South Coast Water Reclamation Pre-Feasibility Study

Barbados Water Authority

Government Of Barbados
Pine Commercial Estate, The Pine, St Michael, BB11103,
Barbados

November 1, 2020

Statement of Qualifications and Limitations

The attached Report (the "Report") has been prepared by AECOM Canada Ltd. ("AECOM") for the benefit of the Client ("Client") in accordance with the agreement between AECOM and Client, including the scope of work detailed therein (the "Agreement").

The information, data, recommendations and conclusions contained in the Report (collectively, the "Information"):

- is subject to the scope, schedule, and other constraints and limitations in the Agreement and the qualifications contained in the Report (the "Limitations");
- represents AECOM's professional judgement in light of the Limitations and industry standards for the preparation of similar reports;
- may be based on information provided to AECOM which has not been independently verified;
- has not been updated since the date of issuance of the Report and its accuracy is limited to the time period and circumstances in which it was collected, processed, made or issued;
- must be read as a whole and sections thereof should not be read out of such context;
- was prepared for the specific purposes described in the Report and the Agreement; and
- in the case of subsurface, environmental or geotechnical conditions, may be based on limited testing and on the assumption that such conditions are uniform and not variable either geographically or over time..

AECOM shall be entitled to rely upon the accuracy and completeness of information that was provided to it and has no obligation to update such information. AECOM accepts no responsibility for any events or circumstances that may have occurred since the date on which the Report was prepared and, in the case of subsurface, environmental or geotechnical conditions, is not responsible for any variability in such conditions, geographically or over time.

AECOM agrees that the Report represents its professional judgement as described above and that the Information has been prepared for the specific purpose and use described in the Report and the Agreement, but AECOM makes no other representations, or any guarantees or warranties whatsoever, whether express or implied, with respect to the Report, the Information or any part thereof.

Without in any way limiting the generality of the foregoing, any estimates or opinions regarding probable construction costs or construction schedule provided by AECOM represent AECOM's professional judgement in light of its experience and the knowledge and information available to it at the time of preparation. Since AECOM has no control over market or economic conditions, prices for construction labour, equipment or materials or bidding procedures, AECOM, its directors, officers and employees are not able to, nor do they, make any representations, warranties or guarantees whatsoever, whether express or implied, with respect to such estimates or opinions, or their variance from actual construction costs or schedules, and accept no responsibility for any loss or damage arising therefrom or in any way related thereto. Persons relying on such estimates or opinions do so at their own risk.

Except (1) as agreed to in writing by AECOM and Client; (2) as required by-law; or (3) to the extent used by governmental reviewing agencies for the purpose of obtaining permits or approvals, the Report and the Information may be used and relied upon only by Client.

AECOM accepts no responsibility, and denies any liability whatsoever, to parties other than Client who may obtain access to the Report or the Information for any injury, loss or damage suffered by such parties arising from their use of, reliance upon, or decisions or actions based on the Report or any of the Information ("improper use of the Report"), except to the extent those parties have obtained the prior written consent of AECOM to use and rely upon the Report and the Information. Any injury, loss or damages arising from improper use of the Report shall be borne by the party making such use.

This Statement of Qualifications and Limitations is attached to and forms part of the Report and any use of the Report is subject to the terms hereof.

AECOM: 2015-04-13

Quality information

Prepared by	Checked by	Verified by	Approved by
Vijay Sundaram			

Revision History

Revision	Revision date	Details	Authorized	Name	Position

Distribution List

# Hard Copies	PDF Required	Association / Company Name

Prepared for:

Prepared by:

AECOM Canada Ltd.

99 Commerce Drive

Winnipeg, MB R3P 0Y7

Canada

T: 204.477.5381

F: 204.284.2040

aecom.com

Table of Contents

Figures

Tables

Appendix

Acronyms

AACE	American Society of Cost Engineering
ADWF	Average Dry Weather Flow
AOP	Advanced Oxidation Process
ARV	Air/ Vacuum Relief Value
ASTM	American Society for Testing and Materials
AWT	advanced water treatment
AWWA	American Water Works Association
BOV	Ball Valve
BSTP	Bridgetown Sewage treatment plant
BWA	Barbados Water Authority
CAS	conventional activated sludge
CEC	chemical of emerging concern
CIP	clean-in-place
DAF	dissolved air flotation
DBP	disinfection byproducts
DPR	direct potable use
EPA	United States Environmental Protection Agency
EPD	Barbados Environmental Protection Department
EPS	extracellular polymeric substance
FAO	Food and Agricultural Organization of the United Nations
GMF	granular media filtration
HAA	haloacetic acids
HDD	Horizontal Directional Drilling
HDPE DR	High Density Polyethylene, Diameter Ratio
IPR	indirect potable reuse
km	kilometer
km	kilometer
kPa	Kilopascals
LBS	Land-Based Sources
m	meter
m	meter(s)
m/s	metres per second
m^3/d	cubic metres per day
MBR	membrane bioreactor
MF	microfiltration

mg/L	milligrams per litre
MIGD	million imperial gallons per day
mm	millimetre(s)
NDMA	N-Nitrosodimethylamine
NSF	National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
Project	South Coast Water Reclamation Project
PWWF	Peak Wet Weather Flow
RAS	return activated sludge
RO	reverse osmosis
ROW	right-of-way
SCSTP	South Coast Sewage Treatment Plant
SCWRRF	South Coast Water Reclamation Facility
SRT	solids retention time
SS	sanitary sewer
TBL	triple bottom line
TDS	total dissolved solids
THM	trihalomethanes
TN	total nitrogen
TSS	total suspended solids
UV	ultraviolet
µmho/cm	micro mhos per centimetre
WAS	waste activated sludge
WHO	World Health Organization
WRRF	water resource recovery facility

1. Introduction

1.1 Project Overview

The Barbados Water Authority (BWA) is evaluating the feasibility of upgrading its South Coast Sewage Treatment Plant (SCSTP) from existing advanced preliminary wastewater treatment with a tertiary/advanced treatment plant capable of producing water suitable for groundwater recharge in a potable aquifer and/or a non-potable aquifer, or suitable for edible food crop irrigation. The proposed South Coast Water Reclamation Project (Project) is a vital and sustainable water initiative that helps BWA and its partners in transforming the existing SCSTP into a futuristic South Coast Water Resource Recovery Facility (SCWRRF). Goals of the Project include: augment existing water supplies, mitigate climate change effects, address seawater intrusion and sea level rise, diversify potable water sources, enhance water supply resiliency, and reduce the impact of treated effluent on marine life and the environment.

1.2 Background and Project Drivers

Barbados receives significant seasonal rainfall every year, yet it remains one of the most water scarce countries in the world. The limited water storage on the island is a product of topography, geology and land use. This combined with a high population density and limited land space results in the need for careful use of existing water resources. Climate change has resulted in more frequent and intense droughts and flooding. In addition, the water supply infrastructure is aged and there are significant transmission losses and unaccounted for water. Saline intrusion is also a reality currently being experienced. While there is an active mains replacement programme and the country is seeking to go to tertiary treatment of sewage and groundwater recharge, it is also recognized that stormwater management must also be treated as a key component of the overall freshwater solution.

The BWA estimates (in the absence of production flow metres) that it currently abstracts approximately 155000 m^3/day, (~34 MIGD), via two springs, 17 sheet water wells, five stream water wells, and seven boreholes, including, under contract to the BWA, the privately operated wells at Groves, St. Philip (~ 6800 m^3/day) (~1.5 MIGD), the privately operated brackish water reverse osmosis (BWRO) plant (~45000 m^3/day) (~ 10 MIGD) and the RO plant at Hope (570 m^3) (0.125 MIGD). A further 36000 m^3/day (8 MIGD) is estimated to be abstracted by private wells (again in the absence of monitored flow metres) and those operated by the Barbados Agricultural Development and Marketing Corporation (BADMC) for agriculture.

The current population density is 663 km^2, which is amongst the highest in the world, and 100% of the total population (285000 in 2013) has access to improved water sources. Sixty years ago, only 35% of the population had piped water to their homes, and the water utility abstracted approximately 60000 m^3/day (13.2 MIGD) (21.9 million m^3/year) of groundwater to service the population.

Land use patterns have changed drastically in the last 60 years, with perhaps unforeseen impacts on groundwater recharge rates. Change of use from agriculture to residential/commercial has reduced the permeable surface area. As sugar cane plantations go out of production, the scores of suck wells on each plantation have been abandoned and/or are poorly maintained. Although Town Planning requires developers of commercial lots to contain stormwater on their properties (i.e., dig stormwater wells), there is no such stipulation for individual residential lots, where the objective is to get the stormwater off the property and into a surface drain as quickly as possible.

In 2014 the Food and Agricultural Organization of the United Nations (FAO) estimated the total renewable water resources for Barbados at 80 million m^3/year under average rainfall conditions. This is equivalent to 281 m^3/year per inhabitant, which is significantly less than the threshold of 1000 m^3/year /person that defines water scarcity. The driest year on record in Barbados since 1947 was 2019; just 736.5 mm (29") of rainfall was recorded at the airport in that year, whereas in an average year approximately 1270 mm (50”) of rainfall would be expected.

Rainfall varies considerably with elevation, ranging from an average of 1875 mm (74”) per year in the higher central area to 1275 mm (50”) in the coastal zone. Drought conditions are expected to continue into 2020, and the long-term trend, due to climate change, is expected to bring decreased overall precipitation, longer dry spells, and more intense rainfall events (when the rain does fall).

All of the currently operating public supply wells (PSWs) on the west coast (Alleynedale, Ashton Hall, The Whim, Haymans and Carlton) are experiencing increased salinity at current abstraction rates. Pumping from PSWs has had to be stopped at Molyneux and Trents. Water table levels are at historical lows at PSWs like Bowmanston. The agricultural sector is faring no better, with the Ministry of Agriculture, restricting the supply of irrigation water due to increased salinity in its wells both in the north (Springhall) and in the southeast (River Plantation) over the last few years.

Currently, the BWA is barely able to meet national potable water demand in an average rainfall year and is unable to meet demand under a 1 in 15 year drought (which is becoming more common). The Ministry of Agriculture is unable to meet current agricultural demand for irrigation water and there is likely significant suppressed demand. Simply put, the rate of freshwater abstraction is now greater than the rate of recharge. The demand for water in the agricultural sector is expected to increase because the Covid-19 pandemic and its economic aftermath have resulted in a renewed emphasis on food security. Therefore, water reclamation projects are essential for the island’s sustainable water resource management and sustainable development.

