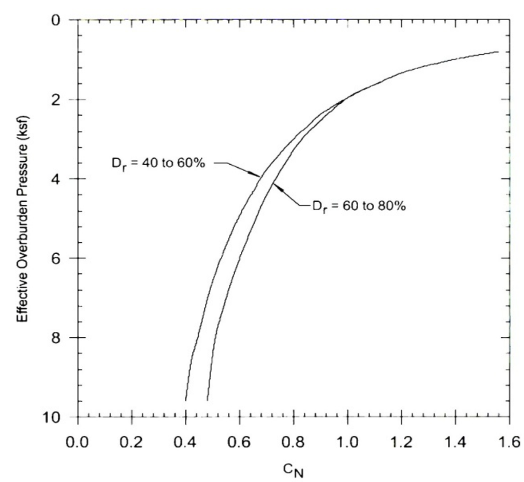
σ'_v: Effective Overburden Stress in MPa

N: Uncorrected SPT-N Value

Alternative Overburden Correction Factors (C_N): See table/figure below. Equations within cells must be modified)

Overburden correction factors (C_N) (after Carter and Bentley, 1991)

Reference	Correction Factor (C_N)	Units of overburden pressure (σ_v')
Peck and Bazaraa (1969)	$C_N = \begin{cases} \frac{4}{1+2\sigma_v'} & \sigma_v' \le 1.5 \\ \frac{4}{3.25+0.5\sigma_v'} & \sigma_v' > 1.5 \end{cases}$	ksf
Peck et al. (1974)	$C_N = 0.77\log_{10}\frac{20}{\sigma_v'}$	kg/cm² or tsf
Tokimatsu and Yoshimi (1983)	$C_N = \frac{1.7}{0.7+\sigma_v'}$	kg/cm² or tsf
Liao and Whitman (1986)	$C_N = \sqrt{\frac{1}{\sigma_v'}}$	kg/cm² or tsf
Skempton (1986)	$C_N = \begin{cases} \frac{2}{1+\sigma_v'} & \text{For fine sands of medium relative density} \\ \frac{3}{2+\sigma_v'} & \text{For dense, coarse sands when normally consolidated} \\ \frac{1.7}{0.7+\sigma_v'} & \text{For overconsolidated fine sands} \end{cases}$	kg/cm² or tsf



Energy Correction Factor (C_E):

C_E = ER/60

where, C_E is the hammer energy correction factor and ER is the hammer system energy ratio.

Energy Correction Factors (C_E) from Seed et al., 1985

Hammer Type	ER(%)	C_E
Donut	45	0.75
Safety	60	1.0
Trip	100	1.67

Rod Length Correction Factor (C_R):

Skempton's correction factor is used for this spreadsheet. An alternate may be used, however, the spreadsheet equation must be changed.

	C_R		
Rod length (ft)	Seed et al. (1985)	Skempton (1986)	Youd & Idriss (1997)
< 10	0.75	-	-
10 to 13	1.00	0.75	0.75
13 to 20	1.00	0.85	0.85
20 to 30	1.00	0.95	0.95
> 30	1.00	1.00	1.00
> 100	1.00	1.00	< 1.0

Borehole Diameter Correction Factor (C_B):

Borehole Diameter (inches)	C_B
2.5 to 4.5	1.00
6	1.05
8	1.15

Liner Correction Factor (C_S):

Sampler Configuration	C_S
Std sampler (with liners)	1.00
US sampler without liners	1.1 to 1.3

Anvil Correction Factor (C_A):

Hammer Type	Anvil	C_A
Donut	Small (4.4 lb)	0.85
	Large (26.5 lb)	0.70
Safety	5.5 lb	0.90

Blow Count Frequency Correction Factor (C_{BF}) - only for sands below the water table:

$N_{1,60}$	Frequency of Hammer Blows	C_{BF}
< 20	10 to 20 bpm	0.95
> 20	10 to 20 bpm	1.05

Note: If the frequency of hammer blows is 30 to 40 blows per minute, use C_{BF} = 1.0

Hammer Cushion Correction Factor (C_C):

Type of Cushion	C_C
none	1.00
new	0.95
used	0.90

Corrections for saturated very fine or silty sand (Meyerhof, 1956):

N = 15 + (N' - 15)/2 for N' > 15

where N' is the measured blow count and N is the corrected blow coun

CENTURY ENGINEERING

Project: **Bridgetown Sewage Plant - Barbados**

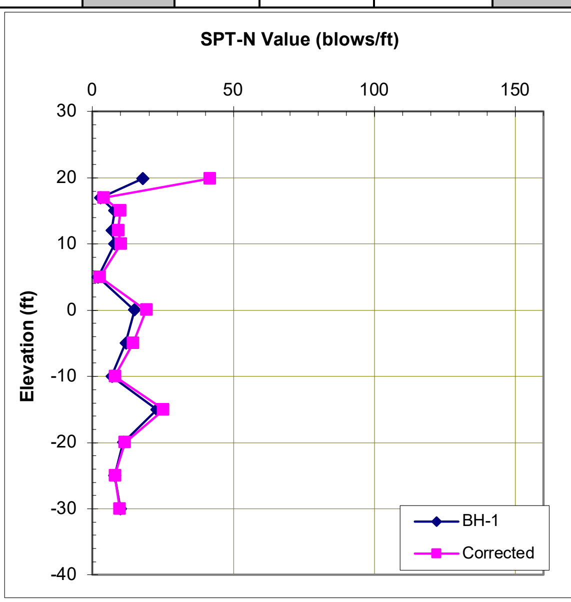
		S.O. Number:		Sheet:	of
Subject:	Foundation Design	Computed by:	TEM	Date:	7/8/21
		Checked by:		Date:	

Note: shaded cells are data to be input

Boring No: **BH-1**

Ground Elevation:	20.00	(ft)	6.096	(m)		
Ground Water Depth:	3.50	(ft)	1.067	(m)		
Wet Unit Weight of Soil Above Groundwater Table:			115	(pcf)	18.1	(kN/m^3)
Unit Weight of Soil Below Ground Water Table:			120	(pcf)	18.9	(kN/m^3)
Hammer Type (Donut, Safety, Trip):			Safety	C_E =	1.00	
Note: Rod Length Correction Factor is calculated from sample depths						
Borehole Diameter (2.5 to 4.5, 6, or 8"):			6	C_B =	1.05	
Split Spoon Liner Type (Liner, No Liner):			No Liner	C_S =	1.20	
Anvil Type (Donut-Small, Donut-Large, Safety):			Safety	C_A =	0.90	
Blow Count Frequency (10-20, 30-40, or 40+ bpm):			30-40	C_{BF} =	1.00	
Type of Wood Hammer Cushion (None, New, Used):			None	C_C =	1.00	

Soil Sample No.	Depth (ft)	Depth (m)	Elevation (ft)	Elevation (m)	SPT-N Value	Effective Stress (ksf)	Effective Stress (MPa)	Rod Length Correction	Blow-Count Frequency Correction	Corrected $N_{1,60}$
S-1	0.10	0.031	19.90	6.066	18	0.012	0.00055	0.75	1.00	41.8
S-2	3.00	0.914	17.00	5.182	3	0.345	0.01652	0.75	1.00	4.1
S-3	5.00	1.524	15.00	4.572	8	0.489	0.02341	0.75	1.00	10.0
S-4	8.00	2.438	12.00	3.658	7	0.662	0.03169	0.85	1.00	9.3
S-5	10.00	3.048	10.00	3.048	8	0.777	0.03720	0.85	1.00	10.2
S-6	15.00	4.572	5.00	1.524	2	1.065	0.05099	1.00	1.00	2.7
S-7	20.00	6.096	0.00	0.000	15	1.353	0.06478	1.00	1.00	19.3
S-8	25.00	7.620	-5.00	-1.524	12	1.641	0.07856	1.00	1.00	14.5
S-9	30.00	9.144	-10.00	-3.048	7	1.929	0.09235	1.00	1.00	8.1
S-10	35.00	10.668	-15.00	-4.572	23	2.217	0.10614	1.00	1.00	25.3
S-11	40.00	12.192	-20.00	-6.096	11	2.505	0.11993	1.00	1.00	11.6
S-12	45.00	13.716	-25.00	-7.620	8	2.793	0.13371	1.00	1.00	8.1
S-13	50.00	15.240	-30.00	-9.144	10	3.081	0.14750	1.00	1.00	9.8



Project: **Bridgetown Sewage Plant - Barbados**

Subject:	Foundation Design	S.O. Number:		Sheet:	of
		Computed by:	TEM	Date:	7/8/21
		Checked by:		Date:	

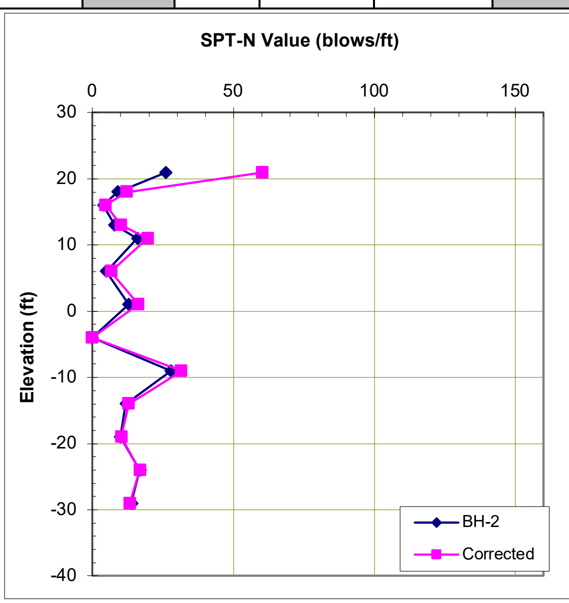
Note: shaded cells are data to be input

Boring No: **BH-2**

Ground Elevation:	21.00	(ft)	6.401	(m)	
Ground Water Depth:	5.50	(ft)	1.676	(m)	
Wet Unit Weight of Soil Above Groundwater Table:		115	(pcf)	18.1	(kN/m^3)
Unit Weight of Soil Below Ground Water Table:		120	(pcf)	18.9	(kN/m^3)

Hammer Type (Donut, Safety, Trip):	Safety	C_E =	1.00
Note: Rod Length Correction Factor is calculated from sample depths			
Borehole Diameter (2.5 to 4.5, 6, or 8"):	6	C_B =	1.05
Split Spoon Liner Type (Liner, No Liner):	No Liner	C_S =	1.20
Anvil Type (Donut-Small, Donut-Large, Safety):	Safety	C_A =	0.90
Blow Count Frequency (10-20, 30-40, or 40+ bpm):	30-40	C_{BF} =	1.00
Type of Wood Hammer Cushion (None, New, Used):	None	C_C =	1.00

Soil Sample No.	Depth (ft)	Depth (m)	Elevation (ft)	Elevation (m)	SPT-N Value	Effective Stress (ksf)	Effective Stress (MPa)	Rod Length Correction	Blow-Count Frequency Correction	Corrected $N_{1,60}$
S-1	0.10	0.031	20.90	6.370	26	0.012	0.00055	0.75	1.00	60.3
S-2	3.00	0.914	18.00	5.486	9	0.345	0.01652	0.75	1.00	12.2
S-3	5.00	1.524	16.00	4.877	4	0.575	0.02754	0.75	1.00	4.8
S-4	8.00	2.438	13.00	3.962	8	0.777	0.03719	0.85	1.00	10.2
S-5	10.00	3.048	11.00	3.353	16	0.892	0.04270	0.85	1.00	19.7
S-6	15.00	4.572	6.00	1.829	5	1.18	0.05649	1.00	1.00	6.7
S-7	20.00	6.096	1.00	0.305	13	1.468	0.07028	1.00	1.00	16.3
S-8	25.00	7.620	-4.00	-1.219	0	1.756	0.08407	1.00	1.00	0.0
S-9	30.00	9.144	-9.00	-2.743	28	2.044	0.09785	1.00	1.00	31.6
S-10	35.00	10.668	-14.00	-4.267	12	2.332	0.11164	1.00	1.00	12.9
S-11	40.00	12.192	-19.00	-5.791	10	2.62	0.12543	1.00	1.00	10.3
S-12	45.00	13.716	-24.00	-7.315	17	2.908	0.13921	1.00	1.00	16.9
S-13	50.00	15.240	-29.00	-8.839	14	3.196	0.15300	1.00	1.00	13.4



CENTURY ENGINEERING

Project: **Bridgetown Sewage Plant - Barbados**

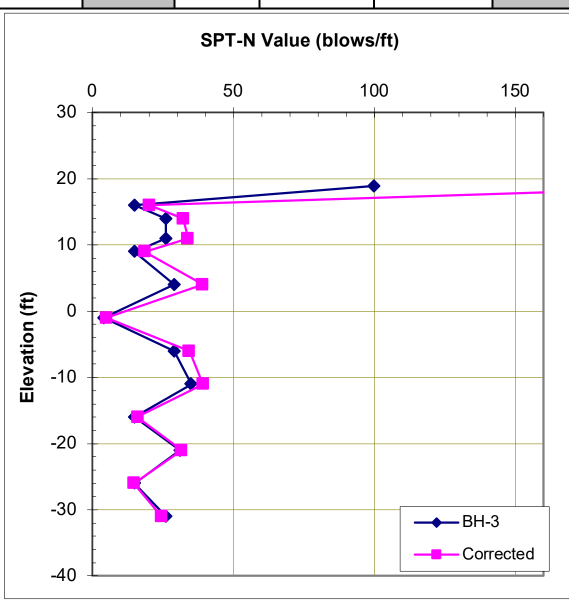
		S.O. Number:		Sheet:	of
Subject:	Foundation Design	Computed by:	TEM	Date:	7/8/21
		Checked by:		Date:	

Note: shaded cells are data to be input

Boring No:	**BH-3**					
Ground Elevation:	19.00	(ft)	5.791	(m)		
Ground Water Depth:	3.60	(ft)	1.097	(m)		
Wet Unit Weight of Soil Above \			120	(pcf)	18.9	(kN/m^3)
Unit Weight of Soil Below Ground Water Table:			125	(pcf)	19.6	(kN/m^3)

Hammer Type (Donut, Safety, Trip):	Safety	C_E =	1.00
Note: Rod Length Correction Factor is calculated from sample depths			
Borehole Diameter (2.5 to 4.5, 6, or 8"):	6	C_B =	1.05
Split Spoon Liner Type (Liner, No Liner):	No Liner	C_S =	1.20
Anvil Type (Donut-Small, Donut-Large, Safety):	Safety	C_A =	0.90
Blow Count Frequency (10-20, 30-40, or 40+ bpm):	30-40	C_{BF} =	1.00
Type of Wood Hammer Cushion (None, New, Used):	None	C_C =	1.00