Water crisis is one the highest risks for urban development, industrial growth, and food security. In recent years, communities from Cape Town, South Africa, to Arizona, USA have been experiencing water stress. As the world population grows, there are often competing interests for water resources. A clear plan is needed for managing various elements of the hydrosphere (e.g., wastewater, stormwater, industrial water use, agricultural/irrigation water consumption, etc.) to meet and forecast future water needs. Reuse of treated wastewater has been shown to provide a new source of water supply. Storing advanced treated reclaimed water in aquifers establishes locally controlled water reserves that are relatively secure during protracted droughts.

Climate change impacts water availability, management, and infrastructure. To mitigate this impact, considerable amounts of energy are being used for water and wastewater conveyance and treatment. Energy use related to water infrastructure can be a sizable portion of the overall energy demand of an economy. Regulations governing water reuse must be protective of public health. However, overregulation can result in implementation of energy and resource intensive treatment and management solutions that exacerbate greenhouse gas emissions and climate change. Therefore, energy consumption related to water must be minimized to the extent feasible.

There are currently two municipal sewage treatment plants on the island. The Bridgetown Sewage treatment plant (~7000 m^3/day) services the Bridgetown catchment area and employs secondary treatment of wastewater by use of activated sludge. The SCSTP (~9000 m^3/day – average dry weather flow [ADWF]) services part of the southern section of the island and treats the wastewater to an advanced primary stage before its disposal via a marine outfall situated off Needham’s Point.

In an effort to mitigate the effects of climate change on the island’s potable and non-potable water supply and increase resilience to climate change and reduce the impact of the primary treated effluent on the marine environment, BWA is evaluating an upgrade of the SCSTP to a treatment level that is suitable for crop irrigation and recharge of groundwater aquifers through a newly designed and constructed water reclamation distribution network system.

Properly managed water reclamation projects are and will continue to be essential for the island’s sustainable water resource management and sustainable development.

1.3 Pre-Feasibility Study

BWA retained AECOM to assist in the preparation of a pre-feasibility study for the upgrade of the SCSTP to SCWRRF and a reclaimed water distribution and recharge well system. BWA intends that the proposed project be delivered using a design build approach. This pre-feasibility study is, by its nature, a high-level evaluation of the proposed project and cannot be used as is for detailed design of the project. Any design builder selected for the design and construction of the project will need to do its own due diligence and develop its own design. Sizes of proposed infrastructure are presented within this pre-feasibility study. These were used to develop Class 5 relative cost estimates for the purposes of alternatives analysis and budgeting purposes. Infrastructure sizes presented within this pre-feasibility study will need to be confirmed by the design builder as part of its design process.

2. South Coast Water Reclamation Scenarios

2.1 Reclaimed Water End Uses

Reuse of municipal wastewater effluent is not new. Well-known reuse projects have been in practice since the 1980s. However, the methods for providing advanced treatment to wastewater and the realistic options for reuse water have changed significantly as new technologies are developed and increased public education occurs. The new water planning paradigm considers all water in the hydrosphere as “one water.” The possibilities for water reuse at SCSTP are a continuum, much like a spectrum of light. Within the water reuse spectrum, the varying uses of treated product water (e.g., aquifer recharge, crop irrigation) are key factors in determining the degree of treatment needed and the required reliability of that treatment.

2.1.1 Potable Reuse

In potable reuse projects, highly purified wastewater effluent is used to augment potable drinking water supplies. Within the potable reuse approach, there are four methods of potable water augmentation: groundwater recharge, surface water augmentation, raw water augmentation, and treated water augmentation. The first two methods are generally grouped under “indirect potable reuse” (IPR), and the last method is referred to as “direct potable reuse” (DPR). Southern California, Virginia, Singapore, and Namibia are currently planning and implementing potable reuse projects as a more economical alternative.

2.1.2 Potable Aquifer Recharge

Municipal wastewater effluent is highly purified to generate exceptional quality treated water that meets all regulatory requirements for potable reuse (including drinking water standards) and that is recharged and stored in potable water aquifers (e.g., the St. Philip or St. Michael aquifers). With potable water aquifer recharge projects, both regulators and the public are concerned about pathogens, potential carcinogens (such as disinfection byproducts (DBPs), pesticides, heavy metals), and chemicals of emerging concern (CECs) which include hormones, pharmaceuticals, and personal care products. Treatment approaches for the Project under study will be developed to address concerns related to pathogens, potential carcinogens, and CECs.

2.1.3 Non-Potable Aquifer Recharge

Treated municipal wastewater effluent is recharged and stored in aquifers that do not serve as potable drinking water supplies (e.g., the Christ Church aquifer). Although the end use for this type of recharge is not potable water augmentation, the treatment approach for this type of end use will be developed to address pathogens, turbidity, and nutrients.

2.1.4 Food Crop Irrigation

Highly disinfected and filtered reclaimed water that is safe for edible food crop and other agricultural irrigation will be distributed to agricultural users. The use of reclaimed water for agricultural irrigation provides a reliable water source that can support the expansion of agricultural practices, production and food security in Barbados. Use of reclaimed water for both uncooked and edible food crop irrigation has been practiced in Salinas, Monterey, and the Central Valley in California, and throughout the State of Florida, USA, for several decades. The reclaimed water can also be safely used for irrigation of sports fields and public parks in addition to being utilized by the Barbados Fire Services for firefighting purposes.

It should be noted the soil problems most commonly encountered and used as a basis to evaluate water quality are those related to: salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

Salinity

Salinity, or salts in soil or water reduces water availability to the crop to such an extent that yield is affected.

Water Infiltration Rate

Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation point to the next.

Specific Ion Toxicity

Certain ions (sodium, chloride, boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields.

Miscellaneous

Excessive nutrients such as nitrogen reduce yields in that there is excessive vegetative growth, delayed crop maturity or fruiting; unsightly deposits on fruit or foliage reduce marketability; excessive corrosion of equipment increases maintenance and repairs.

2.2 Applicable Water Quality Standards for Reclaimed Water End Uses

In the 2018, Barbados established a National Water Reuse Policy, which was approved in principle by Cabinet. The Environmental Protection Department (EPD) has recommended water quality standards for both potable aquifer recharge and non-potable water reclamation (including non-potable aquifer and agricultural reuse). The newly developed Barbados reclaimed water quality standards are summarized in Tables 2-1 and 2-2. Reclaimed water standards from other jurisdictions are provided in Appendix A.

2.2.1 Reclaimed Water for Potable Aquifer Recharge

Table 2-1 is a summary of recharge water quality standards recommended by EPD for potable aquifer recharge.

Table 2-1: Potable Aquifer Recharge Water Quality Standards

Parameter	Reclaimed Water Quality	Basis for Standard
Total Organic Carbon (TOC)	Less than 3 mg/L	USEPA 2004 Guidelines for Water Reuse (“USEPA”)
Turbidity	Less than 2 Nephelometric Turbidity Units	USEPA
Total Nitrogen (as N)	Less than 5 mgN/l	USEPA
Total Phosphorus (as P)	As needed, depending on site-specific factors.	
pH	Between 6.5 and 8.5	USEPA

Parameter	Reclaimed Water Quality	Basis for Standard
Fecal Coliform	<1 CFU fecal coliforms/sample volume (ml)	USEPA
Total Coliform	<1 CFU total coliforms/sample volume (ml)	WHO
Chlorine residual	Below 0.1 mg/L prior to recharge or discharge to marine environment	USEPA
Drinking Water Standards	Meet primary and secondary drinking water standards	USEPA
Total Dissolved Solids (TDS)	Less than 450 mg/L	WHO/FAO

2.2.2 Reclaimed Water for Non-Potable Reclamation (Non-Potable Recharge and Food Crop Irrigation)

Table 2-2 is a summary of non-potable reclamation water quality standards recommended by EPD for non-potable reclamation (including non-potable aquifer recharge and agricultural food crop irrigation). Applicable Water Quality Standards for irrigation are shown in Appendix B – WHO Agricultural Reuse Guidelines. A list of prohibited concentrations is shown in Appendix C – Prohibited Concentrations.

Table 2-2: Non-Potable Reclamation (Non-Potable Aquifer Recharge and Food Crop Irrigation) Water Quality Standards

Parameter	Reclaimed Water Quality	Basis for Standard
Biochemical Oxygen Demand (5-day)	Less than 30 mg/L	List of prohibited concentrations (see Appendix C)
Total Suspended Solids	Less than 30 mg/L	List of prohibited concentrations
Total Nitrogen, as N	Less than 5 mgN/l	List of prohibited concentrations (see Appendix C)
Total Phosphorus	As needed, depending on site-specific factors.	List of prohibited concentrations (see Appendix C)
Total Dissolved Solids	Less than 450 mg/L	WHO/FAO (see Appendix B)
pH	Between 6.5 and 8.4	List of prohibited concentrations (see Appendix C)
Fecal Coliforms & Total Coliforms	<1 CFU/100ml	WHO and USEPA
Chlorine residual	Below 0.1 mg/L prior to recharge or discharge to marine environment	List of prohibited concentrations (see Appendix C)

2.3 South Coast Water Reclamation Scenarios

Based on multiple, in-depth discussions with BWA and after due consideration of the technical, regulatory, practical, and economic factors, four screening-level options were selected for the end uses of reclaimed water, and these options are described below.

2.3.1 Scenario A

In this scenario, reclaimed water would be recharged to the St. Philip potable aquifer upgradient of the Carrington and Hampton Pumping Stations. Highly treated purified water would be directly introduced into the aquifer through up to five deep recharge wells that penetrate the saturated zone of the karst limestone aquifer. The recharge wells would be placed directly outside the 300-day Time of Travel Capture Zones for the Carrington and Hampton Pumping Stations, as developed by Burnside (2011). A certain percentage of the reclaimed water would be diverted for agricultural reuse prior to advanced treatment, especially during the 6 to 9 months of the year when the weather is generally dry and irrigation demand is significant. River Plantation, Sandford/Mapps, and Golden Grove areas are possible areas that will be irrigated under Scenario A.

Figure 2-1 is a process flow diagram for reclaiming water for potable aquifer recharge and agricultural reuse under Scenario A. Note that the flow of reclaimed water would average 9000 m^3 /day, and the reverse-osmosis (RO) concentrate and excess flows would be directed to the marine outfall.