Soil Sample No.	Depth (ft)	Depth (m)	Elevation (ft)	Elevation (m)	SPT-N Value	Effective Stress (ksf)	Effective Stress (MPa)	Rod Length Correction	Blow-Count Frequency Correction	Corrected $N_{1,60}$
S-1	0.10	0.031	18.90	5.761	100	0.012	0.00058	0.75	1.00	230.7
S-2	3.00	0.914	16.00	4.877	15	0.36	0.01724	0.75	1.00	20.1
S-3	5.00	1.524	14.00	4.267	26	0.52	0.02489	0.75	1.00	32.1
S-4	8.00	2.438	11.00	3.353	26	0.708	0.03388	0.85	1.00	33.8
S-5	10.00	3.048	9.00	2.743	15	0.833	0.03987	0.85	1.00	18.7
S-6	15.00	4.572	4.00	1.219	29	1.146	0.05486	1.00	1.00	39.1
S-7	20.00	6.096	-1.00	-0.305	4	1.459	0.06984	1.00	1.00	5.0
S-8	25.00	7.620	-6.00	-1.829	29	1.772	0.08483	1.00	1.00	34.4
S-9	30.00	9.144	-11.00	-3.353	35	2.085	0.09981	1.00	1.00	39.2
S-10	35.00	10.668	-16.00	-4.877	15	2.398	0.11480	1.00	1.00	16.0
S-11	40.00	12.192	-21.00	-6.401	31	2.711	0.12978	1.00	1.00	31.6
S-12	45.00	13.716	-26.00	-7.925	15	3.023	0.14477	1.00	1.00	14.7
S-13	50.00	15.240	-31.00	-9.449	26	3.336	0.15975	1.00	1.00	24.5



CENTURY ENGINEERING

Project: Bridgetown Sewage Plant - Barbados

Subject:	Foundation Design	S.O. Number:		Sheet:	of
		Computed by:	TEM	Date:	7/8/21
		Checked by:		Date:	

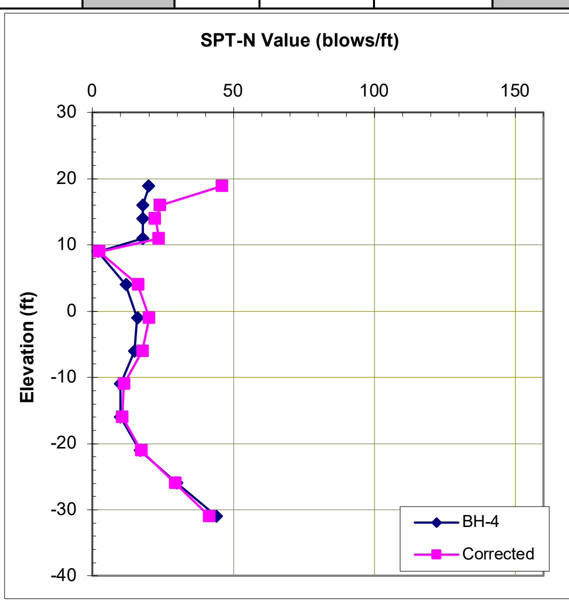
Note: shaded cells are data to be input

Boring No: BH-4

Ground Elevation:	19.00	(ft)	5.791	(m)		
Ground Water Depth:	3.50	(ft)	1.067	(m)		
Wet Unit Weight of Soil Above Groundwater Table:			120	(pcf)	18.9	(kN/m^3)
Unit Weight of Soil Below Ground Water Table:			125	(pcf)	19.6	(kN/m^3)

Hammer Type (Donut, Safety, Trip):	Safety	C_E =	1.00
Note: Rod Length Correction Factor is calculated from sample depths			
Borehole Diameter (2.5 to 4.5, 6, or 8"):	6	C_B =	1.05
Split Spoon Liner Type (Liner, No Liner):	No Liner	C_S =	1.20
Anvil Type (Donut-Small, Donut-Large, Safety):	Safety	C_A =	0.90
Blow Count Frequency (10-20, 30-40, or 40+ bpm):	30-40	C_{BF} =	1.00
Type of Wood Hammer Cushion (None, New, Used):	None	C_C =	1.00

Soil Sample No.	Depth (ft)	Depth (m)	Elevation (ft)	Elevation (m)	SPT-N Value	Effective Stress (ksf)	Effective Stress (MPa)	Rod Length Correction	Blow-Count Frequency Correction	Corrected $N_{1,60}$
S-1	0.10	0.031	18.90	5.761	20	0.012	0.00058	0.75	1.00	46.2
S-2	3.00	0.914	16.00	4.877	18	0.36	0.01724	0.75	1.00	24.2
S-3	5.00	1.524	14.00	4.267	18	0.514	0.02461	0.75	1.00	22.3
S-4	8.00	2.438	11.00	3.353	18	0.702	0.03360	0.85	1.00	23.5
S-5	10.00	3.048	9.00	2.743	2	0.827	0.03960	0.85	1.00	2.5
S-6	15.00	4.572	4.00	1.219	12	1.14	0.05458	1.00	1.00	16.2
S-7	20.00	6.096	-1.00	-0.305	16	1.453	0.06957	1.00	1.00	20.2
S-8	25.00	7.620	-6.00	-1.829	15	1.766	0.08455	1.00	1.00	17.8
S-9	30.00	9.144	-11.00	-3.353	10	2.079	0.09954	1.00	1.00	11.2
S-10	35.00	10.668	-16.00	-4.877	10	2.392	0.11452	1.00	1.00	10.7
S-11	40.00	12.192	-21.00	-6.401	17	2.705	0.12951	1.00	1.00	17.4
S-12	45.00	13.716	-26.00	-7.925	30	3.018	0.14449	1.00	1.00	29.5
S-13	50.00	15.240	-31.00	-9.449	44	3.331	0.15947	1.00	1.00	41.5



PROJECT:	Bridgetown Sewage Plant				
SUBJECT:	Shallow Foundation Bearing Capacity				
CALCULATED BY:	TEM	DATE:	7/18/21	CHECKED BY:	DATE:

REFERENCE: A.S. Vesic, "Analysis of Ultimate Loads of Shallow Foundations", ASCE Journal of Soil Mechanics and Foundation Division, Vol. 99, No. SM1, January 1973
N.F. Ismael and A.H.N. Ahmed, "Bearing Capacity of Footings on Calacareous Sands." Journal of Soils and Foundations, Vol. 30, No. 3, pp 81-80.

Footing Information

Note: Inputs Are Shaded Cells

B	=Width of footing	**4**	ft =	1219	mm
L	=Length of footing	**4**	ft =	1219	mm
D_f	=Depth to base of footing	**2**	ft =	610	mm
D_w	=Highest groundwater depth from ground surface	**3**	ft =	914	mm
β	=Slope of ground from base (downward is +)	**0**	deg		

Foundation Soil Information

c	=Soil cohesion	**0**	psf =	0.00	kPa
ϕ_f	=Total stress angle of internal friction	**32**	deg		
c_A	=Adhesion of soil to base <= c	**0**	psf =	0.00	kPa
γ_m	=Total unit weight	**120.0**	pcf =	1922	kg/m³
γ	=Weighted average soil unit weight	**73.2**	pcf =	1173	kg/m³
q	=Effective overburden pressure	**240.0**	psf =	11.49	kPa
E	=Youngs Modulus (psf)	**150.0**	ksf =	7.18	MPa
ν	=Poisson's Ratio	**0.3**			

Load Information

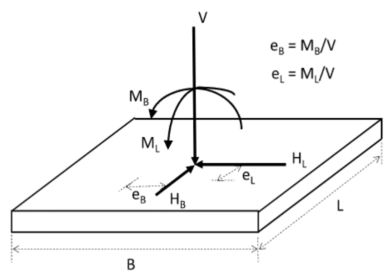
Load Combination:

H_B	=Horizontal component of inclined in B direction		kips =	0.00	kN
H_L	=Horizontal component of inclined in L direction		kips =	0.00	kN
H	=Horizontal component of inclined load on footing	0.0	kips =	0.00	kN
V	=Vertical component of inclined load at bottom of footing	**40.0**	kips =	0.00	kN
M_B	=Bending moment in the B direction at bottom of footing		kips-ft =	0.00	kN-m
M_L	=Bending moment in the L direction at borrom of footing		kips-ft =	0.00	kN-m

General Bearing Capacity Formula

$$q_{ult} = cN_c\xi_{cs}\xi_{ci}\xi_{cd} + 0.5\gamma BN_\gamma\xi_{\gamma s}\xi_{\gamma i}\xi_{\gamma d} + qD_fN_q\xi_{qs}\xi_{qi}\xi_{qd}$$

I_r	=Rigidity index	384.696
$I_{r(cr)}$	=Critical rigidity index	85.4891
$\xi_{qc}, \xi_{\gamma c}$	=Compressibility factors	2.00272
N_q	=Bearing capacity factor for overburden q	23.18
N_γ	=Bearing capacity factor for soil internal friction angle	30.21
N_c	=Bearing capacity factor for soil cohesion	35.49
$N_{q(mod)}$	=Bearing capacity factor for overburden q (modified for compressibility)	23.18
$N_{\gamma(mod)}$	=Bearing capacity factor for friction angle (modified for compressibility)	30.21
$N_{c(mod)}$	=Bearing capacity factor for soil cohesion (modified for compressibility)	35.49



Bearing Capacity Considerations:

Considering Eccentric Loading? **No** (Yes or No)

e_B	=Eccentricity of load in the B direction measured from centroid of footing	0.000	ft =	0.0	mm
e_L	=Eccentricity of load in the L direction measured from centroid of footing	0.000	ft =	0.0	mm
B'	=Effective width of Load eccentric in direction of B	4.000	ft =	1219.2	mm
L'	=Effective width of Load eccentric in direction of L	4.000	ft =	1219.2	mm

e_B > =B/6? No — **e_W >= L/6? No**

O. K. for dimension in B direction — **O. K. for dimension in L direction**

Considering Footing Shape with Eccentricity? **No** (Yes or No)

ξ_c	=Shape factor for soil cohesion	1.000
ξ_γ	=Shape factor for wedge	1.000
ξ_q	=Shape factor for overburden	1.000

Considering Inclined Loading? **No** (Yes or No)

R_{BL}	=B/L if H||B or R_{BW} = L/B if H||L	1
m	=(2 + R_{BW})/(1 + R_{BW})	1.50
θ	=Angle of load eccentricity (deg)	N/A
ξ_{ci}	=Inclination load factor for soil cohesion (dim)	1.000
ξ_{qi}	=Inclination load factor for wedge (dim)	1.000
$\xi_{\gamma i}$	=Inclination load factor for surcharge (dim)	1.000

CENTURY ENGINEERING

PROJECT:	**Bridgetown Sewage Plant**
SUBJECT:	**Shallow Foundation Bearing Capacity**

CALCULATED BY: **TEM** **DATE:** **7/18/21** **CHECKED BY:** ____ **DATE:** ____

REFERENCE: A.S. Vesic, "Analysis of Ultimate Loads of Shallow Foundations", ASCE Journal of Soil Mechanics and Foundation Division, Vol. 99, No. SM1, January 1973
N.F. Ismael and A.H.N. Ahmed, "Bearing Capacity of Footings on Calacareous Sands." Journal of Soils and Foundations, Vol. 30, No. 3, pp 81-80.

Considering Embedment Depth? **No** (Yes or No)

k	=D/B if D/B <= 1 or $\tan^{-1}$(D/B) if D/B > 1 (radians)	0.500
ξ_{cd}	=embedment factor for cohesion	1.000
$\xi_{\gamma d}$	=embedment factor for wedge	1.000
ξ_q	=embedment factor for surcharge	1.000

Ultimate Bearing Resistance q_{ult}:

$$q_{ult} = cN_c\xi_{cs}\xi_{ci}\xi_{cd} + 0.5\gamma BN_\gamma\xi_{\gamma s}\xi_{\gamma i}\xi_{\gamma d} + qD_fN_q\xi_{qs}\xi_{qi}\xi_{qd}$$

q_{ult} = (0) (35.49) (1) (1) (1) + (0.5) (73.2) (4) (30.21) (1) (1) (1) + (120) (2) (23.177) (1) (1) (1)

q_{ult}= 0.000 + 4423 + 3393 = 7817 psf = **7.82** ksf = 374 kPa

Ultimate Bearing Capacity Recommended for Design q_{ultR} (ksf): **7.82** ksf = 374 kPa

Recommended Factor of Safety (FS): **3.0**

Allowable Bearing Capacity: q_R = Q_{ultR} / FS = (7.82) / (3) = 2.61 ksf = 125 kPa

Bearing Pressure Calculation

Effective Footing Area: A' = B'L' = (4) (4) = **16.00** ft^2 = 1.49 m^2

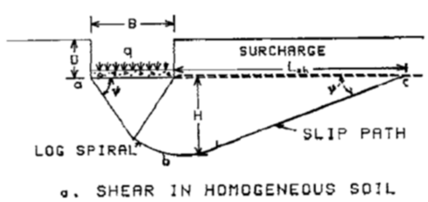
Effective footing pressure: q_E = V /A' = (40) / (16) = **2.500** ksf = 120 kPa

q_E = 2.500 < 2.61 = q_R (A good footing dimension)

Maximum Footing Pressure under This Loading Combination:

$$q_{max} = \frac{V}{BL}\left(1+\frac{6e_L}{L}+\frac{6e_B}{B}\right) = 2.50 \text{ ksf} = 120 \text{ kPa}$$

This solution considers correction factors for eccentricity, load inclination, and foundation depth. The influence of the shear strength of soil above the base of the foundation is considered in this solution. Therefore, beneficial effects of the foundation can be included in the analysis. Assumptions include use of a shape factor ξ_q for surcharge, soil at plastic equibrium, and a log spiral failure surface that includes shear above the base of foundation. The angle ψ=45+φ/2 was used for determination of N_γ. The following tables illustrate the Vesic dimensionless bearing capacity and correction factors required for solution of the bearing capacity equation (Vesic, 1970).

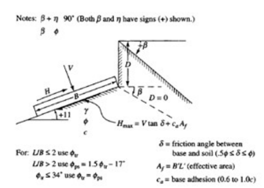


General Soil Failure (Terzaghi Model)

General:† $q_{ult} = cN_cs_cd_ci_cg_cb_c + \bar{q}N_qs_qd_qi_qg_qb_q + 0.5\gamma B'N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$

when $\phi = 0$

use $q_{ult} = 5.14s_u(1 + s'_c + d'_c - i'_c - b'_c - g'_c) + \bar{q}$



$$N_q = e^{\pi\tan\phi}\tan^2\left(45 + \frac{\phi}{2}\right)$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_\gamma = 2(N_q + 1)\tan\phi$$

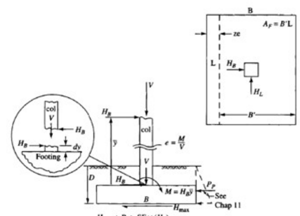


TABLE 4-5c

Table of inclination, ground, and base factors for the Vesić (1973, 1975b) bearing-capacity equations. See notes below and refer to sketch for identification of terms.