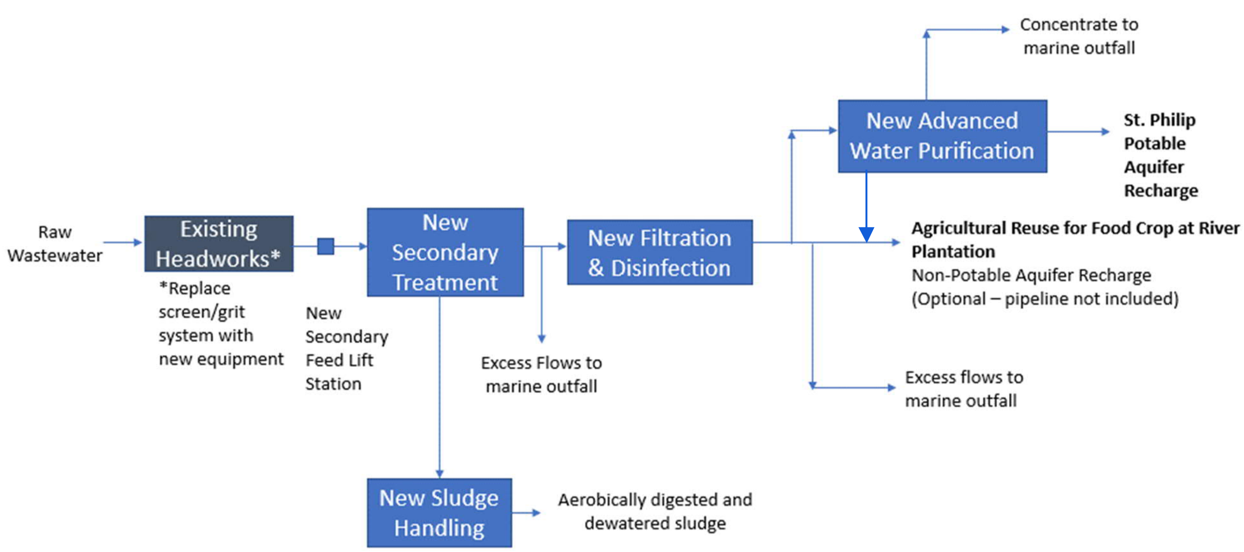


Figure 2-1: Scenario A Water Reclamation Concept

Scenario A includes the following end uses:

- Potable aquifer recharge in St. Philip Aquifer
- Unrestricted agricultural food crop irrigation at River Plantation, Sandford/Mapps, and Golden Grove areas in St. Philip

2.3.2 Scenario A1

In this scenario, reclaimed water would be used for agricultural reuse and any remaining reclaimed water would be recharged to the non-potable aquifer near the southern tip of Barbados. Non-potable water would be directly introduced into the aquifer through up to five deep recharge wells that penetrate the saturated zone of the karst limestone aquifer. Under Scenario A1, most of the reclaimed water would be used for agricultural reuse, especially during the 6 to 9 months of the year when the weather is generally dry and irrigation demand is significant. River Plantation, Sandford/Mapps, and Golden Grove areas are targeted for irrigation under Scenario A1.

Figure 2-2 is a process flow diagram for reclaiming water for non-potable aquifer and agricultural reuse under Scenario A1. Note that the flow of reclaimed water would average 9000 m^3/day. The reverse-osmosis (RO) concentrate from the TDS reduction system, and excess flows would be directed to the marine outfall.

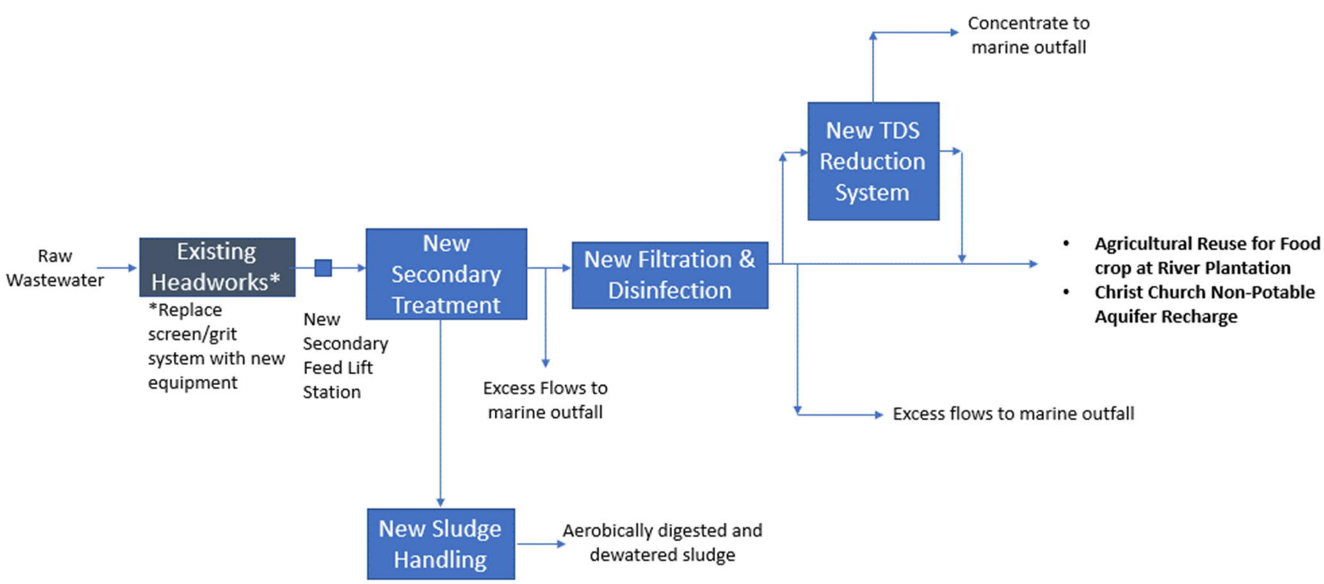


Figure 2-2: Scenario A1 Water Reclamation Concept

Scenario A1 includes the following end uses:

- Non-potable aquifer recharged in Christ Church Aquifer
- Unrestricted agricultural food crop irrigation at River Plantation, Sandford/Mapps, and Golden Grove areas in St. Philip

2.3.3 Scenario B

In this scenario, reclaimed water would be used for agricultural irrigation and recharge of the non-potable Christ Church Aquifer near the southern tip of Barbados. Non-potable water would be directly introduced into the aquifer through up to five deep recharge wells that penetrate the saturated zone of the karst limestone aquifer. Under Scenario B, most of the reclaimed water would be used for agricultural reuse, especially during the 6 to 9 months of the year when the weather is generally dry and irrigation demand is significant. Gibbons Boggs, Fairy Valley and Fairview agricultural sites are the main target areas for irrigation under Scenario B.

Figure 2-3 is a process flow diagram for reclaiming water for non-potable aquifer recharge and agricultural reuse under Scenario B. Note that the flow of reclaimed water would average 9000 m^3/day. The reverse-osmosis (RO) concentrate from the TDS reduction system, and excess flows would be directed to the marine outfall.

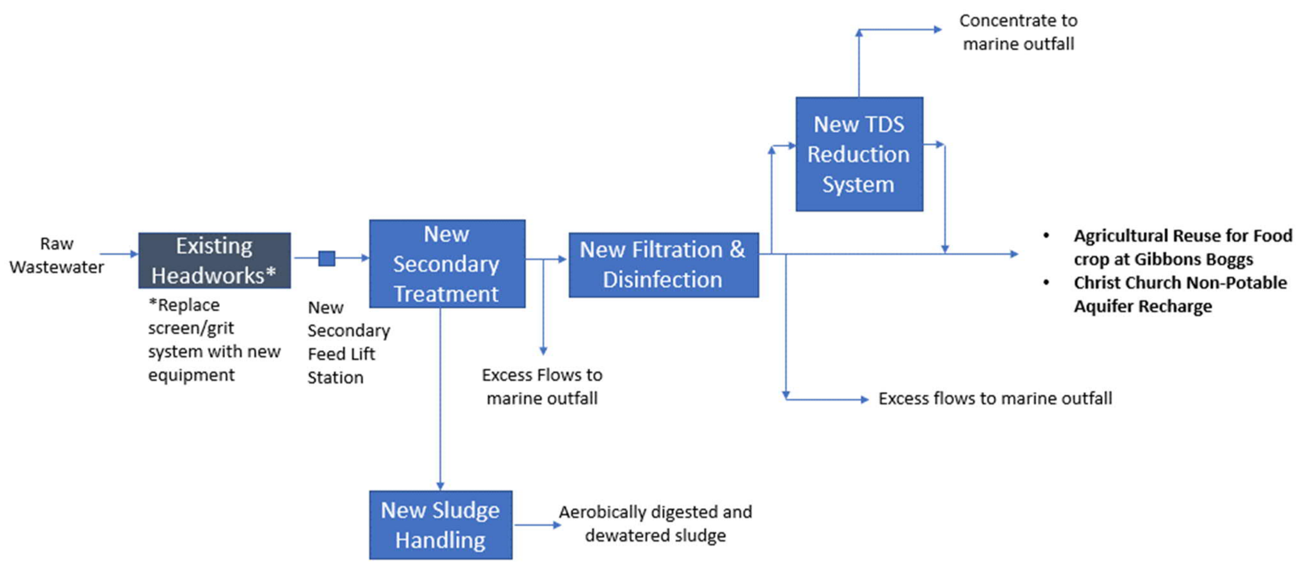


Figure 2-3: Scenario B Water Reclamation Concept

Scenario B includes the following end uses:

- Non-potable aquifer recharged in Christ Church Aquifer
- Unrestricted agricultural food crop irrigation at Gibbons Boggs, Fairy Valley and Fairview areas

2.3.4 Scenario C

In this scenario, reclaimed water would be used to recharge the St. Michael Potable Aquifer upgradient of the New Market and Constant Pumping Stations. Highly treated purified water would be directly introduced into the aquifer through up to five deep recharge wells that penetrate the saturated zone of the karst limestone aquifer. A certain percentage of the reclaimed water, prior to advanced treatment, would be used for agricultural use in the same general area, especially during the 6 to 9 months of the year when the weather is generally dry and irrigation demand is significant.

Figure 2-4 is a process flow diagram for reclaiming water for potable aquifer recharge and agricultural reuse under Scenario C. Note that the flow of reclaimed water would average 9000 m^3/day, and the RO concentrate and excess flows would be directed to the marine outfall.

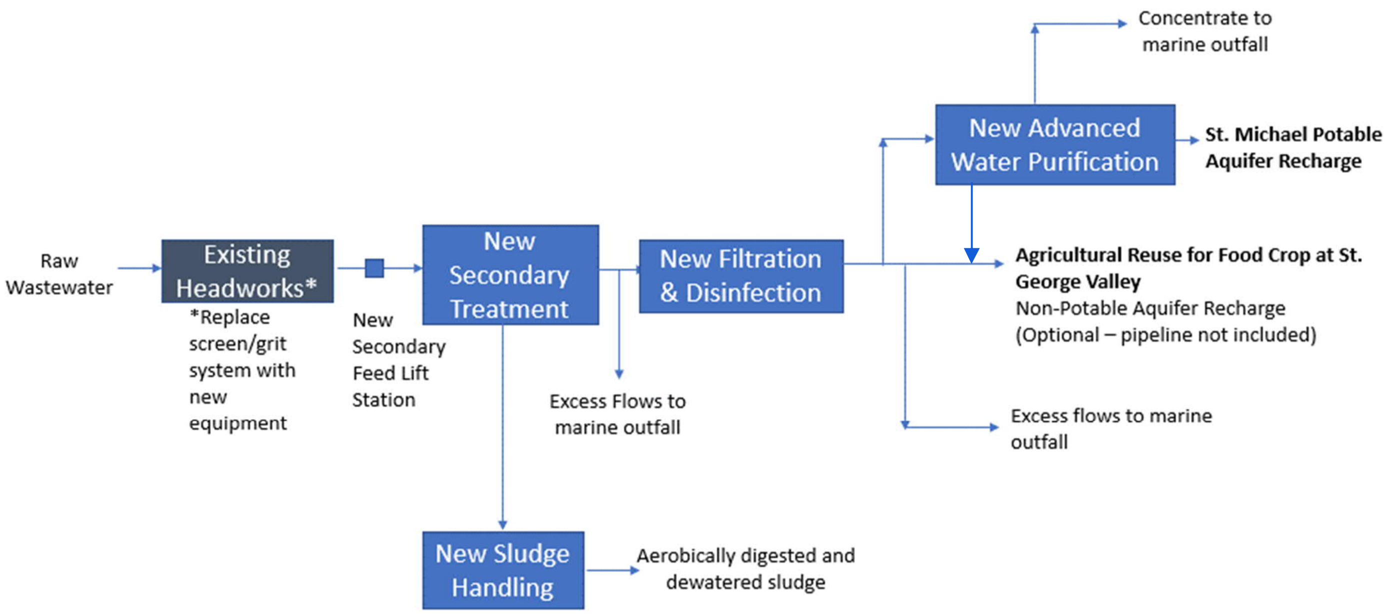


Figure 2-4: Scenario C Water Reclamation Concept

Scenario C includes the following end uses:

- Potable aquifer recharge in St. Michael Aquifer
- Unrestricted agricultural food crop irrigation at St. George Valley

2.4 Preliminary Hydrogeological Desktop Evaluation

AECOM performed a preliminary evaluation of hydrogeologic conditions in Barbados as a basis for understanding groundwater recharge and flow and for selecting potential scenarios for reclaimed water use. The hydrogeologic evaluation was based largely on the work of several key investigations:

- Draft Final Report, Barbados Regional Groundwater Model – Developed for Planning Purposes [1]
- Comprehensive Review and Overhaul of Barbados' Groundwater Protection Zoning Policy and System Volume 3 [2].
- Geochemical Evolution of Groundwater in the Pleistocene Limestone Aquifer of Barbados [3]

- Hydrogeologic and climatic influences on spatial and interannual variation of recharge to a tropical karst island aquifer [4]

AECOM also reviewed information provided by BWA, such as water quality, soil-types, and supply-well data.

Key elements of the physiography, geology, groundwater occurrence, groundwater recharge, groundwater resource potential, water-supply wells and groundwater quality of Barbados are summarized below. Refer also to maps prepared by or adapted from previous investigators.

2.4.1 General Physiography

Barbados is an island of roughly 432 km^2 (167 mi^2), whose land-surface elevation ranges from sea level along the coastline to roughly 335 m (1100 feet) near the center of the island at Sugar Hill.

2.4.2 Generalized Geology

The main geologic feature is a Pleistocene coral-reef limestone up to 90 m thick, which caps 87% of the island. The limestone rests unconformably on Tertiary (Eocene to Miocene age) rocks of deep-sea origin, which consist of mudstones and marls up to 350 m thick. The Tertiary rocks are exposed only in the highlands in the east-central portion of the island. For the most part, the Tertiary rocks are assumed to act as an aquiclude, preventing downward movement of groundwater from the limestone.

Barbados has been continuously uplifted from the east due to the collision of the Atlantic and Caribbean plates. Uplift has caused the top of the Tertiary rocks (and the base of the limestone) to arch radially and slope generally to the northwest, west, southwest, and south (Figure 2-5).