Inclination factors	Ground factors (base on slope)
$i'_c = 1 - \frac{mH_i}{A_fc_aN_c}$ ($\phi = 0$)	$g'_c = \frac{\beta}{5.14}$ β in radians
$i_c = i_q - \frac{1-i_q}{N_q - 1}$ ($\phi > 0$)	$g_c = i_q - \frac{1-i_q}{5.14\tan\phi}$ $\phi > 0$
i_q, and m defined below	i_q defined with i_c
$i_q = \left[1.0 - \frac{H_i}{V + A_fc_a\cot\phi}\right]^m$	$g_q = g_\gamma = (1.0 - \tan\beta)^2$
	Base factors (tilted base)
$i_\gamma = \left[1.0 - \frac{H_i}{V + A_fc_a\cot\phi}\right]^{m+1}$	$b'_c = g'_c$ ($\phi = 0$)
$m = m_B = \frac{2 + B/L}{1 + B/L}$	$b_c = 1 - \frac{2\beta}{5.14\tan\phi}$
$m = m_L = \frac{2 + L/B}{1 + L/B}$	$b_q = b_\gamma = (1.0 - \eta\tan\phi)^2$

Notes:

1. When $\phi = 0$ (and $\beta \neq 0$) use $N_\gamma = -2\sin(\pm\beta)$ in N_γ term.
2. Compute $m = m_B$ when $H_i = H_B$ (H parallel to B) and $m = m_L$ when $H_i = H_L$ (H parallel to L). If you have both H_B and H_L use $m = \sqrt{m_B^2 + m_L^2}$. Note use of B and L, not B', L'.
3. Refer to Table sketch and Tables 4-5a,b for term identification.
4. Terms N_c, N_q, and N_γ are identified in Table 4-1.
5. Vesić always uses the bearing-capacity equation given in Table 4-1 (uses B' in the N_γ term even when $H_i = H_L$).
6. H_i term ≤ 1.0 for computing i_q, i_γ (always).

Shape and depth factors for use in either the Hansen (1970) or Vesić (1973, 1975b) bearing-capacity equations of Table 4-1. Use s'_c, d'_c when $\phi = 0$ only for Hansen equations. Subscripts H, V for Hansen, Vesić, respectively.

Shape factors	Depth factors
$s'_{c(H)} = 0.2\frac{B'}{L'}$ ($\phi = 0°$)	$d'_c = 0.4k$ ($\phi = 0°$)
$s_{c(H)} = 1.0 + \frac{N_q}{N_c}\cdot\frac{B'}{L'}$	$d_c = 1.0 + 0.4k$
$s_{c(V)} = 1.0 + \frac{N_q}{N_c}\cdot\frac{B}{L}$	$k = D/B$ for $D/B \le 1$; $k = \tan^{-1}(D/B)$ for $D/B > 1$; k in radians
$s_c = 1.0$ for strip	
$s_{q(H)} = 1.0 + \frac{B'}{L'}\sin\phi$	$d_q = 1 + 2\tan\phi(1 - \sin\phi)^2k$
$s_{q(V)} = 1.0 + \frac{B}{L}\tan\phi$ for all ϕ	k defined above
$s_{\gamma(H)} = 1.0 - 0.4\frac{B'}{L'}$ ≥ 0.6	$d_\gamma = 1.00$ for all ϕ
$s_{\gamma(V)} = 1.0 - 0.4\frac{B}{L}$ ≥ 0.6	

Notes:

1. Note use of "effective" base dimensions B', L' by Hansen but not by Vesić.
2. The values above are consistent with either a vertical load or a vertical load accompanied by a horizontal load H_B.
3. With a vertical load and a load H_L (and either $H_B = 0$ or $H_B > 0$) you may have to compute two sets of shape s_i and d_i as $s_{i,B}$, $s_{i,L}$ and $d_{i,B}$, $d_{i,L}$. For i, L subscripts of Eq. (4-2), presented in Sec. 4-6, use ratio L'/B' or D/L'.

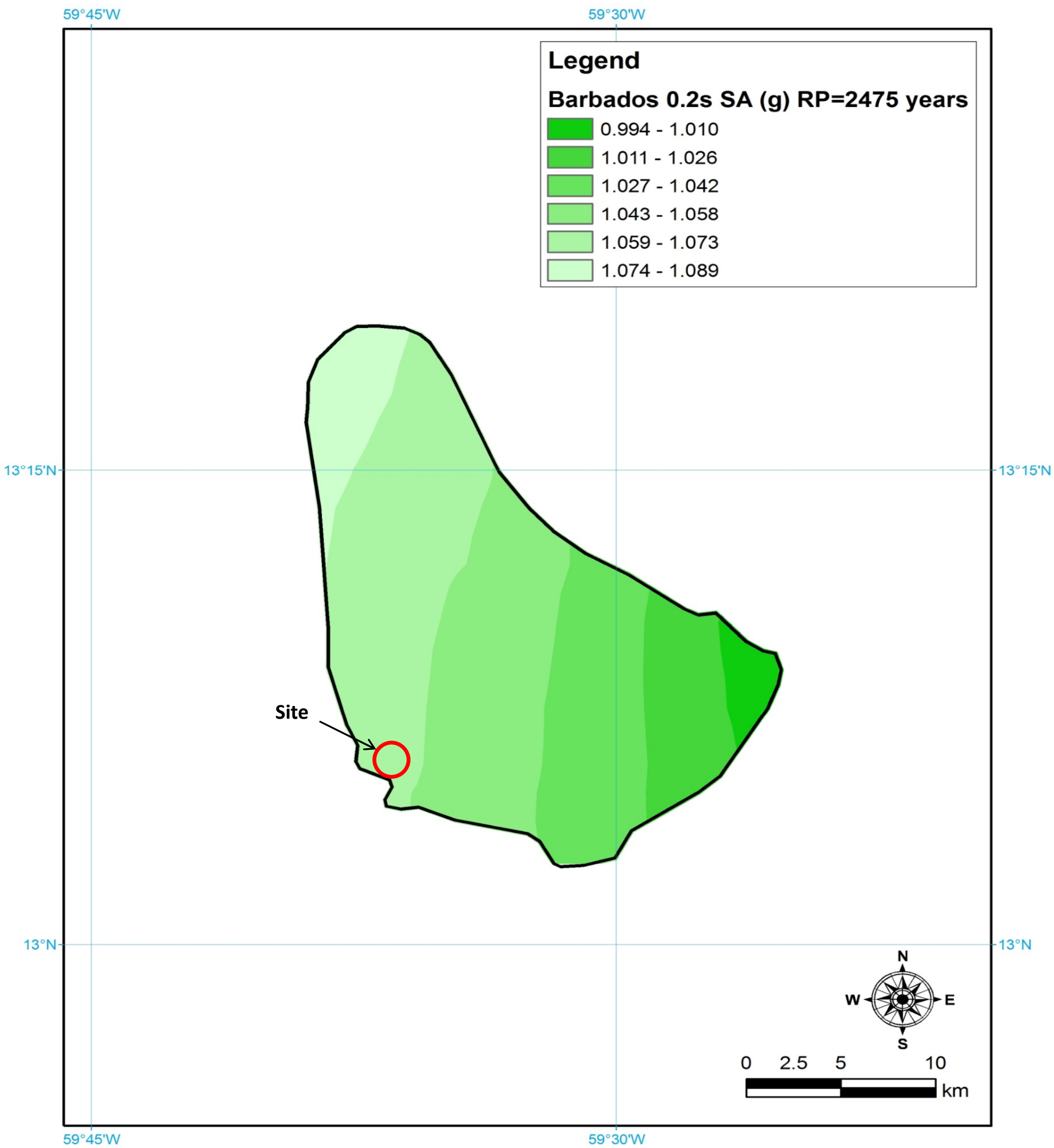
PROJECT: **Bridgetown Sewage Plant**

SUBJECT: **Shallow Foundation Bearing Capacity**

CALCULATED BY: TEM DATE: 7/18/2021 CHECKED BY: ______ DATE: ______

REFERENCE: University of West Indies, Seismic Research Unit, http://www.uwiseismic.com/Maps.aspx
Maximum Design Loads for Buildings and Other Structures, ASCE, 2010.
International Building Code, ICC, 2012

The short-period spectral response acceleration, S_s, is determined from the following chart:



Site Location:	City:	Bridgetown	County:		State:	Barbados

The maximum considered earthquake ground moption for the conterminous united states of 0.2 sec spectral response acceleration (5 percent of critical damping), S_s = **1039** **gals = 1.060 g**

CENTURY ENGINEERING

PROJECT: Bridgetown Sewage Plant

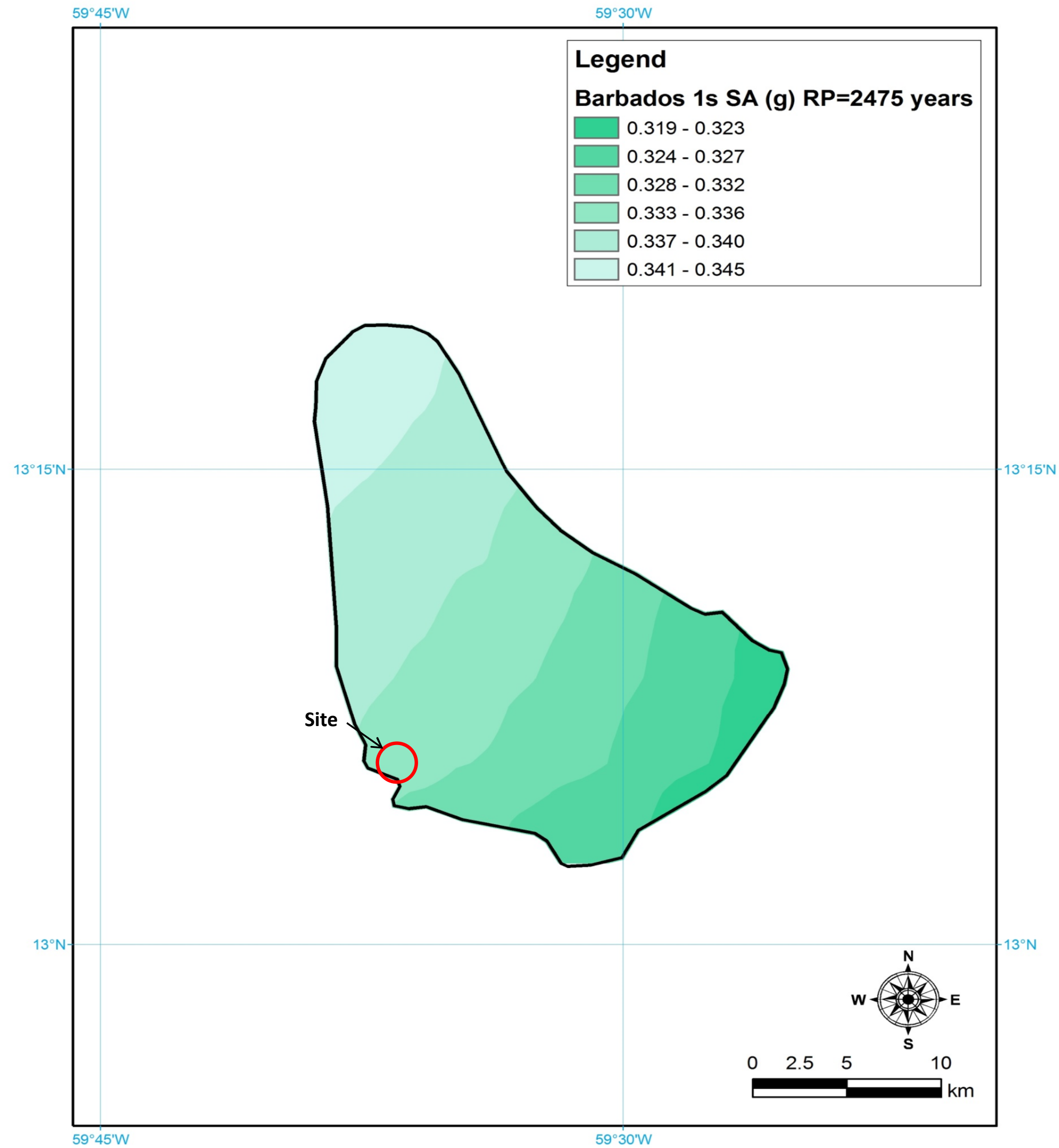
SUBJECT: Shallow Foundation Bearing Capacity

CALCULATED BY: TEM DATE: 7/18/2021 CHECKED BY: ______ DATE: ______

REFERENCE: University of West Indies, Seismic Research Unit, http://www.uwiseismic.com/Maps.aspx
Maximum Design Loads for Buildings and Other Structures, ASCE, 2010.
International Building Code, ICC, 2012

The short-period spectral response acceleration, S_s, is determined from the following chart:

The spectral response acceleration at 1-second period, $S_{1,}$ is determined from the following chart:



The maximum considered earthquake ground moption for the conterminous united states of 1 sec spectral response acceleration (5 percent of critical damping), S_1 = **331** **gals =** **0.338 g**

CENTURY ENGINEERING

PROJECT: Bridgetown Sewage Plant

SUBJECT: Shallow Foundation Bearing Capacity

CALCULATED BY: TEM **DATE:** 7/18/2021 **CHECKED BY:** ______ **DATE:** ______

REFERENCE: University of West Indies, Seismic Research Unit, http://www.uwiseismic.com/Maps.aspx
Maximum Design Loads for Buildings and Other Structures, ASCE, 2010.
International Building Code, ICC, 2012

The short-period spectral response acceleration, S_s, is determined from the following chart:
The Site Class Definition:

Table 20.3-1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard rock	>5,000 ft/s	NA	NA
B. Rock	2,500 to 5,000 ft/s	NA	NA
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the following characteristics: —Plasticity index $PI > 20$, —Moisture content $w \geq 40\%$, —Undrained shear strength $\bar{s}_u < 500$ psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1 ft/s = 0.3048 m/s; 1 lb/ft^2 = 0.0479 kN/m^2.

Reference: Maximum Design Loads for Buildings and Other Structures, ASCE, 2010.

By applying the criteria, the Site Class can be classified as: **E** , with soil profile name of: **Soft soil profile**

Adjusted Maximum Considered Earthquake Spectral Response Accelaration Parameters

The maximum considered earthquake spectral response acceleration at short periods, S_{MS}, $F_{MS} = F_a S_s$ (Eq. 16-37, IBC 2012)

The maximum considered earthquake spectral response acceleration for 1-sec periods, S_{M1}, $F_{M1} = F_v S_1$ (Eq. 16-38, IBC 2012)

Where:

F_a = Site coefficient defined in Table 1613.3.3.(1) **0.90**

F_v = Site coefficient defined in Table 1613.3.3.(2) **2.65**

TABLE 1613.3.3(1) VALUES OF SITE COEFFICIENT F_a[a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIOD				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at short period, S_s.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

CENTURY ENGINEERING

PROJECT: Bridgetown Sewage Plant

SUBJECT: Shallow Foundation Bearing Capacity

CALCULATED BY: TEM **DATE:** 7/18/2021 **CHECKED BY:** ________ **DATE:** ________

REFERENCE: University of West Indies, Seismic Research Unit, http://www.uwiseismic.com/Maps.aspx
Maximum Design Loads for Buildings and Other Structures, ASCE, 2010.
International Building Code, ICC, 2012

The short-period spectral response acceleration, S_s, is determined from the following chart:

TABLE 1613.3.3(2) VALUES OF SITE COEFFICIENT F_v[a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, S_1.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

Design Spectral Response Acceleration Parameters

Five-percent damped design spectral response acceleration at short periods, $S_{DS} = 2/3S_{MS} = 2/3F_a S_s =$ 0.636 (Eq. 16-39, IBC, 2012)

Five-percent damped design spectral response acceleration at 1-second period, $S_{D1} = 2/3S_{M1} = 2/3F_v S_1 =$ 0.5967 (Eq. 16-40, IBC, 2012)

General Procedure Response Spectrum

For periods less than or equal to T_0, the design spectral response acceleration, S_a, shall be determined by:

$$S_a = 0.6\frac{S_{DS}}{T_0}T + 0.4S_{DS}$$ (Eq. 11.4-5, ASCE 7, 2010)

For periods greater than T_s but less than T_L, the design spectral response acceleration, S_a, shall be determined by:

$$S_a = \frac{S_{D1}}{T}$$ (Eq. 11.4-6, ASCE 7, 2010)

For periods greater than T_L, the design spectral response acceleration, S_a, shall be determined by:

$$S_a = \frac{S_{D1}T_L}{T^2}$$ (Eq. 11.4-7, ASCE 7, 2010)

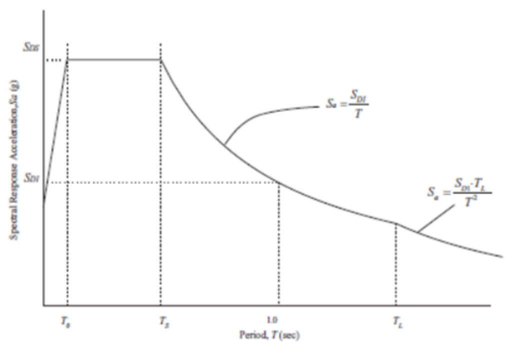


FIGURE 11.4-1 Design Response Spectrum.