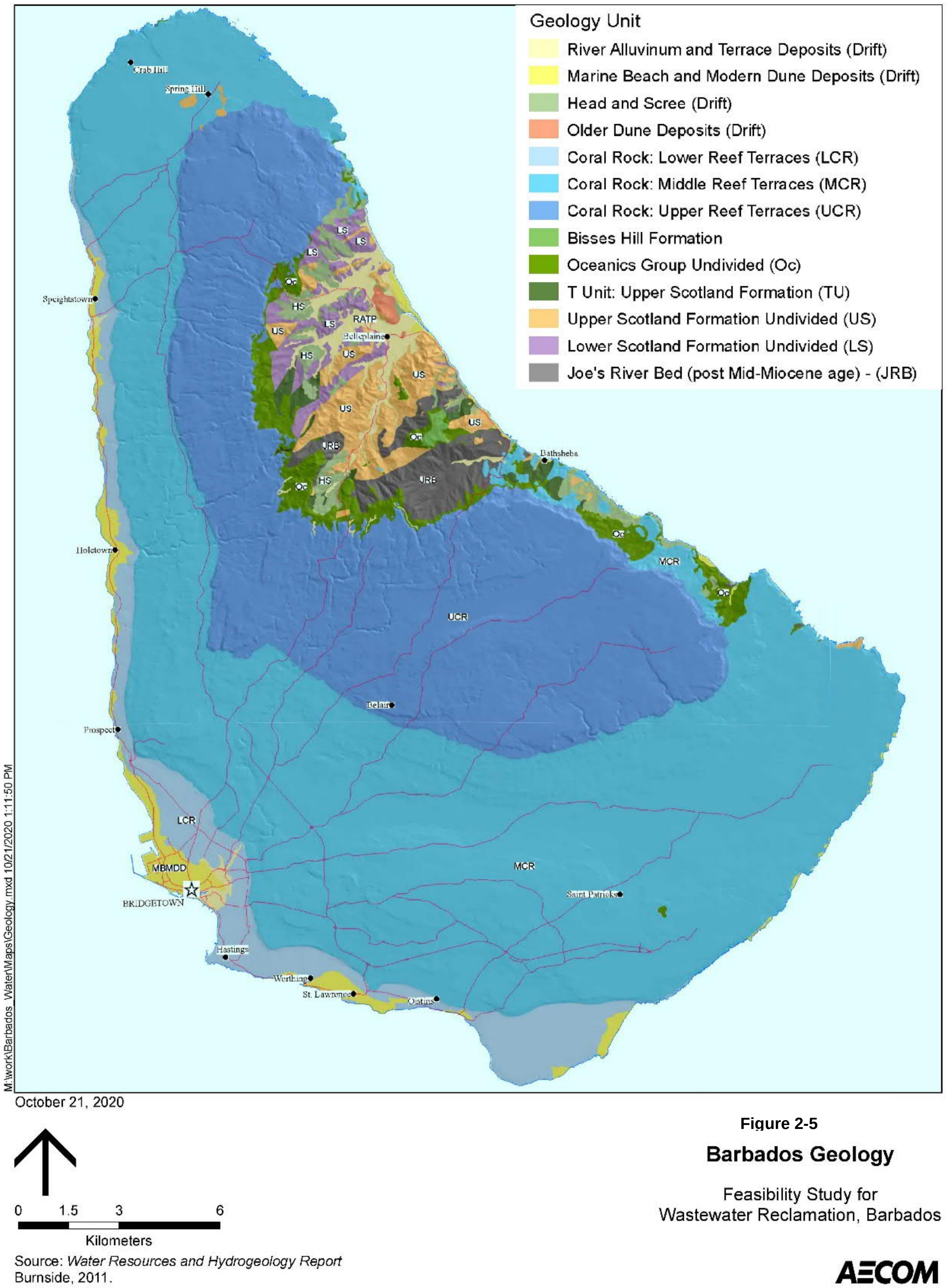


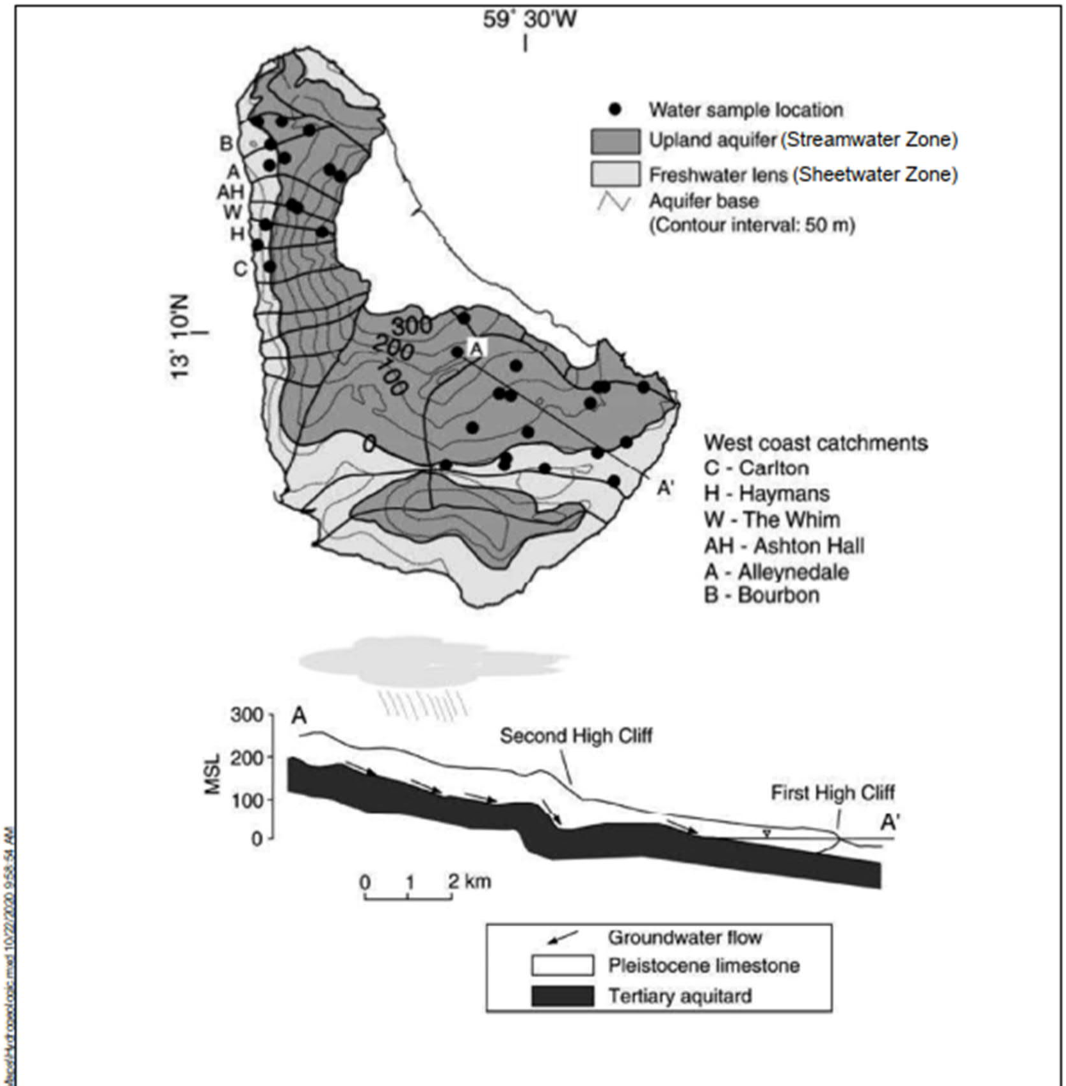
Figure 2-5: Barbados Geology

2.4.3 Groundwater Occurrence

Groundwater in the coral-reef limestone aquifer is unconfined. Near and along the coast, the base of the limestone slopes downward, extending beneath sea level. Groundwater in this zone, which pools at elevations slightly above sea level, is categorized as “sheet-water.” Groundwater in the sheet-water zone is assumed to flow laminarly towards the ocean and to float on seawater, creating a lens of freshwater 10 to 25 m thick (Figure 2-6 and Figure 2-7).

Inland, the base of the limestone extends above sea level, sloping upward toward the highlands and reaching elevations up to 250 m. Groundwater in this zone is categorized as “stream-water”. While water-table elevations in the stream-water zone have not been systematically measured, groundwater modeling suggests hydraulic gradients ranging from about 0.01 to 0.06. Groundwater in the stream-water zone is assumed to flow in conduits in karstic limestone. The saturated thickness of groundwater in the stream-water zone may be only a few metres.

Borehole video inspections, and borehole and surface geophysical surveys conducted by Burnside (2011) provide insight into the makeup of the coral-limestone aquifer. The limestone is described in some areas as banded with “variations from sandy to clayey layers.” Clay-rich zones occur frequently, which can perch groundwater locally. The limestone commonly contains vugs, conduits, fractures, joints, fissures, cavities, caverns, and other karstic features, all of which enhance the porosity and permeability. While intergranular porosity undoubtedly exists in the limestone, much of the flow of groundwater in both the stream-water and sheet-water zones is assumed to flow through discrete conduits. It is noteworthy that the groundwater model developed by XCG (2010) assumes intergranular porosity, as it would be impossible to account for the location and character of individual conduits in the limestone.



Hydrogeologic map of Barbados. The Pleistocene limestone aquifer is divided into several groundwater catchments due to the topography of the Pleistocene-Tertiary contact. Adapted from hydrogeologic map by Stanley Associates (1978) and cross-section by Barbados Ministry of Health et al. (1991).

Figure 2-6: Aquifer Types

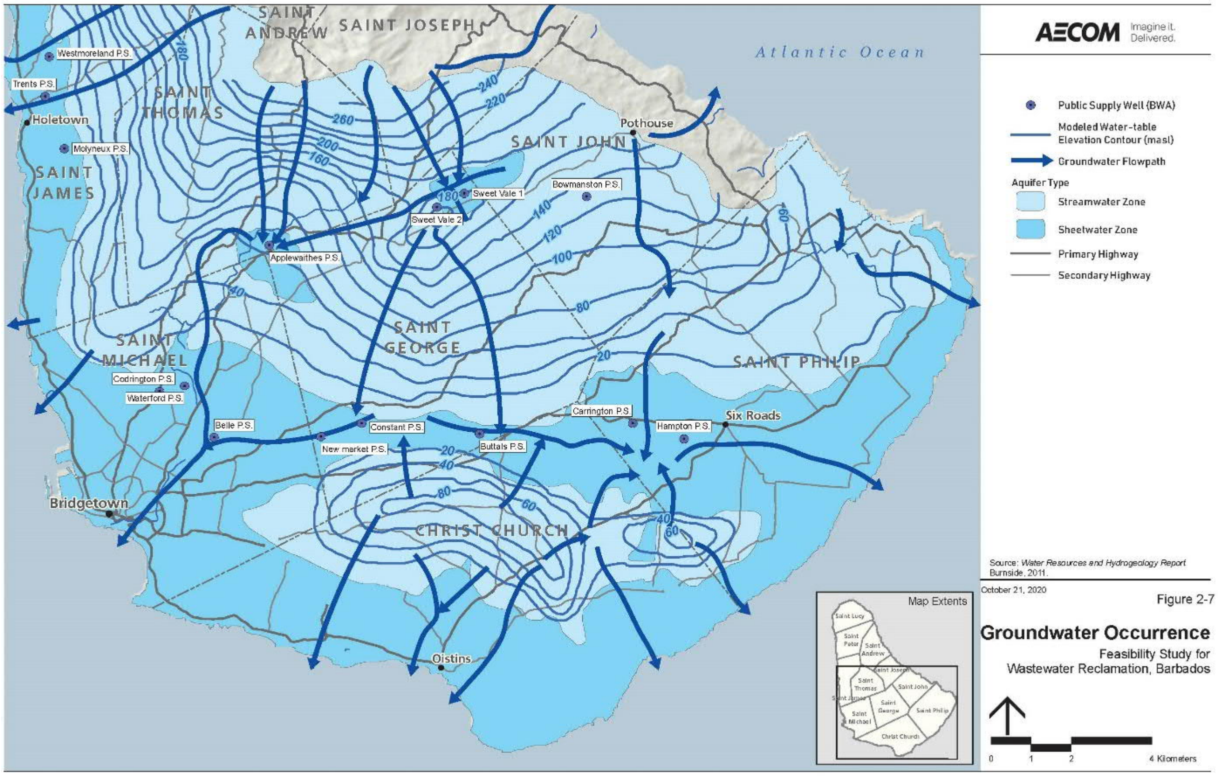


Figure 2-7: Groundwater Occurrence

2.4.4 Groundwater Recharge

The soils covering the limestone aquifer are typically 2 m thick and contain 60% to 70% clay minerals, which can swell when they become wet, reducing infiltration. The measured infiltration rates of the soils range from about 12.5 to greater than 250 millimetres (mm) per hour. In contrast, the underlying limestone has a measured infiltration capacity ranging from 700 to 70000 mm per hour.

Recharge to the coral-limestone aquifer occurs both diffusely through the soils and discretely through dry valleys and sink holes. Both dry valleys and sink holes are numerous, especially at elevations of 100 to 150 m. Most recharge to the aquifer generally occurs only after heavy rain events. Discrete recharge through dry valleys and sinkholes may take several minutes to a few days. Diffuse recharge through soils may take a few days to several months.

Evidence derived primarily from long-term groundwater hydrographs and oxygen isotope testing suggests that most of the annual recharge to the limestone aquifer may occur only in the wettest 1 to 3 months, typically August, September, and October. Monthly rainfall of less than 195 mm (about 7.5 inches) may contribute very little to aquifer recharge because of high evapotranspiration rates.

Average annual recharge is roughly 15% to 30% of annual rainfall, which ranges from 1000 to 2000 mm per year.

2.4.5 Groundwater Resource Potential

Based on studies performed in 1966 and 1978, the potential groundwater resource on Barbados has been estimated to range from 59 to 84 million m^3/year. Groundwater recharge rates estimated by

Burnside in 2011 suggest that the actual groundwater resource could be higher than the earlier estimates. Groundwater use has been estimated to range from 47 to 50 million m^3/year.

2.4.6 Water-Supply Wells

Figure 2-8 shows the BWA water supply wells and other private well locations on the island. Most of BWA's wells are constructed in the sheet-water zone where well capacities are highest. The Belle Pumping Station, for example, typically produces nearly 38000 m^3/day (about 8.35 million imperial gallons per day) of potable water. Wells constructed in the sheet-water zone benefit from high hydraulic conductivity, estimated from groundwater modeling to average 1300 m/day (4300 feet per day). In addition, the saturated thickness of 10 to 25 m, the flat water table and the large catchment areas undoubtedly contribute to the high well capacities of wells in the sheet-water zone. Wells built in the stream-water zone are typically far less productive (Figure 2-7).