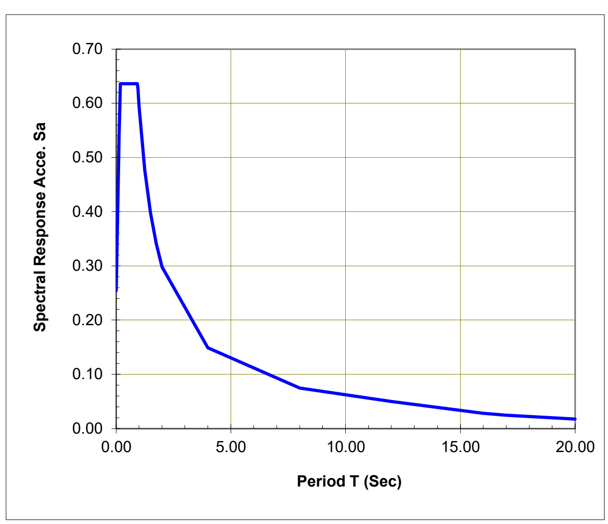
T: = Fundamental period (in seconds) of the structure

T_0: $= 0.2S_{D1}/S_{DS}$ = 0.2 x (0.597) / (0.636) = 0.1876 seconds

T_s: $=S_{D1}/S_{DS}$ = (0.597) / (0.636) = 0.9381 seconds

T_L: = long-period transition period (estimated) = 12 seconds

	Period, T (Sec)	Spec. Response, S_a
0	0.00000	0.25444
$0.25T_0$	0.04690	0.34986
$0.5T_0$	0.0938	0.44527
$0.75T_0$	0.14070	0.54069
T_0	0.18760	0.63610
Ts	0.93810	0.63610
$T_s + 0.25(1-T_s)$	0.95358	0.62575
$T_s + 0.50(1-T_s)$	0.96905	0.61576
$T_s + 0.75(1-T_s)$	0.98453	0.60608
1	1.00000	0.59670
1.25	1.25000	0.47736
1.5	1.50000	0.39780
1.75	1.75000	0.34097
2	2.00000	0.29835
4	4.00000	0.14918
8	8.00000	0.07459
T_L	12.00000	0.04973
16	16.00000	0.02797
17	17.00000	0.02478
18	18.00000	0.02210
20	20.00000	0.01790



REFERENCE: 1. Soils and Geology Procedures For Foundation Design of Building and Other Structures (Except Hydraulic Structures) Unified Facilities Criteria (UFC), UFC 3-200-03FA, Army TM5-818-1, Air Force AFM 88-3, Chap. 7
2. Concrete Floor Slabs on Grade Under Subject to Heavy Loads, Army, TM 5-809-12, Air Force, 88-3 Chap-15

Modulus of Subgrade Reaction for Footings on Grade <u>Note: Inputs Are Shaded Cells</u>

TM 5-809-12/AFM 88-3, Chap. 15

Table 4-1. Typical values of modulus of subgrade reaction

Types of Materials	Modulus of Subgrade Reaction, k, in lb/in³ for Moisture Contents of 1 to 4%	5 to 8%	9 to 12%	13 to 16%	17 to 20%	21 to 24%	25 to 28%	Over 29%
Silts and clays Liquid limit > 50 (OH, CH, MH)	--	175	150	125	100	75	50	25
Silts and clays Liquid limit < 50 (OL, CL, ML)	--	200	175	150	125	100	75	50
Silty and clayey sands (SM & SC)	300	250	225	200	150	—	—	--
Gravelly sands (SW & SP)	300+	300	250	—	—	—	—	--
Silty and clayey gravels (GM & GC)	300+	300+	300	250	—	—	—	--
Gravel and sandy gravels (GW & GP)	300+	300+	—	—	—	—	—	--

NOTE: k values shown are typical for materials having dry densities equal to 90 to 95 percent of the maximum CE 55 density. For materials having dry densities less than 90 percent of maximum CE 55 density, values should be reduced by 50 lb/in³, except that a k of 25 lb/in³ will be the minimum used for design.

Recommended Modulus of Subgrade Reaction for Slab on Grade

Soil type at the project site

Silty and Clayey Gravels (GM & GC) **Recommended Subgrade Reaction** **250** pci = **67.86** MN/m³

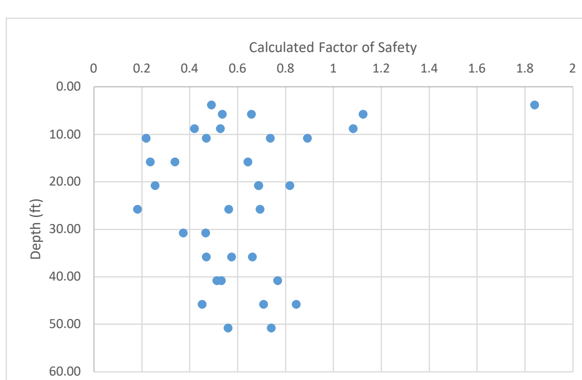
Bridgetown Sewage Plant Seismic Evaluation (lateral spreading)

Borehole	Magnitude	R* (km)	R (km)	Slope (%)	T15 (m)	F15 (%)	D50 (mm)	D (m)	D (Ft)
BH-1	6.8	45.1	42.5	1	10.7	30.5	1	0.02	0.049432
BH-1	6.8	45.1	42.5	5	10.7	30.5	1	0.03	0.085165
BH-1	6.8	45.1	42.5	10	10.7	30.5	1	0.03	0.107648
BH-1	8.7	169.3	42.5	1	10.7	30.5	1	1.91	6.265757
BH-1	8.7	169.3	42.5	5	10.7	30.5	1	3.29	10.79507
BH-1	8.7	169.3	42.5	10	10.7	30.5	1	4.16	13.645
BH-2	6.8	45.1	42.5	1	9.9	32.5	1	0.01	0.042988
BH-2	6.8	45.1	42.5	5	9.9	32.5	1	0.02	0.074063
BH-2	6.8	45.1	42.5	10	9.9	32.5	1	0.03	0.093615
BH-2	8.7	169.3	42.5	1	9.9	32.5	1	1.66	5.448958
BH-2	8.7	169.3	42.5	5	9.9	32.5	1	2.86	9.387832
BH-2	8.7	169.3	42.5	10	9.9	32.5	1	3.62	11.86625
BH-3	6.8	45.1	42.5	1	3.0	17.5	5	0.00	0.013328
BH-3	6.8	45.1	42.5	5	3.0	17.5	5	0.01	0.022962
BH-3	6.8	45.1	42.5	10	3.0	17.5	5	0.01	0.029024
BH-3	8.7	169.3	42.5	1	3.0	17.5	5	0.51	1.689386
BH-3	8.7	169.3	42.5	5	3.0	17.5	5	0.89	2.910588
BH-3	8.7	169.3	42.5	10	3.0	17.5	5	1.12	3.678992
BH-4	6.8	45.1	42.5	1	4.6	18.3	5	0.00	0.016048
BH-4	6.8	45.1	42.5	5	4.6	18.3	5	0.01	0.027648
BH-4	6.8	45.1	42.5	10	4.6	18.3	5	0.01	0.034947
BH-4	8.7	169.3	42.5	1	4.6	18.3	5	0.62	2.034111
BH-4	8.7	169.3	42.5	5	4.6	18.3	5	1.07	3.504504
BH-4	8.7	169.3	42.5	10	4.6	18.3	5	1.35	4.429704

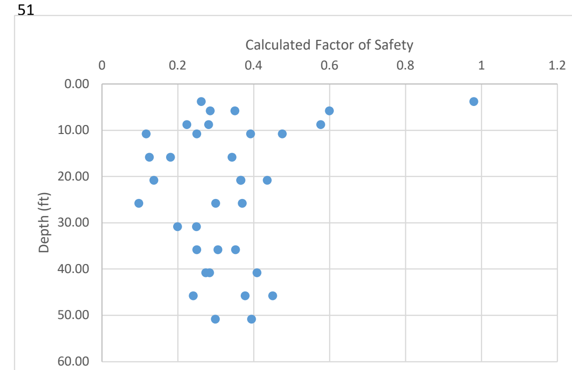
Bridgetown Sewage Plant Seismic Evaluation (liquefaction, post-liquefaction settlement, shear strength reduction)

Soil properties	CL	120	pcf	GP-GM	120 pcf	GM	120 pcf
PGA							

Borehole	Sample	Depth	Mid depth (ft)	Mid depth (m)	N1(60)	Total Stess (psf)	Effect Stress (psf)	Material	FC	GWT	GWT	rd	PGA	CSR	a	b	N1(60)cs	CRR7.5	MSF6.8	MSF8.7	FS6.8	FS8.7	VS (%) 6.8	VS (%) 8.7	Thickness (	Set 6.8	Set 6.8 in	Set 8.7	Set 8.7 in	Liq SS	phi
	S-1	0.10	0.85	0.26	41.8	102.0	102.0	GC	40	3.5	>GWT	0.999802	0.439	0.285294	5	1.2	55	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	1.55	1.2467	14.9604	1.2517	15.0204	0	0
	S-2	3.00	3.75	1.14	4.1	450.0	434.4	CL	75	3.5		0.992579	0.439	0.293404	5	1.2	10	0.112229	1.284627	0.683645	0.491377	0.261498	3.6%	3.6%	2.45	1.2467	14.9604	1.2517	15.0204	26.3	3.5
	S-3	5.00	5.75	1.75	10.0	690.0	549.6	CL	75	3.5		0.987206	0.439	0.353662	5	1.2	17	0.181295	1.284627	0.683645	0.65853	0.350453	2.5%	2.5%	2.50	1.1585	13.902	1.1635	13.962	57.9	6.0
	S-4	8.00	8.75	2.67	9.3	1050.0	722.4	SP-SM	15	3.5		0.978935	0.439	0.406016	2.498163	1.048095	12	0.133004	1.284627	0.683645	0.420821	0.22395	3.2%	3.2%	2.50	1.096	13.152	1.101	13.212	71.8	5.7
	S-5	10.00	10.75	3.28	10.2	1290.0	837.6	GM	20	3.5		0.973188	0.439	0.427689	3.614668	1.079443	15	0.156499	1.284627	0.683645	0.470068	0.250158	2.6%	2.6%	3.50	1.016	12.192	1.021	12.252	89.3	6.1
	S-6	15.00	15.75	4.80	2.7	1890.0	1125.6	GM	20	3.5		0.957141	0.439	0.458597	3.614668	1.079443	7	0.084063	1.284627	0.683645	0.235479	0.125316	4.5%	4.5%	5.00	0.925	11.1	0.93	11.16	56.7	2.9
BH-1	S-7	20.00	20.75	6.32	19.3	2490.0	1413.6	SP-SM	15	3.5		0.936677	0.439	0.470804	2.498163	1.048095	23	0.25237	1.284627	0.683645	0.688612	0.366462	1.8%	1.9%	5.00	0.7	8.4	0.705	8.46	0.0	0.0
	S-8	25.00	25.75	7.85	14.5	3090.0	1701.6	GM	20	3.5		0.908788	0.439	0.470914	3.614668	1.079443	19	0.20667	1.284627	0.683645	0.563783	0.300031	2.1%	2.1%	5.00	0.61	7.32	0.61	7.32	0.0	0.0
	S-9	30.00	30.75	9.37	8.1	3690.0	1989.6	GM	20	3.5		0.870512	0.439	0.460695	3.614668	1.079443	12	0.134019	1.284627	0.683645	0.373705	0.198876	3.1%	3.1%	5.00	0.505	6.06	0.505	6.06	179.8	5.2
	S-10	35.00	35.75	10.90	25.3	4290.0	2277.6	GM	20	3.5		0.820246	0.439	0.440861	3.614668	1.079443	31	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.35	4.2	0.35	4.2	0.0	0.0
	S-11	40.00	40.75	12.42	11.6	4890.0	2565.6	GM	20	3.5		0.759361	0.439	0.412996	3.614668	1.079443	16	0.171307	1.284627	0.683645	0.532852	0.28357	2.5%	2.5%	5.00	0.35	4.2	0.35	4.2	299.5	6.7
	S-12	45.00	45.75	13.94	8.1	5490.0	2853.6	GM	20	3.5		0.692818	0.439	0.380344	3.614668	1.079443	12	0.134019	1.284627	0.683645	0.452654	0.240891	3.2%	3.2%	5.00	0.225	2.7	0.225	2.7	257.9	5.2
	S-13	50.00	50.75	15.47	9.8	6090.0	3141.6	GM	20	3.5		0.627647	0.439	0.347184	3.614668	1.079443	14	0.15155	1.284627	0.683645	0.560755	0.298419	2.6%	2.6%	2.50	0.065	0.78	0.065	0.78	324.0	5.9
	S-1	0.10	0.85	0.26	60.3	102.0	102.0	GC	40	5.5	>GWT	0.999802	0.439	0.285294	5	1.2	77	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	1.55	1.0598	12.7176	1.19	14.28	0.0	0.0
	S-2	3.00	3.75	1.14	12.2	450.0	450.0	CL	75	5.5	>GWT	0.992579	0.439	0.283232	5	1.2	20	0.210425	1.284627	0.683645	Not Liquef	Not Liquef	0.4%	3.0%	2.45	1.0598	12.7176	1.19	14.28	0.0	0.0
	S-3	5.00	5.75	1.75	4.8	690.0	674.4	CL	75	5.5		0.987206	0.439	0.288216	5	1.2	11	0.120396	1.284627	0.683645	0.536626	0.285578	3.4%	3.4%	2.50	1.05	12.6	1.1165	13.398	44.8	3.8
	S-4	8.00	8.75	2.67	10.2	1050.0	847.2	SP-SM	15	5.5		0.978935	0.439	0.346206	2.498163	1.048095	13	0.142517	1.284627	0.683645	0.528819	0.281424	3.0%	3.0%	2.50	0.965	11.58	1.0315	12.378	90.3	6.1
	S-5	10.00	10.75	3.28	19.7	1290.0	962.4	SP-SM	15	5.5		0.973188	0.439	0.372228	2.498163	1.048095	23	0.258628	1.284627	0.683645	0.892573	0.475004	1.0%	1.9%	3.50	0.89	10.68	0.9565	11.478	0.0	0.0
	S-6	15.00	15.75	4.80	6.7	1890.0	1250.4	SP-SM	15	5.5		0.957141	0.439	0.412826	2.498163	1.048095	10	0.10883	1.284627	0.683645	0.338655	0.180223	3.5%	3.5%	5.00	0.855	10.26	0.89	10.68	100.3	4.6
BH-2	S-7	20.00	20.75	6.32	16.3	2490.0	1538.4	GM	20	5.5		0.936677	0.439	0.432611	3.614668	1.079443	21	0.231479	1.284627	0.683645	0.68737	0.3658	2.0%	2.1%	5.00	0.68	8.16	0.715	8.58	0.0	0.0
	S-8	25.00	25.75	7.85	0.0	3090.0	1826.4	GM	20	5.5		0.908788	0.439	0.438736	3.614668	1.079443	4	0.062279	1.284627	0.683645	0.182355	0.097044	5.2%	5.2%	5.00	0.58	6.96	0.61	7.32	54.8	1.7
	S-9	30.00	30.75	9.37	31.6	3690.0	2114.4	GM	20	5.5		0.870512	0.439	0.433503	3.614668	1.079443	38	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.32	3.84	0.35	4.2	0.0	0.0
	S-10	35.00	35.75	10.90	12.9	4290.0	2402.4	GM	20	5.5		0.820246	0.439	0.417959	3.614668	1.079443	18	0.187031	1.284627	0.683645	0.574853	0.305922	2.4%	2.4%	5.00	0.32	3.84	0.35	4.2	0.0	0.0
	S-11	40.00	40.75	12.42	10.3	4890.0	2690.4	GM	20	5.5		0.759361	0.439	0.393838	3.614668	1.079443	15	0.157595	1.284627	0.683645	0.514046	0.273562	2.6%	2.6%	5.00	0.2	2.4	0.23	2.76	288.9	6.1
	S-12	45.00	45.75	13.94	16.9	5490.0	2978.4	GM	20	5.5		0.692818	0.439	0.364407	3.614668	1.079443	22	0.239927	1.284627	0.683645	0.845805	0.450115	1.4%	2.0%	5.00	0.07	0.84	0.1	1.2	0.0	0.0
	S-13	50.00	50.75	15.47	13.4	6090.0	3266.4	GM	20	5.5		0.627647	0.439	0.333919	3.614668	1.079443	18	0.192483	1.284627	0.683645	0.740506	0.394078	2.4%	2.5%	2.50	0.06	0.72	0.0625	0.75	0.0	0.0
	S-1	0.10	0.85	0.26	230.7	102.0	102.0	GC	40	3.6	>GWT	0.999802	0.439	0.285294	5	1.2	282	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	1.55	0.46195	5.5434	0.49225	5.907	0.0	0.0
	S-2	3.00	3.75	1.14	20.1	450.0	440.6	GC	40	3.6		0.992579	0.439	0.289249	5	1.2	29	0.414403	1.284627	0.683645	1.84047	0.97945	0.1%	0.5%	2.45	0.46195	5.5434	0.49225	5.907	0.0	0.0
	S-3	5.00	5.75	1.75	32.1	690.0	555.8	SP-SM	15	3.6		0.987206	0.439	0.349692	2.498163	1.048095	36	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	2.50	0.4595	5.514	0.48	5.76	0.0	0.0
	S-4	8.00	8.75	2.67	33.8	1050.0	728.6	SP-SM	15	3.6		0.978935	0.439	0.402539	2.498163	1.048095	38	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	2.50	0.4595	5.514	0.48	5.76	0.0	0.0
	S-5	10.00	10.75	3.28	18.7	1290.0	843.8	SP-SM	15	3.6		0.973188	0.439	0.424526	2.498163	1.048095	22	0.243403	1.284627	0.683645	0.736545	0.39197	1.7%	2.0%	3.50	0.4595	5.514	0.48	5.76	0.0	0.0
	S-6	15.00	15.75	4.80	39.1	1890.0	1131.8	SP-SM	15	3.6		0.957141	0.439	0.456069	2.498163	1.048095	44	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.4	4.8	0.41	4.92	0.0	0.0
BH-3	S-7	20.00	20.75	6.32	5.0	2490.0	1419.8	SP-SM	15	3.6		0.936677	0.439	0.468735	2.498163	1.048095	8	0.09365	1.284627	0.683645	0.256658	0.136587	4.0%	4.0%	5.00	0.4	4.8	0.41	4.92	95.7	3.9
	S-8	25.00	25.75	7.85	34.4	3090.0	1707.8	GM	20	3.6		0.908788	0.439	0.469193	3.614668	1.079443	41	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.2	2.4	0.21	2.52	0.0	0.0
	S-9	30.00	30.75	9.37	39.2	3690.0	1995.8	GM	20	3.6		0.870512	0.439	0.459254	3.614668	1.079443	46	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.2	2.4	0.21	2.52	0.0	0.0
	S-10	35.00	35.75	10.90	16.0	4290.0	2283.8	GM	20	3.6		0.820246	0.439	0.439657	3.614668	1.079443	21	0.226588	1.284627	0.683645	0.662063	0.352333	2.0%	2.1%	5.00	0.2	2.4	0.21	2.52	0.0	0.0
	S-11	40.00	40.75	12.42	31.6	4890.0	2571.8	GM	20	3.6		0.759361	0.439	0.411994	3.614668	1.079443	38	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0.1	1.2	0.105	1.26	0.0	0.0
	S-12	45.00	45.75	13.94	14.7	5490.0	2859.8	GM	20	3.6		0.692818	0.439	0.379514	3.614668	1.079443	20	0.209615	1.284627	0.683645	0.709531	0.377594	2.0%	2.1%	5.00	0.1	1.2	0.105	1.26	0.0	0.0
	S-13	50.00	50.75	15.47	24.5	6090.0	3147.8	GM	20	3.6		0.627647	0.439	0.346496	3.614668	1.079443	30	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	2.50	0	0	0	0	0.0	0.0
	S-1	0.10	0.85	0.26	46.2	102.0	102.0	GC	40	3.5	>GWT	0.999802	0.439	0.285294	5	1.2	60	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	1.55	0.766	9.192	0.871	10.452	0.0	0.0
	S-2	3.00	3.75	1.14	24.2	450.0	434.4	GC	40	3.5		0.992579	0.439	0.293404	5	1.2	34	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	2.45	0.766	9.192	0.871	10.452	0.0	0.0
	S-3	5.00	5.75	1.75	22.3	690.0	549.6	SP-SM	15	3.5		0.987206	0.439	0.353662	2.498163	1.048095	26	0.30979	1.284627	0.683645	1.12527	0.598839	0.5%	1.5%	2.50	0.766	9.192	0.871	10.452	0.0	0.0
	S-4	8.00	8.75	2.67	23.5	1050.0	722.4	SP-SM	15	3.5		0.978935	0.439	0.406016	2.498163	1.048095	27	0.342552	1.284627	0.683645	1.083827	0.576785	0.5%	1.5%	2.50	0.7535	9.042	0.8335	10.002	0.0	0.0
	S-5	10.00	10.75	3.28	2.5	1290.0	837.6	SP-SM	15	3.5		0.973188	0.439	0.427689	2.498163	1.048095	5	0.072991	1.284627	0.683645	0.219239	0.116673	4.6%	4.6%	3.50	0.741	8.892	0.796	9.552	40.9	2.8
	S-6	15.00	15.75	4.80	16.2	1890.0	1125.6	GW	20	3.5		0.957141	0.439	0.458597	3.614668	1.079443	21	0.229834	1.284627	0.683645	0.643814	0.342621	2.0%	2.0%	5.00	0.58	6.96	0.635	7.62	0.0	0.0
BH-4	S-7	20.00	20.75	6.32	20.2	2490.0	1413.6	GM	20	3.5		0.936677	0.439	0.470804	3.614668	1.079443	25	0.300058	1.284627	0.683645	0.818733	0.435708	1.0%	1.7%	5.00	0.48	5.76	0.535	6.42	0.0	0.0
	S-8	25.00	25.75	7.85	17.8	3090.0	1701.6	GM	20	3.5		0.908788	0.439	0.470914	3.614668	1.079443	23	0.25435	1.284627	0.683645	0.693853	0.36925	1.7%	1.9%	5.00	0.43	5.16	0.45	5.4	0.0	0.0
	S-9	30.00	30.75	9.37	11.2	3690.0	1989.6	GM	20	3.5		0.870512	0.439	0.460695	3.614668	1.079443	16	0.167507	1.284627	0.683645	0.467086	0.248571	2.5%	2.5%	5.00	0.345	4.14	0.355	4.26	227.2	6.5
	S-10	35.00	35.75	10.90	10.7	4290.0	2277.6	GM	20	3.5		0.820246	0.439	0.440861	3.614668	1.079443	15	0.161276	1.284627	0.683645	0.469943	0.250091	2.6%	2.6%	5.00	0.22	2.64	0.23	2.76	250.4	6.3
	S-11	40.00	40.75	12.42	17.4	4890.0	2565.6	GM	20	3.5		0.759361	0.439	0.412996	3.614668	1.079443	22	0.246986	1.284627	0.683645	0.768252	0.408844	1.8%	2.0%	5.00	0.09	1.08	0.1	1.2	0.0	0.0
	S-12	45.00	45.75	13.94	29.5	5490.0	2853.6	GM	20	3.5		0.692818	0.439	0.380344	3.614668	1.079443	35	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	5.00	0	0	0	0	0.0	0.0
	S-13	50.00	50.75	15.47	41.5	6090.0	3141.6	GM	20	3.5		0.627647	0.439	0.347184	3.614668	1.079443	48	Not Liquefi	1.284627	0.683645	Not Liquef	Not Liquef	0.0%	0.0%	2.50	0	0	0	0	0.0	0.0



51



	32	35
	52	52
liq : # total samples	0.615385	0.673077
liq : # sat samples	0.344086	0.376344

LABORATORY ANALYSES RESULTS

APPENDIX D

INTEGRATED SUSTAINABILITY

Appendix 2 – GHG Emission Analysis

Internal Greenhouse Gas Emission Analysis

1 INTRODUCTION

The following is an internal analysis of greenhouse gas (GHG) emissions from the project that can be categorized within two major groups, i.e., direct, and indirect emissions.

The following are the 7 different types of gases that are considered as GHGs by the Intergovernmental Panel of Climate Change (IPCC):

- Carbon dioxide (CO_2);
- Methane (CH_4);
- Nitrous oxide (N_2O);
- Hydrofluorocarbons (HFCs);
- Perfluorocarbons (PFCs);
- Sulphur hexafluoride (SF_6); and
- Nitrogen trifluoride (NF_3);

The GHGs associated with wastewater treatment only include, CO_2, CH_4 and N_2O; therefore, other fluorinated gases were not considered. These GHG emissions can be the result of the treatment process such as N_2O from incomplete denitrification processes or CO_2 and CH_4 from digestion of activated sludge. N_2O is equal to 296 kgCO_2e, while one kg CH_4 is equal to 23 kg CO_2. The N_2O typically generated at WWTP's is due to inefficient nitrogen removal processes and given the existing treatment system does not include any methods for treating nitrogen (i.e., nitrification or denitrification), the N_2O emissions have been omitted from this assessment.

The GHG emissions are categorized as direct and indirect emissions. **Figure A** shows direct and some indirect GHG emissions from a wastewater treatment plant with anoxic, aerobic, solids settling, and sludge treatment.

Direct GHG Emissions are associated with the treatment process itself. For example, CO_2 is generated due to endogenous respiration and BOD oxidation throughout the process. CH_4 is generated during anaerobic digestion of sludge.

Indirect GHG emissions are associated with the activities that are a consequence of the wastewater treatment process. The indirect GHG emissions included in this study are only associated with the power that is used during the treatment process. Direct GHG emissions from typical wastewater treatment processes (Snip 2009)

The principally diesel generated electricity distributed through the power network in Barbados has an average GHG emission of 0.66 kgCO_2e/kWh. In comparison, when using natural gas for generating power, the emissions decrease to 0.4 kgCO_2/kWh, indicating the potential to reduce the GHG emissions by almost 40% when using natural gas instead of diesel. **Table A** shows the calculations used for deriving the average power emissions factor when using diesel and natural gas, excluding any emissions resulted from transportation of diesel or natural gas to the Island.

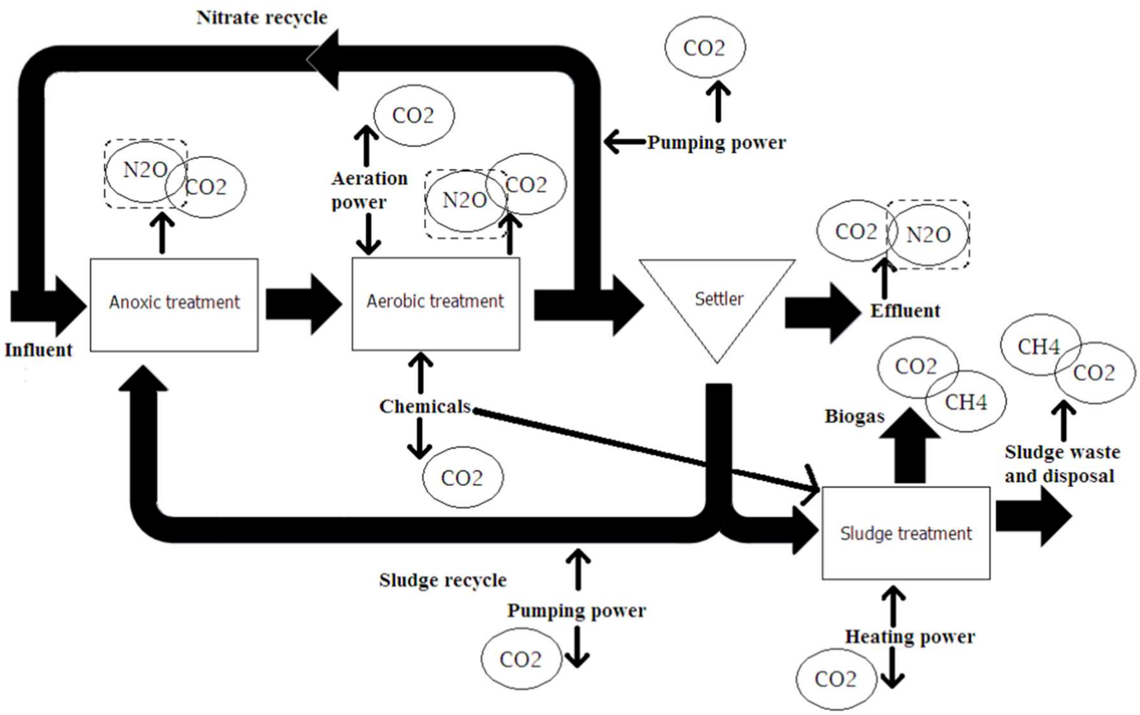


Figure A. Direct and Indirect GHG Emissions

Table A. Diesel and Natural Gas Power CO_2 Emissions

Item	Unit	Value
Power Generated from Diesel		
Diesel Emissions Factor[1]	kg CO_2 e/kWh	0.25
Power Conversion Efficiency[2]	%	38
Barbados Power Grid Emissions Factor	Kg CO_2 e/kWh	0.66
Power Generated from Natural Gas		
Natural Gas Emissions Factor[1]	$kgCO_2$ e/kWh	0.18
Power Conversion Efficiency[2]	%	45
Power Emissions Factor	$kgCO^2$ e/kWh	0.40

[1] https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

[2]Power conversion efficiency based on typical generator performance

Exclusions:

- Emissions from transfer of chemical and sludge to and from the BSTP.
- Emissions associated with the construction of the upgrades at the BSTP.
- Embodied GHG emissions of material and chemicals used for operation and construction of the WWTP.