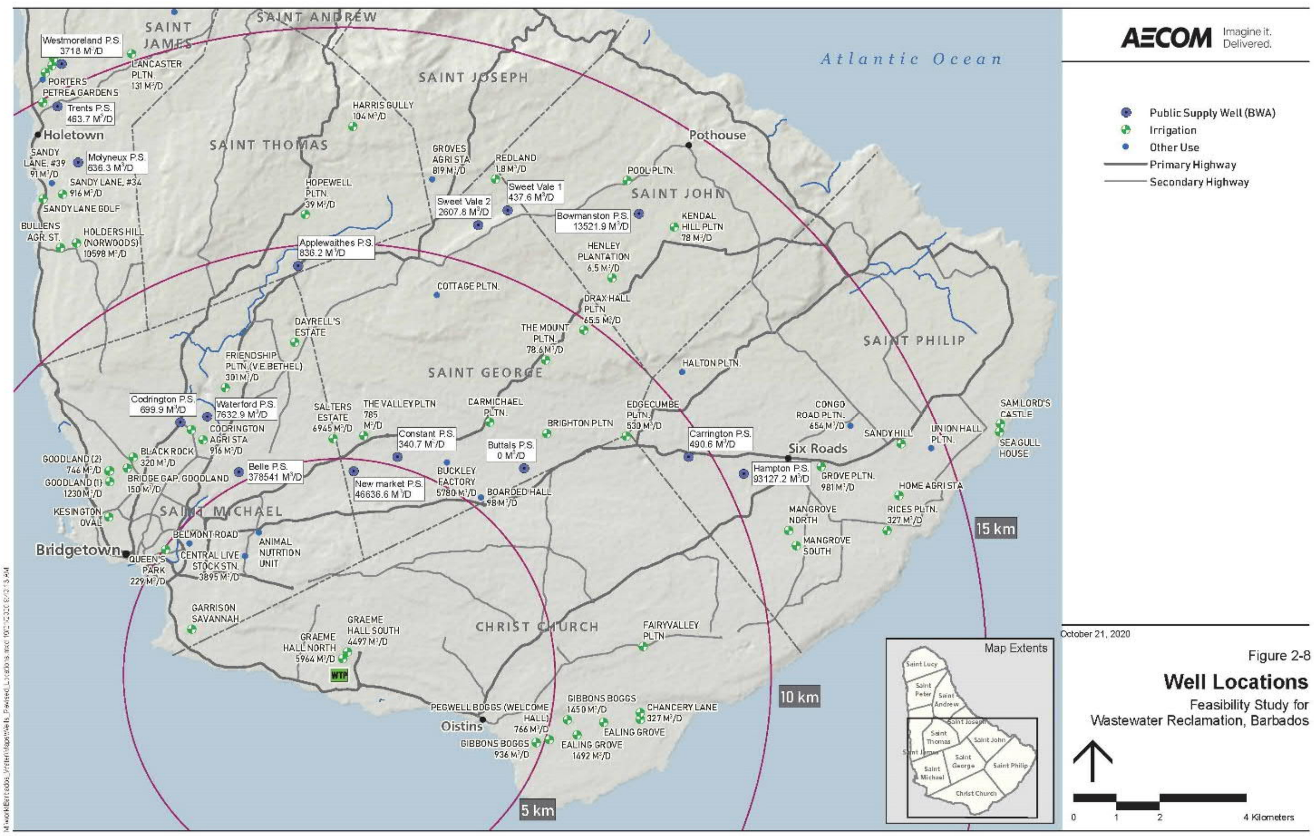


Figure 2-8: Well Locations

2.4.7 Groundwater Quality

The water quality monitoring programme is a joint programme between the EPD and the BWA. Table 2-3 summarizes the overall groundwater quality tested by BWA at the Belle Pumping Station and the Hampton Pumping Station for the period from 2015 to 2020. These data are presumed to be representative of groundwater quality in the sheet-water zone of the St. George Valley, where direct recharge of reclaimed water is being considered through recharge wells, under Scenarios A and C. The goal would be to match the water quality of the reclaimed water to that of the host aquifer, especially in terms of alkalinity, hardness, pH and total dissolved solids (TDS) in an effort to minimize dissolution of the karstic limestone when recharge takes place.

2.4.8 Summary

The foregoing summary of hydrogeologic conditions suggests that direct or indirect recharge of the limestone aquifer using reclaimed water is feasible. The direct recharge approach, involving a series of recharge wells placed strategically upgradient of existing BWA pumping stations, holds the promise of achieving maximum (near 100%) recharge efficiency. The indirect approach, involving spreading basins or similar means, would result in the loss of reclaimed water to evaporation. During the dry months (perhaps 9 months of the year) evaporation rates would be expected to be high.

From a conceptual standpoint, recharge wells are a feasible option for recharging potable and non-potable aquifers in Barbados. In Scenarios A and C, areas for potable aquifer recharge wells have been selected that are directly upgradient of the modeled 300-day capture zone (Figure 2-9). In Scenarios A1 and B, areas have been selected for recharge well locations for non-potable aquifer recharge (Figure 2-9). Detailed design will require the installation of exploratory boreholes and other investigatory work to prove the concept and then select final recharge well locations. For budgeting purposes, it is assumed that five recharge wells will be required to recharge up to 9000 m^3/day of reclaimed water. In addition, AECOM has assumed that four monitoring wells will be needed to monitor groundwater quality between the recharge wells and BWA pumping stations.

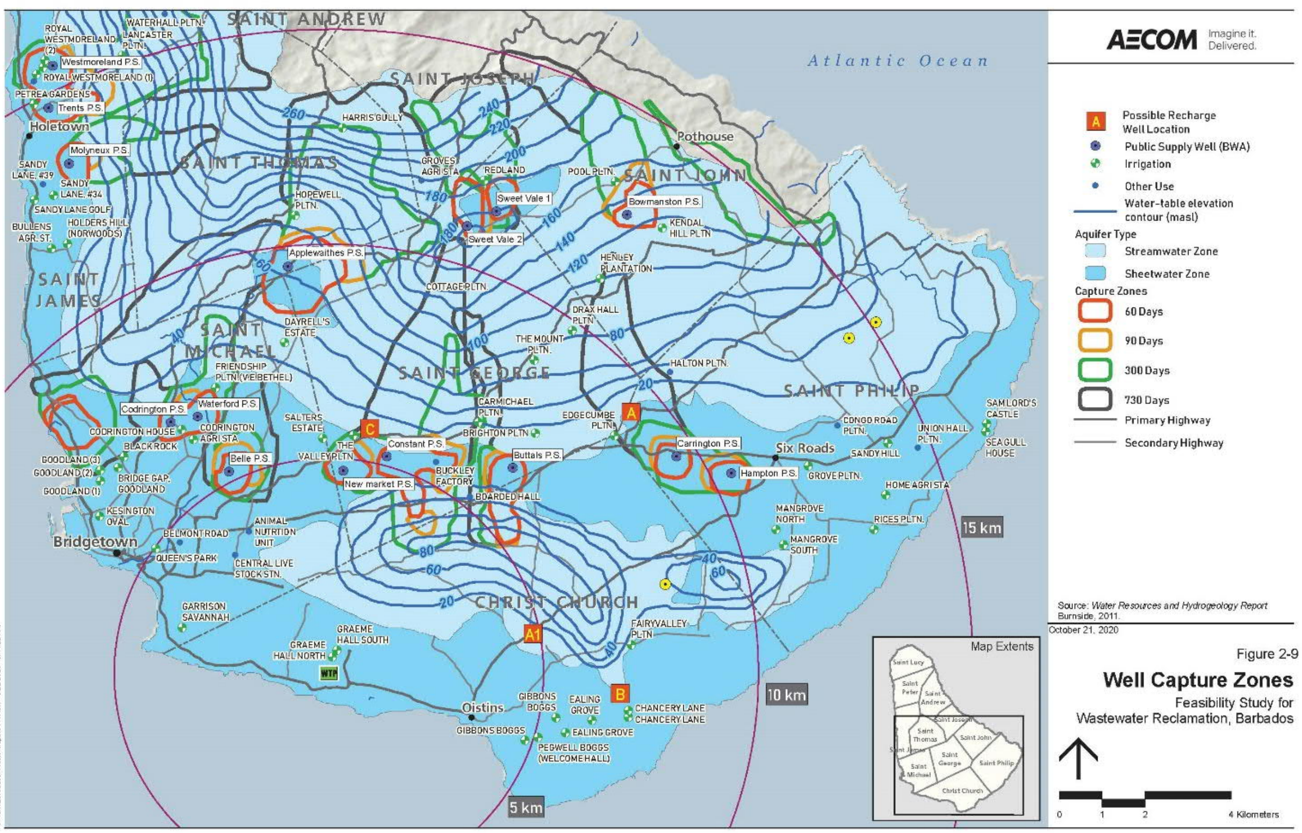


Figure 2-9: Well Capture Zones

Table 2-3: Summary of Key Water Quality Parameters - Belle and Hampton Pumping Stations, Barbados Water Authority, Typical Range, 2015 – 2020

Parameter	Units	Belle Pumping Station		Hampton Pumping Station	
		Minimum	Maximum	Minimum	Maximum
Total Alkalinity (as $CaCO_3$)	mg/L	212	299	118	242
Ammonia-N	mg/L	<0.05	0.27	<0.05	0.26
Bicarbonate	mg/L	259	362	144	289
Calcium	mg/L	190	322	133	278
Chloride	mg/L	45	97	79	117
Conductivity	µmho/cm	637	913	531	852
Magnesium	mg/L	26	68	31	70
Nitrate-N	mg/L	5.9	11	<1	11.2
pH	Standard Units	6.4	7.4	6.2	7.5
Potassium	mg/L	3.0	6.3	2.8	4.8
Sodium	mg/L	30	77	24	73
Sulfate	mg/L	26	42	10	35
TDS	mg/L	360	543	290	525
Total Phosphate	mg/L	<0.05	0.22	<0.05	0.3
Total Hardness (as $CaCO_3$)	mg/L	230	386	165	329

3. Influent and Effluent Criteria

The design of the secondary treatment facility was based on the wastewater loads outlined in the South Coast Sewerage Scheme Final Report[5]. These loads were reviewed and based on the information available that was deemed suitable for conceptual-level sizing and layouts. Table 3-1 summarizes the influent loads used for conceptual-level sizing of the secondary treatment facility. In addition to the load criteria below, the secondary treatment facility was sized for an average dry weather flow (ADWF) of 9000 m^3/d, with a peak wet weather flow (PWWF) of 24000 m^3/d.

Table 3-1: Influent Wastewater Quality

Parameter	Load
TSS	2000 kg/d
BOD_5	1815 kg/d
COD	4085 kg/d
NH3-N	455 kg/d
TN	635 kg/d
TP	73 kg/d
TDS	9,000 kg/d (1000 mg/L)
pH	7.5

Tables 3-2 to 3-6 summarizes the effluent water quality criteria for potable aquifer recharge, non-potable aquifer recharge and irrigation end use, as well as RO concentrate and excess effluent discharges to the marine environment.

With regard to effluent criteria for discharge to marine outfall, it should be noted that all discharges to the marine environment will be subject to the table of prohibited concentrations (see Appendix C) under the Marine Pollution Control Act, CAP 392A. Where the technology is such that the standards cannot be met at the discharge point for Class 1 or Class 2 waters, allowances can be negotiated based on the most recent science for the discharger to enter into an extra-strength agreement and pay for the variation from the standard. It should also be noted that where there is no discharge standard, the ambient standards must be satisfied at an agreed distance from the discharged point if the EPD deems it appropriate and the marine environment is protected. Where a mixing zone is agreed, the ambient standards should be met at the end of the mixing zone.