- N_2O emissions throughout the process were considered negligible.

Assumptions:

- Electricity used at the BSTP is generated using diesel fuel.
- Electricity emissions offset for the new upgrades is based on a maximum treatment capacity of 9,000 m^3/day.
- Average treatment capacity at BSTP of 4,100 m^3/day.
- Electricity consumption of the existing BSTP facilities is based on the average yearly consumption of 2019-2020.
- Wastewater quality at BSTP is of typical North American wastewater characteristics (Metcalf & Eddy 2014).
- Barbados receives an average of 8.3 hours of sunlight per day.
- BTSTP currently has ~3,000 m^2 of solar panels installed on site. These panels have not been utilized to date. The power density of the panels is assumed to be 160 W/m^2 based on similar PV performances in Barbados.
- PV panels installed at the BTSTP are assumed to have an average surface area of 2 m^2.

2 BSTP GHG EMISSIONS ANALYSIS

The following provides calculated direct and indirect GHG emissions from the existing BSTP and proposed upgrades facilities.

2.1 Direct GHG Emissions

The general wastewater load on the existing BSTP facility compared with the proposed upgrades is assumed to be 9,000 m3/d and the net direct GHG emissions (i.e. direct emissions from the treatment process) are expected to remain the same as may be released by the existing CAS process. Therefore, no direct GHG credit is assumed for any of the upgrades.

2.2 Indirect GHG Emissions

0 illustrates the power consumption at the existing BSTP infrastructure and the expected consumption for the three upgrade configuration being considered. The existing treatment facility at BSTP has smaller indirect GHG emissions compared with the proposed new upgrades mainly due to having a lower power consumption. However, the tertiary reuse effluent quality for all three options offsets the negative impact associated with the indirect GHG emissions. Table B provides a summary of the power produced by the existing PV panels and the estimated additional PV panels required to offset the extra power demands for the upgrade options.

Renewable sources of energy should be considered to mitigate the impact of the upgrades on GHG emissions. In addition to providing additional PV panels, anaerobic digestion of the biosolids to produce methane can also be considered.

Table B Power Consumption and Indirect GHG Emissions for BSTP Upgrade Options

Treatment Infrastructure	Unit	Value
BSTP - Existing Facility		
Maximum Capacity	m^3/day	9,000
Energy Consumption	kWh/year	1,245,867
Available Solar Energy[1]	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	0
Indirect GHG Emissions	tCO_2e/year	822
Total additional Solar Power Required[1]	kW	0
BSTP - CAS 4-Stage Bardenpho Upgrade		
Maximum Capacity	m^3/day	9,000
Power Consumption	kWh/year	1,734,480
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	289,320
Total Additional Solar Power Required	kW	95
Indirect GHG Emissions for Additional Power	tCO_2e/year	191
BSTP - MBBR Upgrade		
Maximum Capacity	m^3/day	9,000
Power Consumption	kWh/year	4,432,560
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	2,987,400
Total Additional Solar Power Required	kW	986
Indirect GHG Emissions	tCO_2e/year	1,972
BSTP - MBR Upgrade		
Maximum Capacity	m^3/day	9,000
Power Consumption	kWh/year	2,645,520
Available Solar Power	kWh/year	1,445,160
Net Power Consumption from Grid	kWh/year	1,200,360
Total Additional Solar Power Required	kW	396
Indirect GHG Emissions	tCO_2e/year	792

[1]Based on a total covered area of 3,000 m^2 by solar panels at the site, with assumed power density of 160 W/m^2

2.3 Solar Power Potential

0 provides the estimated maximum power load required for operating the BTSTP after upgrades are implemented. Solar power as a potential method for providing such power provides a significant potential for the 5C's to not only offset the indirect emissions of the upgrades but also generate extra power to supply the power grid with clean power when the WWTP is not operating at maximum demand.

Figure B shows the BSTP site and potential available areas to install high efficiency solar panels to generate solar power.

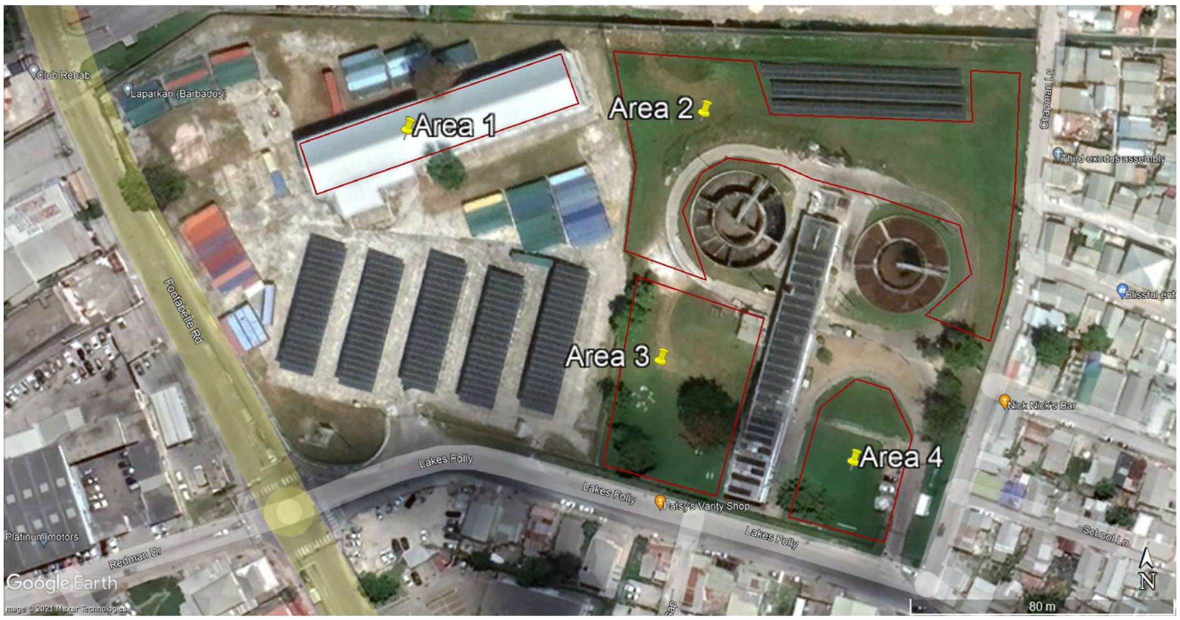


Figure B. Figure 1: BSTP Site and Potential Areas for Solar Panels

The available surface area as well as power generation potential is provided in **Error! Reference source not found.**.

Table B. Solar Power Generation Potential

Area #	Available Surface Area (m^2)	Total Solar Power Generated[1] (kW)	Solar Power Potential Per Year[2] (kWh/yr)	GHG Offset Potential[3] (tCO_2e/yr)
1	1,300	208	630,136	416
2	4,400	704	2,132,768	1,408
3	2,100	336	1,017,912	672
4	1,200	192	581,664	384
Total	9,000	1,440	4,362,480	2,880

[1]Based on PV power density of 160 W/m^2.

[2]Based on average of 8.3 hours of sunshine per day[1]

Area #	Available Surface Area (m^2)	Total Solar Power Generated[1] (kW)	Solar Power Potential Per Year[2] (kWh/yr)	GHG Offset Potential[3] (tCO_2e/yr)

[3] Based on assuming solar power will replace burning diesel at 0.66 tCO_2/MWh

By utilising the open area and roof top available at the BSTP, there is a potential to generate more than 1.4 MW of clean electricity to power not only the plant upgrades but also contribute to the local power grid with clean energy, further reducing the regions dependence on diesel for power.

2.4 Anaerobic Digestion and Biogas

2.4 shows the potential net power capacities from biogas generated through single and two stages anaerobic digestion process. As shown, the biogas generated through anaerobic digestion, or the potential solar energy will not be sufficient to offset the GHG emissions from the upgrades when operating at maximum flow capacity. However, anaerobic digestion and biogas generation provides other sustainable advantages such as an approach for biosolids remediation and economic prosperity, which make this option worth further exploring.

Table C. Renewable Sources of Energy and Required Capacities Based on the BSTP Upgrades Options

Renewable Options	Unit	Anaerobic Digestion[1]	Anaerobic Digestion (Two Stages)[2]
Net Potential Capacity (Electricity)	kWh/year	10,000	20,000
Equivalent CO_2e Offset	tCO_2e/year	15	30

[1] Electricity from biogas generated through CHP (Born 2021)

3 CONCLUSION

Implementing the new upgrades enhances the treatment of wastewater at BSTP, which results in reducing the overall direct GHG emissions of treatment process. On the other hand, the upgrades will require more power, which negatively impacts the overall carbon footprint of the BSTP upgrades. Introducing renewable energy initiatives such as solar panels and methane gas generation from biosolids have the potential to push the operation of the BSTP upgrades towards carbon neutrality.

4 REFERENCES

Born, Jens. 2021. "Energy Options in Wastewater Treatment."

Das, Seema Rani. 2011. "Estimation of Greenhouse Gases Emissions from Biological Wastewater Treatment Plants at Windsor." Windsor. https://scholar.uwindsor.ca/cgi/viewcontent.cgi?article=1076&context=etd.

Metcalf & Eddy. 2014. *Wastewater Engineering: Treatment and Resource Recovery.* 5th Edition. New York: McGraw-Hill.

RTI International. n.d. *Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories: Solid Waste Disposal Wastewater Treatment Ethanol Fermentation.* EPA. https://www3.epa.gov/ttn/chief/efpac/ghg/GHG_Biogenic_Report_draft_Dec1410.pdf.

Snip, Laura. 2009. "Quantifying the greenhouse gas emissions of wastewater treatment plants." https://modeleau.fsg.ulaval.ca/fileadmin/modeleau/documents/Publications/MSc_s/sniplaura_msc.pdf.

Appendix 3 – Design Option Cost Comparisons

Option Considered	Description	Flow (m^3/day)	Power Req'd (kW)	Annual Electricity Req'd (kWh/year)	Daily Electricity Req'd (kWh/day)	Annual Cost to Run Power ($US)	Additional Annual Cost to O&M Plant ($US)
1	BSTP CAS Process to Serve all of Bridgetown	56,700	896	7,848,960	21,504	$2,197,709	$0
1	Existing BSTP CAS at Design Capacity	13,003	205	1,800,000	4,932	$504,000	$0
1	Existing BSTP CAS secondary treatment process	9,000	142	1,245,867	3,413	$348,843	$0
2	Upgrade the BSTP to tertiary treatment using **CAS** treatment technology	9,000	Equivalent to Option 1 above. No significant change reported.			$845,000	$496,157
3	Upgrade the BSTP to tertiary treatment using **MBBR** treatment technology	9,000	673	5,892,838	16,145	$2,279,000	$1,930,157
4	Upgrade the BSTP to tertiary treatment using **MBR** treatment technology	9,000	430	3,764,019	10,312	$1,363,000	$1,014,157
5	Upgrade the BSTP to tertiary treatment to include **RO** treatment technology	9,000	551	4,828,950	13,230	$1,352,107	$5,256,000

Capital Cost of Treatment System Upgrade ($US)	Solar Needed to offset Electrical load and be Carbon Neutral (# of panels)	Capital Cost of Solar Needed to be Carbon Neutral ($US)	Total Cost (Power + O&M + Tech + Solar) ($US)	Comments
$0	6,556	$0	$2,197,709	
$0	1,504	$0	$504,000	It is estimated that the current number of solar panels on site should meet the current electrical demand, at an average annual power consumption level of 1,800,000 kWh, as reported within 2018 & 2019 Barbados Light & Power bills.
$0	1,041	$0	$348,843	
$28,683,000	1,041	$0	$30,024,157	
$30,066,257	4,922	$1,367,470	$35,642,884	Solar costs are based off the increase of panels needed in addition to the existing 1500 panels that exist on-site at the BSTP. Cost of solar does not include installation costs.
$33,755,906	3,144	$656,204	$36,789,268	Solar costs are based off the increase of panels needed in addition to the existing 1500 panels that exist on-site at the BSTP. Cost of solar does not include installation costs.
$4,400,000	4,034	$1,613,415	$12,621,521	Cost of solar does not include installation costs.

Piping Options	Irrigation Route	Aquifer Recharge	Injection Wells (No.)	Estimated Pipeline Length (km)	Estimated Total Cost (US$)
1	BSTP to Waterford (Botanical Gardens) then northwards to recharge point at Trents (Greenwich) (find points or take-offs along the way).	Trents and Waterford (to be modelled for impact on nitrates and where the water goes).	6	13	$12,402,107
2	Extend option 1 all the way to Spring Hall Land Lease, St. Lucy – all other points remain the same. Assume 9 injection wells will be included in this option	Trents and Waterford (to be modelled for impact on nitrates and where the water goes).	9	27	$19,477,107
3	BSTP to Waterford (Botanical Gardens) with take-off at Hothersal roundabout to Friendship plantation the turn south along ABC H'way And Then Turn North Along Belle Road up to Lears (Roberts Manufacturing) – irrigation can be done for lands on east and west of that road. Also take in Neil's Plantation, Salters, Constant and Valley Plantation. Assume 6 injection wells will be included in this option	Waterford (to be modelled for impact on nitrates and where the water goes).	6	9	$10,402,107
4	BSTP to Spring Garden BWRO desalination plant.	All the reclaimed water would be used to recharge the aquifer around the Spring Garden BWRO WTP.	3	3	$1,575,000

Estimated Cost Factors:

Estimated cost ($US) for a set of 3 injection wells, including pumping station	$25,000
Estimated cost ($US) for per km of pipeline to supply & install	$500,000
Estimated cost ($US) for an RO treatment system	$4,400,000

Estimated annual cost ($US) to run the power req'd for an RO treatment system	$1,352,107

Comments
These costs do not factor the disturbance to commercial and private industries as a result of the proposed construction efforts to install this proposed pipeline along existing highways and main arterial roadways.
These costs do not factor the disturbance to commercial and private industries as a result of the proposed construction efforts to install this proposed pipeline along existing highways and main arterial roadways.
These costs do not factor the disturbance to commercial and private industries as a result of the proposed construction efforts to install this proposed pipeline along existing highways and main arterial roadways.
Due to recent discussions with Sr. Operators at the Spring Garden BWRO WTP, it is not expected that adding additional ground water source (from reclaimed water) will result in the need to expand this existing plant, therefore no additional cost associated with this is included. If an expansion is deemed necessary, it is further assumed that this cost would be absorbed by the private sector and not the BWA (although a slight increase in the BWA monthly rate may arise, but is not assumed).

Appendix 4 – Financial and Economic Analysis Exhibits

Exhibit 1

Key Assumptions

Wastewater Treatment							
Water Treatment Plant Cost Upgrade	3,333	US$/$M^3$					
Size of Plant - PDWF	9,000	M^3/day (1)					
Annual O&M Cost	111.12	US$/$M^3$					
Capital Expenditure (Years 11- 20)	10%	of Overall Expenditure					
Capital Expenditure (Years 21- 30)	17%	of Overall Expenditure					
Water Reclaimed - ADWF	7,200	M^3/day (1)					
Construction Schedule		**Year 1**	**Year 2**	**Year 3**	**Year 4**		
Water Treatment Plant	100%	40%	40%	20%	0%		
Wastewater Reverse Osmosis (RO) Treatment							
Water Treatment Plant Cost	1,078	US$/$M^3$					
Size of Plant - PDWF	9,000	M^3/day					
Annual O&M Cost	148.5	US$/$M^3$					
Capital Expenditure (Years 11- 20)	25%	of Overall Expenditure					
Capital Expenditure (Years 21- 30)	25%	of Overall Expenditure					
Construction Schedule		**Year 1**	**Year 2**	**Year 3**	**Year 4**		
Wastewater Reverse Osmosis Treatment		60%	40%	0%	0%		
Computerised Maintenance Management System (CMMS)							
CMMS Cost	125	US$'000 -Fixed					
Capital Expenditure (Years 11- 20)	0%	of Overall Expenditure					
Capital Expenditure (Years 21- 20)	100%	of Overall Expenditure					
Injection Wells							
Injection Well Cost	33	US$'000/well					
Annual O&M Cost	10	US$'000/well					
Capital Expenditure (Years 11- 20)	5%	of Expenditure/Well					
Capital Expenditure (Years 21- 30)	5%	of Expenditure/Well					
Construction Schedule		**Year 1**	**Year 2**	**Year 3**	**Year 4**		
Injection Wells		100%	0%	0%	0%		
				Option 1	**Option 2**	**Option 3**	**Option 4**
Number of wells				6	9	6	3
Wastewater Networks and Transmission in Bridgetown							
Length of Sewer Pipe	23.5	Kms (1)					
Sewer Construction costs	2,000	US$/Meter					
Capital Expenditure (Years 11- 20)	0%	of Overall Expenditure					
Capital Expenditure (Years 21- 30)	10%	of Overall Expenditure					

(1) Source: Conceptual Design Report

Treated Water Transmission Network		Option 1	Option 2	Option 3	Option 4
Length of Water Transmission Pipe	Kms	13	27	9	3
Network Construction costs	US$/Meter	500	500	500	500
Capital Expenditure (Years 11- 20)	of Overall Expenditure	0%	0%	0%	0%
Capital Expenditure (Years 21- 30)	of Overall Expenditure	10%	10%	10%	10%

Construction Schedule		Year 1	Year 2	Year 3	Year 4
Wastewater Networks and Transmission in Bridgetown	100%	40%	40%	20%	0%
Treated Water Transmission - Option 1	100%	50%	50%	0%	0%
Treated Water Transmission - Option 2	100%	35%	35%	30%	0%
Treated Water Transmission - Option 3	100%	50%	50%	0%	0%
Treated Water Transmission - Option 4	100%	100%	0%	0%	0%

Energy and Control Systems			Installed Cost		Total Cost
Solar	0.23	MW	2,400	US$/kW	561,600
Capital Expenditure (Years 11- 20)	15%	of Overall Expenditure			
Capital Expenditure (Years 21- 20)	25%	of Overall Expenditure			
Feed in Tariff (Years 1 - 10)	0.18	US$/kW			
Feed in Tariff (Years 11 - 20)	0.15	US$/kW			
Feed in Tariff (Years 21 - 30)	0.12	US$/kW			
DC to AC power conversion	0.75				
AC Power to Kwh conversion	1,800				
Costs for Solar	20%				

Construction Schedule		Year 1	Year 2	Year 3	Year 4
Energy and Control Systems	100%	60%	40%	0%	0%

Operating Costs (Percentage of Total Expenses)	
Asset operating Costs (excluding electricity)	20.0%
Maintenance Costs	15.0%
Employee Expenses	55.0%
Other Expenses	10.0%

Electricity Expense		
Annual Electricity Usage	4,038,360	kwh/year
Annual Electricity Cost - US$/Kwh	0.29	

Project Inflows		
Percentage of Treated Water going to Agriculture	40%	
Percentage of Treated Water to Acquifer replenishment	60%	
Percentage of Treated Water loss	20%	
Sale price of water	$ 2.60	M^3
Phosphorus Generated	61	Tonne/year
Price of Prosphorus	$ 1,200	Tonne
Operating cost without Project	85%	

Exhibit 2

Capital Expenditure for the BSTP as well as the cost of the options for the treated water distribution network

(Amounts in US$million)

Business Area	Contributing Driver	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-Year Total
WASTEWATER	Wastewater Networks and Transmission	18.8	18.8	9.4	-	-	-	-	-	-	-	47.0	-	4.7	51.7
	Wastewater Treatment	12.0	12.0	6.0	-	-	-	-	-	-	-	30.0	3.0	5.1	38.1
	Energy and Control Systems	0.3	0.2	-	-	-	-	-	-	-	-	0.6	0.1	0.1	0.8
	CMMS	0.1	-	-	-	-	-	-	-	-	-	0.1	-	0.1	0.3
Grand Total		**31.3**	**31.0**	**15.4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**77.7**	**3.1**	**10.1**	**90.8**
Treated Water - Option 1															
	Water Network Transmission	3.3	3.3	-	-	-	-	-	-	-	-	6.5	-	0.7	7.2
	Wastewater Reverse Osmosis (RO) Treatment	5.8	3.9	-	-	-	-	-	-	-	-	9.7	2.4	2.4	14.6
	Injection Wells (6)	0.2	-	-	-	-	-	-	-	-	-	0.2	0.0	0.0	0.2
		9.3	**7.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**16.4**	**2.4**	**3.1**	**21.9**
Treated Water - Option 2															
	Water Network Transmission	4.7	4.7	4.1	-	-	-	-	-	-	-	13.5	-	1.4	14.9
	Wastewater Reverse Osmosis (RO) Treatment	5.8	3.9	-	-	-	-	-	-	-	-	9.7	2.4	2.4	14.6
	Injection Wells (9)	0.3	-	-	-	-	-	-	-	-	-	0.3	0.0	0.0	0.3
		10.9	**8.6**	**4.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**23.5**	**2.4**	**3.8**	**29.7**
Treated Water - Option 3															
	Water Network Transmission	2.3	2.3	-	-	-	-	-	-	-	-	4.5	-	0.5	5.0
	Wastewater Reverse Osmosis (RO) Treatment	5.8	3.9	-	-	-	-	-	-	-	-	9.7	2.4	2.4	14.6
	Injection Wells (6)	0.2	-	-	-	-	-	-	-	-	-	0.2	0.0	0.0	0.2
		8.3	**6.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**14.4**	**2.4**	**2.9**	**19.7**
Treated Water - Option 4															
	Water Network Transmission	1.5	-	-	-	-	-	-	-	-	-	1.5	-	0.2	1.7
	Wastewater Reverse Osmosis (RO) Treatment	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Injection Wells (3)	0.1	-	-	-	-	-	-	-	-	-	0.1	0.0	0.0	0.1
		1.6	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1.6**	**0.0**	**0.2**	**1.8**

Exhibit 3

Results of the Willingness to Pay Survey

Barbados Wastewater Treatment Survey Results

A total of 75 respondents completed at least part of the survey. All respondents indicated that they were representing households (i.e., there are no business responses).

Table 1: Demographic characteristics of sample

Variable	n	Average or percentage
Age (years)	56	48.91
Male	56	55%
Main Income earner in household = yes	56	64%
Christ Church	55	29%
St. Andrew	55	0%
St. George	55	4%
St. James	55	25%
St. John	55	4%
St. Joseph	55	0%
St. Lucy	55	2%
St. Michael	55	16%
St. Peter	55	4%
St. Philip	55	9%
St. Thomas	55	7%
Education at least some college	55	84%
Monthly Income (BBD)	48	$7,177

Table 2: Where does wastewater go when it leaves your home? (62 responses)

Responses	Percentage
Into a septic tank or hole/well (that does not connect to a soak-away field)	37%
Into a septic tank or hole/well that connects to a soak-away field (that soaks into the ground)	21%
Into a pipe that flows into a sewer collection system	5%
Into a pipe that flows outside, but not into a sewer collection system (pit latrine)	5%
Other	11%
I don't know	0%

Table 3: How often is the water supply to your home interrupted so that you cannot get water from your taps when you need it? (60 responses)

Responses	Percentage
Very often. At least one time per week.	3%
At least one time per month.	10%
Only a few times per year.	35%
Rarely. Once or twice per year.	38%
Never.	12%
I don't know.	2%

Table 4: How satisfied are you with the water supplied to and removed from your home? (54 – 58 responses)

	Satisfied	Neutral/Unsure	Dissatisfied
The cleanliness of the water supplied to your home	57%	24%	19%
The taste of the water supplied to your home	50%	28%	22%
Water pressure in your home	69%	9%	22%
Interruptions to your household water supply	53%	31%	16%
Disposal of wastewater from your home	63%	23%	14%
The price you pay for water supplied to your home	50%	43%	7%
The price you pay for garbage disposal and wastewater treatment (garbage and sewerage contribution)	31%	47%	22%

Table 5: Please indicate whether you were aware of the following water conditions in Barbados before taking this survey. (56 – 58 responses)

	Yes, I was aware of this	**No, I was not aware of this**
Barbados is ranked as one of the top 15 water scarce countries in the world.	62%	38%
Groundwater/aquifers in Barbados are becoming depleted.	72%	28%
Loss of groundwater can lead to water outages if necessary restrictions are not placed on some areas.	82%	18%
There are only 2 municipal (BWA) wastewater treatment plants in Barbados.	72%	28%
Less than 5% of properties in Barbados are connected to a BWA wastewater treatment plant.	46%	54%
All wastewater that is treated from both treatment plants is discharged into the sea.	65%	35%
All wastewater from septic tanks, soak-away fields and pit latrines flows into the ground and into the aquifer beneath Barbados.	61%	39%

Table 6: Please indicate whether the following aspects of a new wastewater management system in Barbados are very important to you. (54 – 57 responses)

	Yes, this is very important to me	No, this is not very important to me
More water available to households and businesses.	93%	7%
Fewer interruptions to household/business water supply.	93%	7%
More water available for agriculture/farming.	95%	5%
Fewer interruptions to agriculture water supply.	88%	13%
Energy recovery from waste.	89%	11%
Less wastewater (pollution) discharged into the sea.	96%	4%
Fewer sewer leaks into the environment.	100%	0%
Low cost to taxpayers.	93%	7%
Few disruptions to traffic and business during construction.	93%	7%

Table 7: Upgrading the wastewater management system in Barbados will require funds for planning, construction, operation and maintenance. Noting the above benefits to upgrading the wastewater management system in Barbados, in principle, would you be willing to pay an additional $____ BBD per month ($____ BBD per year) to your BWA bill to help pay for the costs of these improvements? (34 responses)

Monthly fee amount	# offered	% Yes
$1.00	7	100%
$2.00	4	100%
$5.00	6	83%
$10.00	6	83%
$20.00	7	71%
$30.00	4	75%
Average amount respondents are willing to pay per month [3] = $15.94		

[3] For the dichotomous choice WTP question, average willingness to pay is calculated using the Turnbull method. See Schuhmann et al. (2019) for details.

Table 8: Upgrading the wastewater management system in Barbados will require funds for planning, construction, operation and maintenance. Noting the above benefits to upgrading the wastewater management system in Barbados, please choose the value below that represents the maximum additional amount that you would be willing to pay on your BWA bill per month to help fund improvements in wastewater management in Barbados. (19 responses)

Maximum monthly fee amount	Number of respondents who selected this amount
$0.00	1
$1.00	1
$2.00	1
$5.00	0
$10.00	6
$20.00	8
$30.00	2
Average amount respondents are willing to pay per month = $15.10	

Table 9: Do you agree or disagree with the following statements? (54-56 responses)

	Agree	Neutral/Unsure	Disagree
Barbados has a shortage of available clean water.	75%	22%	4%
Discharging wastewater into the sea negatively affects everyone.	91%	9%	0%
Households and businesses that use more water should pay higher fees for water.	78%	20%	2%
Everyone in Barbados will benefit from improved wastewater management.	93%	6%	2%

Table 10: If wastewater were treated to the highest level so that it could be distributed in a pipe system for uses other than drinking, to what extent do you approve of the following uses? (56 responses)

	Approve	Neutral/Unsure	Do not approve
Watering crops on farms	89%	9%	2%
Watering sport fields and golf courses	88%	7%	5%
Watering household gardens	91%	9%	0%
Car washing	88%	7%	5%
Household toilet flushing	95%	4%	2%
Household laundry	46%	27%	27%

Reference:

Schuhmann, P., Waite, R., Skeete, R., Lorde, T., Oxenford, H., Moore, W. and Spencer, F., 2019. Visitors' Willingness to Pay Conservation Fees in Barbados, *Tourism Management*, 71, 315-326.

Exhibit 4

Annual operating costs for the upgraded BSTP

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-year
Conventional Activated Sludge (CAS) with Waste Water Treatment RO Plant														
Asset operating Costs	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	5.12	6.14	7.37	18.63
Maintenance Costs	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.42	3.84	4.61	5.53	13.97
Electricity Expenses	1.17	1.19	1.22	1.24	1.27	1.29	1.32	1.35	1.37	1.40	12.82	15.39	18.47	46.68
Employee Expenses	1.29	1.31	1.34	1.36	1.39	1.42	1.45	1.48	1.51	1.54	14.07	16.89	20.26	51.22
Other Expenses	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	2.56	3.07	3.68	9.31
Total Operating Costs	**3.51**	**3.58**	**3.65**	**3.72**	**3.80**	**3.87**	**3.95**	**4.03**	**4.11**	**4.19**	**38.41**	**46.09**	**55.31**	**139.81**

Conventional Activated Sludge (CAS) without Waste Water Treatment RO Plant														
Asset operating Costs	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.24	2.19	2.63	3.15	7.97
Maintenance Costs	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.18	1.64	1.97	2.37	5.98
Electricity Expenses	0.50	0.51	0.52	0.53	0.55	0.56	0.57	0.58	0.59	0.60	5.51	6.62	7.94	20.07
Employee Expenses	0.55	0.56	0.57	0.58	0.60	0.61	0.62	0.63	0.64	0.66	6.02	7.23	8.67	21.92
Other Expenses	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.12	0.12	1.10	1.31	1.58	3.99
Total Operating Costs	**1.50**	**1.53**	**1.56**	**1.60**	**1.63**	**1.66**	**1.69**	**1.73**	**1.76**	**1.80**	**16.46**	**19.76**	**23.71**	**59.93**

Exhibit 5

Gross Project Inflows from the Implementation of this Project

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 10 - 20	Year 21 - 30	30-year
Net Project Inflows														
Proceeds from Treated Water	5.47	5.47	5.47	5.47	5.47	5.47	5.47	5.47	5.47	5.47	54.66	65.59	78.71	198.97
Electricity Generated	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.57	0.47	0.38	1.43
Sale of phosphorus	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.73	0.73	0.73	2.20
Gross Project Inflows	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**5.60**	**55.97**	**66.80**	**79.82**	**202.59**

Exhibit 6

Gross Project Flows incorporating Option 1 for the Treated Water Distribution Network

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-year
Benefits														
Inflows with Project	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Inflows without Project	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Incremental Inflows	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Costs														
Total Operating Costs	3.57	3.64	3.71	3.78	3.86	3.93	4.01	4.09	4.17	4.26	39.03	46.84	56.20	142.07
Total Capital Costs	40.53	38.15	15.40	-	-	-	-	-	-	-	94.09	5.52	13.15	112.76
Outflows with Project	44.10	41.79	19.11	3.78	3.86	3.93	4.01	4.09	4.17	4.26	133.12	52.36	69.35	254.82
Outflows without Project	2.98	3.04	3.10	3.16	3.23	3.29	3.36	3.42	3.49	3.56	32.65	39.18	47.01	118.84
Net Incremental Outflows	41.12	38.75	16.01	0.62	0.63	0.64	0.65	0.67	0.68	0.70	100.47	13.18	22.34	135.99
Gross Project Flows	**(35.52)**	**(33.16)**	**(10.41)**	**4.98**	**4.97**	**4.95**	**4.94**	**4.93**	**4.92**	**4.90**	**(44.50)**	**53.62**	**57.48**	**66.60**

Note:

An illustration of the derivation of the incremental costs and incremental benefits using Year 1 of this option is shown in Table 4.