Table 3-2: Excess Secondary Effluent Quality (to Marine Outfall)*

Parameter	Water Quality Standard (based on discharges into Class 1 waters)	BWA Performance-Based Target (in addition to water quality standard)
TSS	Less than 30 mg/L	Less than 10 mg/L
BOD_5	Less than 30 mg/L	Less than 10 mg/L
COD	Not included in the water quality standards	
NH3-N	Not included in the water quality standards	
TN	Less than 5 mg/L	Less than 5 mg/L
TP	TP limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)**	
Fecal Coliform	Fecal coliform limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)**	
Total Residual Chlorine	Less than 0.1 mg/L	
Fats, Oil and Grease (FOG)	Less than 15 mg/L	
Floatables	Not visible	
Total Petroleum Hydrocarbons (TPH)	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)**	
Total Oils and Greases	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)**	
TOC	Max daily discharge less than 110 mg/L 30 day average discharge less than 55 mg/L (See Appendix C)**	
pH	6 - 9	

*Excess secondary effluent quality (to marine outfall) – Flows greater than 18000 m^3/d diverted to marine outfall after secondary treatment but before filtration and disinfection.

** With regard to effluent criteria for discharge to marine outfall, it should be noted that all discharges to the marine environment will be subject the table of prohibited concentrations (see Appendix C) under the Marine Pollution Control Act, CAP 392A. Where the technology is such that the standards cannot be met at the discharge point for Class 1 or Class 2 waters, allowances can be negotiated based on the most recent science for the discharger to enter into an extra-strength agreement and pay for the variation from the standard. It should also be noted that where there is no discharge standard, the ambient standards must be satisfied at an agreed distance from the discharged point if the EPD deems it appropriate and the marine environment is protected. Where a mixing zone is agreed, the ambient standards should be met at the end of the mixing zone.

Table 3-3: Excess Filtered and Disinfected Effluent Quality (to Marine Outfall)*

Parameter	Water Quality Standard (based on discharges into Class 1 waters)	BWA Performance-Based Target (in addition to water quality standard)
TSS	Less than 30 mg/L	Less than 5 mg/L
BOD_5	Less than 30 mg/L	Less than 5 mg/L
COD	Not included in the water quality standards	
NH3-N	Not included in the water quality standards	
TN	Less than 5 mg/L	Less than 5 mg/L
TP	TP limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)**	
Fecal Coliform	Less than 200 cfu/100 ml	Less than 1 cfu/100 ml
Fats, Oil and Grease (FOG)	15 mg/L	Less than 7 mg/L
Floatables	Not visible	
Total Petroleum Hydrocarbons (TPH)	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)**	
Total Oils and Greases	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)**	
TOC	Max daily discharge less than 110mg/L 30 day average discharge less than 55 mg/L (See Appendix C)**	

*Excess filtered and disinfected effluent quality (to marine outfall) Flows that are not utilized for agricultural reuse and non-potable aquifer recharge diverted to marine outfall after filtration and disinfection.

** With regard to effluent criteria for discharge to marine outfall, it should be noted that all discharges to the marine environment will be subject the table of prohibited concentrations (see Appendix C) under the Marine Pollution Control Act, CAP 392A. Where the technology is such that the standards cannot be met at the discharge point for Class 1 or Class 2 waters, allowances can be negotiated based on the most recent science for the discharger to enter into an extra-strength agreement and pay for the variation from the standard. It should also be noted that where there is no discharge standard, the ambient standards must be satisfied at an agreed distance from the discharged point if the EPD deems it appropriate and the marine environment is protected. Where a mixing zone is agreed, the ambient standards should be met at the end of the mixing zone.

Table 3-4: RO Product Quality (Prior to Blending)

Parameter	Water Quality Standard	BWA Performance-Based Target (in addition to water quality standard)
TSS	RO permeate (product) stream will not be discharged prior to blending. Therefore, water quality standards are not provided.	Less than 1 mg/L
BOD_5		Less than 1 mg/L
COD		
NH3-N		
TN		Less than 1 mg/L
Fecal Coliform		Non detect
Fats, Oil and Grease (FOG)		Non detect
TDS		Less than 20 mg/L

Table 3-5: RO Concentrate Quality (To Marine Outfall)

Parameter	Water Quality Standard (based on discharges into Class 1 waters)	BWA Performance-Based Target (in addition to water quality standard)
TSS	Less than 30 mg/L	
BOD_5	BOD_5 limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)*	
TN	TN limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)*	Less than 35 mg/L
TP	TP limit will be determined based on the mixing zone/dilution credits (See Appendix C for details)*	Less than 30 mg/L
Fecal Coliform	Less than 200 cfu/100 ml	
TDS		6600 mg/L (average)
Floatables	Not visible	
Total Petroleum Hydrocarbons (TPH)	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)*	
Total Oils and Greases	Max daily discharge less than 10 mg/L 30 day average discharge less than 5 mg/L (See Appendix C)*	
TOC	Max daily discharge less than 110mg/L 30 day average discharge less than 55 mg/L (See Appendix C)*	
pH	6 - 9	

* With regard to effluent criteria for discharge to marine outfall, it should be noted that all discharges to the marine environment will be subject the table of prohibited concentrations (see Appendix C) under the Marine Pollution Control Act, CAP 392A. Where the technology is such that the standards cannot be met at the discharge point for Class 1 or Class 2 waters, allowances can be negotiated based on the most recent science for the discharger to enter into an extra-strength agreement and pay for the variation from the standard. It should also be noted that where there is no discharge standard, the ambient standards

must be satisfied at an agreed distance from the discharged point if the EPD deems it appropriate and the marine environment is protected. Where a mixing zone is agreed, the ambient standards should be met at the end of the mixing zone.

Table 3-6: Final Effluent Quality (For Agricultural Reuse And Non-Potable Aquifer Recharge)

Parameter	Water Quality Standard	BWA Performance-Based Target (in addition to water quality standard)
TSS	Less than 30 mg/L	Less than 5 mg/L
BOD_5	Less than 30 mg/L	Less than 5 mg/L
COD	Not included in the water quality standards	
NH3-N	Not included in the water quality standards	
TN	Less than 5 mg/L	Less than 5 mg/L
TP	As needed, depending on site-specific factors.	
Total Coliforms	Less than 1 cfu/100 ml	Less than 1 CFU/ml
Fats, Oil and Grease (FOG)	Not included in the water quality standards	Less than 7 mg/L
TDS	Less than 450 mg/L	Less than 450 mg/L

The sludge moisture content after dehydration should be 60 to 70%.

Odor control to be provided to reduce odours from the retrofitted headworks area to non-detectable levels at the first sensitive receptor located at the plant fence.

4. Water Reclamation Treatment Approaches

4.1 Headworks

Currently screw lift pumps (one duty and one standby) lift raw wastewater to a single 75 mm manual raked coarse screen for removal of large debris. Downstream of the coarse screens, medium screening is provided through one 20 mm mechanically cleaned bar screen. Grit removal is accomplished by two vortex/teacup-style girt chambers, each rated for 12000 m^3/d. Downstream of grit removal, two 1.5 mm drum screens are installed for removal of fine material. Screenings and grit are compacted and disposed of in the landfill.

Based on AECOM's understanding, the basic infrastructure in the Headworks Facility is suitable for rehabilitation and can potentially be retrofitted with new process equipment where needed. This will need to be verified with a condition assessment of the facility.

In our experience, it would be less expensive to retrofit the existing facility and replace the medium screening with 6 mm bar screens. If a conventional activated sludge (CAS) process is selected for the secondary process, then the fine screening will not be required and can be removed from the treatment train. If a process such as membranes is selected, the fine screen system can be retained and used, but may require upgrade/replacement.

A new lift station will need to be constructed to pump the screened wastewater to secondary treatment. For a flow of 24000 m^3/d, four 25-kilowatt submersible pumps (three duty and one standby) will be installed. The size of the lift station is expected to be approximately 5 m x 3 m.

In addition to the new lift station, replacing the screens, and retrofitting the grit system, a new engineered odour control system consisting of a biotrickling filter (for hydrogen sulfide removal), a biofilter (for volatile organics) and other odour compounds removal, and a granular activated carbon filter (for polishing) will be included to minimize the release of odours to the surrounding area. A new air conditioning system will be installed to keep the headworks building cool, minimizing the time doors are kept open resulting in the release of odour. The screenings from the headworks will be stored in a new enclosed container ventilated to odour control.

4.2 Secondary Treatment

For the purpose of this report two representative secondary treatment options were considered. A conventional activated sludge system configured as a four-stage Bardenpho system, and a more compact membrane bioreactor (MBR) system. Both systems, along with a high-level process comparison, are briefly described below.

4.2.1 Four Stage Bardenpho Activated Sludge

The four-stage Bardenpho configuration is an advanced activated sludge process that is arranged in a series of four anoxic/aerobic zones with an internal recycle loop from the first aerobic zone back to the first anoxic zone. The four-stage Bardenpho configuration is intended to meet lower total nitrogen (TN) concentrations (< 5 mg/L) than possible with other configurations. Approximately 80% of the TN is removed in the first anoxic/aerobic zones, while approximately 10% to 15% is removed in the second anoxic/aerobic zones. Overall, typical effluent TN concentrations are around 3 to 5 mg/L. Addition of an external carbon source can be employed if influent nitrogen concentrations are higher than the concentrations associated with typical municipal wastewater. This process configuration is one of the most common used to meet tight TN limits.

The bioreactor will be constructed as two parallel trains, each with a dimension of 10 m x 40 m x 5.5 m depth. The total nominal liquid volume needed is approximately 4500 m^3. Two secondary clarifiers, each with a diameter of 25 m, would be required.

4.2.2 Membrane Bioreactors

Membrane bioreactors are a combination of suspended growth-activated sludge and membrane filtration. Since secondary clarifiers are not used in this configuration, the need for sludge settling is eliminated, which allows the reactors to be designed smaller, thus minimizing their footprint. Mixed liquor concentrations can be as high as 9000 mg/L, which means that bioreactors for MBRs are approximately 50% the size of conventional activated sludge reactors. For the SCWRRF, the bioreactors would be approximately 2500 m^3. To protect the membranes from damage, most MBR vendors require two-dimensional screening and opening sizes of less than 2 mm to be provided upstream of the membranes.