Net Inflows on the assumption that the project is implemented is reflected in Exhibit 5 and comprise of the potential revenue from the conversion of treated water from the BSTP to portable water which can be sold to residential and commercial customers, the revenue generated from the sale of electricity from the solar PV system to the local electricity company and the sale of the byproduct phosphorus to commercial entities.

Net inflows on the assumption that the project is NOT implemented is **zero** as the wastewater from the BSTP is discarded at sea.

Net outflows on the assumption that the project is implemented is a combination of capital and operating costs. Capital costs include the cost of the upgraded water treatment plant, the cost of the solar PV system, and the cost of the wastewater distribution network in Bridgetown along with the capital cost for this option which includes the cost of 13km of treated water transmission network, the cost of the new RO plant and the cost of 6 injection wells. The operating cost include the incremental projected O&M costs for the upgraded wastewater treatment plant, including the O&M costs associated with undertaking this option.

Net outflows on the assumption that the project is NOT implemented is estimated to be 85% of the projected O&M cost for the upgraded wastewater treatment plant.

Exhibit 7

Gross Project Flows incorporating Option 2 for the Treated Water Distribution Network

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-year
Benefits														
Inflows with Project	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Inflows without Project	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Incremental Inflows	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Costs														
Total Operating Costs	3.60	3.67	3.74	3.81	3.89	3.96	4.04	4.12	4.20	4.30	39.34	47.21	56.65	143.21
Total Capital Costs	42.11	39.63	19.45	-	-	-	-	-	-	-	101.20	5.52	13.86	120.58
Outflows with Project	45.71	43.30	23.19	3.81	3.89	3.96	4.04	4.12	4.20	4.30	140.54	52.74	70.51	263.78
Outflows without Project	2.98	3.04	3.10	3.16	3.23	3.29	3.36	3.42	3.49	3.56	32.65	39.18	47.01	118.84
Net Incremental Outflows	42.73	40.26	20.09	0.65	0.66	0.67	0.68	0.70	0.71	0.74	107.89	13.56	23.50	144.95
Gross Project Flows	**(37.13)**	**(34.67)**	**(14.49)**	**4.95**	**4.94**	**4.92**	**4.91**	**4.90**	**4.89**	**4.86**	**(51.92)**	**53.24**	**56.33**	**57.64**

Note:

An illustration of the derivation of the incremental costs and incremental benefits using Year 1 of option 1, as shown in Exhibit 6, is outlined in Table 4.

Net Inflows on the assumption that the project is implemented is reflected in Exhibit 5 and comprise of the potential revenue from the conversion of treated water from the BSTP to portable water which can be sold to residential and commercial customers, the revenue generated from the sale of electricity from the solar PV system to the local electricity company and the sale of the byproduct phosphorus to commercial entities.

Net inflows on the assumption that the project is NOT implemented is **zero** as the wastewater from the BSTP is discarded at sea.

Net outflows on the assumption that the project is implemented is a combination of capital and operating costs. Capital costs include the cost of the upgraded water treatment plant, the cost of the solar PV system, and the cost of the wastewater distribution network in Bridgetown along with the capital cost for this option which includes the cost of 29km of treated water transmission network, the cost of the new RO plant and the cost of 9 injection wells. The operating cost include the incremental projected O&M costs for the upgraded wastewater treatment plant, including the O&M costs associated with undertaking this option.

Net outflows on the assumption that the project is NOT implemented is estimated to be 85% of the projected O&M cost for the upgraded wastewater treatment plant.

Exhibit 8

Gross Project Flows incorporating Option 3 for the Treated Water Distribution Network

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-year
Benefits														
Inflows with Project	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Inflows without Project	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Incremental Inflows	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Costs														
Total Operating Costs	3.57	3.64	3.71	3.78	3.86	3.93	4.01	4.09	4.17	4.26	39.03	46.84	56.20	142.07
Total Capital Costs	39.53	37.15	15.40	-	-	-	-	-	-	-	92.09	5.52	12.95	110.56
Outflows with Project	43.10	40.79	19.11	3.78	3.86	3.93	4.01	4.09	4.17	4.26	131.12	52.36	69.16	252.63
Outflows without Project	2.98	3.04	3.10	3.16	3.23	3.29	3.36	3.42	3.49	3.56	32.65	39.18	47.01	118.84
Net Incremental Outflows	40.12	37.75	16.01	0.62	0.63	0.64	0.65	0.67	0.68	0.70	98.47	13.18	22.14	133.79
Gross Project Flows	**(34.52)**	**(32.16)**	**(10.41)**	**4.98**	**4.97**	**4.95**	**4.94**	**4.93**	**4.92**	**4.90**	**(42.50)**	**53.62**	**57.68**	**68.80**

Note:

An illustration of the derivation of the incremental costs and incremental benefits using Year 1 of option 1, as shown in Exhibit 6, is outlined in Table 4.

Net Inflows on the assumption that the project is implemented is reflected in Exhibit 5 and comprise of the potential revenue from the conversion of treated water from the BSTP to portable water which can be sold to residential and commercial customers, the revenue generated from the sale of electricity from the solar PV system to the local electricity company and the sale of the byproduct phosphorus to commercial entities.

Net inflows on the assumption that the project is NOT implemented is **zero** as the wastewater from the BSTP is discarded at sea.

Net outflows on the assumption that the project is implemented is a combination of capital and operating costs. Capital costs include the cost of the upgraded water treatment plant, the cost of the solar PV system, and the cost of the wastewater distribution network in Bridgetown along with the capital cost for this option which includes the cost of 9km of treated water transmission network, the cost of the new RO plant and the cost of 6 injection wells. The operating cost include the incremental projected O&M costs for the upgraded wastewater treatment plant, including the O&M costs associated with undertaking this option.

Net outflows on the assumption that the project is NOT implemented is estimated to be 85% of the projected O&M cost for the upgraded wastewater treatment plant.

Exhibit 9

Gross Project Flows incorporating Option 4 for the Treated Water Distribution Network

(Amounts in US$million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 1 - 10	Year 11 - 20	Year 21 - 30	30-year
Benefits														
Inflows with Project	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Inflows without Project	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net Incremental Inflows	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	55.97	66.80	79.82	202.59
Costs														
Total Operating Costs	1.53	1.56	1.60	1.63	1.66	1.69	1.72	1.76	1.79	1.83	16.78	20.13	24.16	61.06
Total Capital Costs	32.86	31.02	15.40	-	-	-	-	-	-	-	79.28	3.09	10.22	92.59
Outflows with Project	34.40	32.59	16.99	1.63	1.66	1.69	1.72	1.76	1.79	1.83	96.06	23.22	34.38	153.66
Outflows without Project	2.98	3.04	3.10	3.16	3.23	3.29	3.36	3.42	3.49	3.56	32.65	39.18	47.01	118.84
Net Incremental Outflows	31.41	29.55	13.89	(1.54)	(1.57)	(1.60)	(1.63)	(1.67)	(1.70)	(1.73)	63.41	(15.96)	(12.63)	34.82
Gross Project Flows	**(25.82)**	**(23.95)**	**(8.30)**	**7.13**	**7.17**	**7.20**	**7.23**	**7.26**	**7.30**	**7.33**	**(7.45)**	**82.76**	**92.46**	**167.77**

Note:

An illustration of the derivation of the incremental costs and incremental benefits using Year 1 of option 1, as shown in Exhibit 6, is outlined in Table 4.

Net Inflows on the assumption that the project is implemented is reflected in Exhibit 5 and comprise of the potential revenue from the conversion of treated water from the BSTP to portable water which can be sold to residential and commercial customers, the revenue generated from the sale of electricity from the solar PV system to the local electricity company and the sale of the byproduct phosphorus to commercial entities.

Net inflows on the assumption that the project is NOT implemented is **zero** as the wastewater from the BSTP is discarded at sea.

Net outflows on the assumption that the project is implemented is a combination of capital and operating costs. Capital costs include the cost of the upgraded water treatment plant, the cost of the solar PV system, and the cost of the wastewater distribution network in Bridgetown along with the capital cost for this option which includes the cost of 2km of treated water transmission network and the cost of 3 injection wells at the Spring Garden BWRO. The operating cost include the incremental projected O&M costs for the upgraded wastewater treatment plant, including the O&M costs associated with undertaking this option.

Net outflows on the assumption that the project is NOT implemented is estimated to be 85% of the projected O&M cost for the upgraded wastewater treatment plant.

Appendix 5 – Willingness to Pay Survey

Barbados Wastewater Treatment Survey Results

A total of 75 respondents completed at least part of the survey. All respondents indicated that they were representing households (i.e. there are no business responses).

Table 1: Demographic characteristics of sample

Variable	n	Average or percentage
Age (years)	56	48.91
Male	56	55%
Main Income earner in household = yes	56	64%
Christ Church	55	29%
St. Andrew	55	0%
St. George	55	4%
St. James	55	25%
St. John	55	4%
St. Joseph	55	0%
St. Lucy	55	2%
St. Michael	55	16%
St. Peter	55	4%
St. Philip	55	9%
St. Thomas	55	7%
Education at least some college	55	84%
Monthly Income (BBD)	48	$7,177

Table 2: Where does wastewater go when it leaves your home? (62 responses)

Responses	Percentage
Into a septic tank or hole/well (that does not connect to a soak-away field)	37%
Into a septic tank or hole/well that connects to a soak-away field (that soaks into the ground)	21%
Into a pipe that flows into a sewer collection system	5%
Into a pipe that flows outside, but not into a sewer collection system (pit latrine)	5%
Other	11%
I don't know	0%

Table 3: How often is the water supply to your home interrupted so that you cannot get water from your taps when you need it? (60 responses)

Responses	Percentage
Very often. At least one time per week.	3%
At least one time per month.	10%
Only a few times per year.	35%
Rarely. Once or twice per year.	38%
Never.	12%
I don’t know.	2%

Table 4: How satisfied are you with the water supplied to and removed from your home? (54 – 58 responses)

	Satisfied	Neutral/Unsure	Dissatisfied
The cleanliness of the water supplied to your home	57%	24%	19%
The taste of the water supplied to your home	50%	28%	22%
Water pressure in your home	69%	9%	22%
Interruptions to your household water supply	53%	31%	16%
Disposal of wastewater from your home	63%	23%	14%
The price you pay for water supplied to your home	50%	43%	7%
The price you pay for garbage disposal and wastewater treatment (garbage and sewerage contribution)	31%	47%	22%

Table 5: Please indicate whether you were aware of the following water conditions in Barbados before taking this survey. (56 – 58 responses)

	Yes, I was aware of this	No, I was not aware of this
Barbados is ranked as one of the top 15 water scarce countries in the world.	62%	38%
Groundwater/aquifers in Barbados are becoming depleted.	72%	28%
Loss of groundwater can lead to water outages if necessary restrictions are not placed on some areas.	82%	18%
There are only 2 municipal (BWA) wastewater treatment plants in Barbados.	72%	28%
Less than 5% of properties in Barbados are connected to a BWA wastewater treatment plant.	46%	54%
All wastewater that is treated from both treatment plants is discharged into the sea.	65%	35%
All wastewater from septic tanks, soak-away fields and pit latrines flows into the ground and into the aquifer beneath Barbados.	61%	39%

Table 6: Please indicate whether the following aspects of a new wastewater management system in Barbados are very important to you. (54 – 57 responses)

	Yes, this is very important to me	No, this is not very important to me
More water available to households and businesses.	93%	7%
Fewer interruptions to household/business water supply.	93%	7%
More water available for agriculture/farming.	95%	5%
Fewer interruptions to agriculture water supply.	88%	13%
Energy recovery from waste.	89%	11%
Less wastewater (pollution) discharged into the sea.	96%	4%
Fewer sewer leaks into the environment.	100%	0%
Low cost to taxpayers.	93%	7%
Few disruptions to traffic and business during construction.	93%	7%

Table 7: Upgrading the wastewater management system in Barbados will require funds for planning, construction, operation and maintenance. Noting the above benefits to upgrading the wastewater management system in Barbados, in principle, would you be willing to pay an additional $____ BBD per month ($____ BBD per year) to your BWA bill to help pay for the costs of these improvements? (34 responses)

Monthly fee amount	# offered	% Yes
$1.00	7	100%
$2.00	4	100%
$5.00	6	83%
$10.00	6	83%
$20.00	7	71%
$30.00	4	75%
Average amount respondents are willing to pay per month [1] = $15.94		

Table 8: Upgrading the wastewater management system in Barbados will require funds for planning, construction, operation and maintenance. Noting the above benefits to upgrading the wastewater management system in Barbados, please choose the value below that represents the maximum additional amount that you would be willing to pay on your BWA bill per month to help fund improvements in wastewater management in Barbados. (19 responses)

Maximum monthly fee amount	Number of respondents who selected this amount
$0.00	1
$1.00	1
$2.00	1
$5.00	0
$10.00	6
$20.00	8
$30.00	2
Average amount respondents are willing to pay per month = $15.10	

[1] For the dichotomous choice WTP question, average willingness to pay is calculated using the Turnbull method. See Schuhmann et al. (2019) for details.

Table 9: Do you agree or disagree with the following statements? (54-56 responses)

	Agree	Neutral/Unsure	Disagree
Barbados has a shortage of available clean water.	75%	22%	4%
Discharging wastewater into the sea negatively affects everyone.	91%	9%	0%
Households and businesses that use more water should pay higher fees for water.	78%	20%	2%
Everyone in Barbados will benefit from improved wastewater management.	93%	6%	2%

Table 10: If wastewater were treated to the highest level so that it could be distributed in a pipe system for uses other than drinking, to what extent do you approve of the following uses? (56 responses)

	Approve	Neutral/Unsure	Do not approve
Watering crops on farms	89%	9%	2%
Watering sport fields and golf courses	88%	7%	5%
Watering household gardens	91%	9%	0%
Car washing	88%	7%	5%
Household toilet flushing	95%	4%	2%
Household laundry	46%	27%	27%

Reference:

Schuhmann, P., Waite, R., Skeete, R., Lorde, T., Oxenford, H., Moore, W. and Spencer, F., 2019. Visitors' Willingness to Pay Conservation Fees in Barbados, *Tourism Management*, 71, 315-326.