To separate biological solids from the mixed liquor, MBRs use membranes. Based on conventional flux rates, three membrane trains will be required, and each train will house six cassettes. The membrane cassettes will occupy a footprint of approximately 10 m x 10 m. In addition to the membrane cassettes, air scour blowers to prevent fouling of the membranes, backpulse tanks, and cleaning chemicals (citric acid and sodium hypochlorite) will be required. The total footprint, including all ancillary items required by the membrane system, will be approximately 30 m x 20 m. Therefore, the total footprint of the membrane option would be about 800 m^2 versus 1400 m^2 for the conventional activated sludge option. Membrane cassettes typically last approximately 10 years, and then will need to be replaced. The replacement cost of the SCWRRF membrane cassettes would be approximately $1.5 million (US).

The difficulty with meeting tight TN limits (i.e., < 5 mg/L) with MBRs is managing the high dissolved oxygen concentrations in the recycle flows. To prevent fouling of the membranes in the MBRs, the mixed liquor is recirculated at a rate of 4Q (or 36000 m^3/d). This flow is rich in oxygen due to the aeration provided by the air scour blowers. If this flow is returned to the anoxic zones in the bioreactor, it can create aerobic conditions, which then prevent TN from being removed. Therefore, a more complicated arrangement would need to be designed to manage these high oxygen levels, or alternatively a carbon source such as methanol would need to be used. As mentioned, MBRs require blowers to provide air scour to the membrane tanks to prevent membrane fouling. Therefore, while MBRs do have a smaller footprint, they use more energy than a conventional activated sludge plant.

4.2.3 Secondary Treatment Comparison

A comparison of the four-stage Bardenpho conventional activated sludge with an MBR system is shown in Table 4-1.

Table 4-1: Summary of the Biological Secondary Treatment Options

Process Type	Strengths	Weaknesses
Four-Stage Bardenpho – Conventional Activated Sludge	Has long track record Simple to operate. Consistent with other treatment plants in Barbados (commonality in training and parts). Low operational cost Ability to consistently meet < 5 mg/L TN.	Large footprint
MBR	Small footprint MBR components factory assembled – lower on-site labour costs. Eliminate the need for tertiary filters. Utilized for wastewater treatment by the private sector in Barbados	More complex operation More mechanical parts Higher operation cost Potential difficulty meeting TN< 5 mg/L. Chemicals required for cleaning. Ongoing membrane replacement costs. High level of pretreatment required. Impacted by oil and grease. Requires pumping to get flow out of the system, as compared to gravity (CAS). Higher capital cost for achieving biological nitrogen removal.

Based on the strengths and weaknesses listed above, it is recommended that a conventional activated sludge utilizing 4-stage Bardenpho process configuration be carried forward for further evaluation.

4.3 Filtration

Biological secondary treatment provides substantial removal of total suspended solids (TSS). However, additional suspended solids / turbidity removal steps coupled with disinfection processes are required to meet reuse water quality standards.

4.3.1 Disk Filtration

Disk filtration processes use cloth, stainless-steel mesh, or other materials as the filtration surface. The filter disks are arranged in various configurations, depending on the manufacturer, to form a filtration unit, which rotates at very low revolutions per minute. Disks are submerged in the water as the water flows by gravity through the filter surface to a collection header. The effluent turbidity rate is expected to be less than 2.2 NTU. Typical average backwash water use rates are less than 2% to 3% of the influent flow. The capital cost requirements for a disk filter is typically lower than for granular media filtration (GMF) and microfiltration (MF) systems.

4.3.2 Granular Media Filtration

The GMF process uses non-porous materials such as sand, anthracite, or other granular materials as the filtration medium. These filters are operated in gravity or pressure filtration mode. GMF is referred to as "multimedia" when more than one type of medium is used in the same bed. Bed depth generally ranges from 0.3 m to 1.5 m. Filters with several feet of media are referred to as deep bed filters. Deep bed filters offer enhanced reliability and suspended solids removal. Granular media filters include pulsed-bed rapid sand filters, dual media filters, deep bed mono medium filters, traveling bridge filters, and moving bed/continuous backwash filters. In all GMF systems, the filter bed is backwashed at regular intervals or continuously, depending on the GMF type, time of operation, water quality and/or head loss across the bed. A typical backwash volume is about 3 % to 5% of the filter influent flow. The backwash stream is returned to the headworks of the SCWRRF for treatment.

A well-designed and well-maintained dual-media or deep bed sand filtration system is capable of producing effluent with turbidity less than 2 NTU.

4.3.3 Low-Pressure Membrane Filtration

Low-pressure membrane filtration processes use polymeric microfiltration or ultrafiltration (MF/UF) membranes. The water being treated flows through the openings (termed "pores") in the membrane, and the membrane retains particles larger than the opening size. Typical microfiltration membranes have a pore size of 1 micron or less. Ultrafiltration membranes have a pore size of 0.1 micron or less. Ultrafiltration membranes are becoming more common in water reuse applications. A typical MF/UF system includes membrane trains and valve racks, chemical cleaning and neutralization systems, a chemical transfer system, a compressed air and air-scour system, and an overall control system.

In MBR configurations, polymeric membrane modules are typically submerged in the secondary biological treatment aeration tank, and filtered effluent is pulled across the membrane under vacuum. MBR configurations eliminate the need for secondary clarifiers and tertiary filters.

Membrane modules are backwashed to remove particles retained by the membrane. Typical backwash volumes for MF/UF system range from 2% to 4% of the influent flow. Presence of extracellular polymeric substances (EPSs) found in some secondary biological effluents can result in irreversible membrane fouling, which in turn results in: premature flux/throughput decline, reduced membrane flux, increased chemical cleans, and frequent membrane replacement.

To prevent fouling and thereby maintain performance, a membrane maintenance regimen includes specialized activities such as chemical clean-in-place (CIP) and enhanced backwashing. These maintenance activities make MBR and MF/UF systems more complex to maintain and operate than GMF systems.

4.3.4 Filtration Technology Comparison

Table 4-2 is a summary of the various options for the tertiary filtration process.

Table 4-2: Summary of the Tertiary Filtration Process Options

Filtration System Type	Strengths	Weaknesses
Disk Filter	Lowest capital cost Lowest energy cost Lower pumping and storage needs.	Inside-out filter configuration may require additional operations and maintenance needs compared to outside-in filter configuration.
Granular Media Filter (dual media sand filter or deep bed sand filter)	Typically lower effluent turbidities are achieved with well designed and operated dual media or deep bed sand filters.	Higher capital cost Higher operational cost Larger footprint Higher pumping and storage needs.
Granular Media Filter (continuous backwash media/sand filter)	Relatively lower capital cost.	Moderately effective in producing low-turbidity water. Higher operations and maintenance needs.
UF/MF/MBR	High-quality effluent (less than 0.2 NTU) even during upsets.	Highest capital and operating cost.

Based on the strengths and weaknesses listed above, it is recommended that a disk filtration process be carried forward for further evaluation.

4.4 Disinfection

Pathogen removal/ inactivation is a foremost requirement for any water reclamation project.

4.4.1 Chlorination

Chlorination is the most common disinfectant and has the longest track record at WRRFs for pathogen control. Chlorine is now known to produce potentially carcinogenic DBPs with the bulk organics present in the water, and these bulk organics include trihalomethanes (THMs) and haloacetic acids (HAAs). Both THMs and HAAs are included in drinking water standards. Therefore, use of chlorination should be minimized to the extent feasible. However, chlorination can produce a chlorine residual that can reduce biofouling in conveyance pipes and recharge wells. Thus, chlorination has a place in water reclamation projects, but generally not as the primary disinfectant.

4.4.2 UV Disinfection

Two types of ultraviolet irradiation systems are used in water reclamation applications: (1) disinfection systems and (2) advanced oxidation systems. The UV dose required for advanced oxidation is about five to seven times higher than the UV dose required for disinfection. Therefore, only UV disinfection in the context of pathogen inactivation is discussed in this section.

Pathogen inactivation in UV disinfection systems is achieved by disruption of nucleic/genetic material (DNA and RNA). In reuse applications, UV systems are employed in two configurations: open-channel systems and closed-pipe systems. Based on the type of UV lamp being used, systems can be classified as low-pressure and medium-pressure UV lamp systems. Because low-pressure lamps emit UV light at 253.7 nm, which is found to be effective for disinfection, low-pressure lamp systems are widely used compared to medium-pressure systems. Open channel system with low-pressure UV lamps is considered for this project.

The germicidal effectiveness of UV depends on several factors: UV transmittance of the water being treated, UV dose, presence of particles that can shield pathogens from UV, length of time a microorganism is exposed to UV, and power fluctuations of the UV source that impact its wavelength. Reliability and performance of UV disinfection systems are improved if the UV influent is subjected to a robust secondary biological treatment and a filtration step. The advantages of using UV disinfection include: DBPs are not formed during disinfection, and disinfection performance is not generally impacted by the presence of low levels of bulk organics.

4.4.3 Disinfection Technology Comparison

Table 4-3 summarizes the strengths, weaknesses, and secondary benefits of the different disinfection processes.

Table 4-3: Comparison of Disinfection Process Options

Disinfection Process Type	Strengths	Weaknesses
Chlorine	Has longest track record. Provides disinfectant residual.	Generates disinfection byproducts such as THMs and HAAs. Adds salinity
UV	Provides excellent pathogen inactivation. Does not generate any disinfection byproducts.	Does not provide disinfectant residual.

Based on the strengths and weaknesses listed above, it is recommended that UV disinfection process be carried forward for further evaluation. Chlorination (i.e., chlorine residual) will be utilized for maintaining the pipelines and injection wells.

4.5 Advanced Water Purification Options (For Potable Aquifer Recharge Scenarios A and C)

Table 4-4 compares membrane-based (reverse osmosis) and carbon-based (ozone-biofiltration) advanced purification options for potable aquifer recharge (i.e., Scenarios A and C).

Table 4-4: Summary of Advanced Water Purification Options

Category	Membrane-Based (Reverse Osmosis)	Carbon-Based (Ozone-Biofiltration)
Refractory Organics (e.g., CECs)	Concentrated in brine stream.	Degraded and/or adsorbed
Reject/Side Streams	Some	None
Total Dissolved Solids	Concentrated in brine stream.	Unchanged
Corrosivity	Increased	Unchanged
Net Total Organic Carbon Removal	Limit of Technology ≤0.5 mg/L.	Function of carbon change-out frequency.
Energy, Maintenance, & Capital Cost	Highest on all accounts.	Substantial Advantage

Based on the strengths and weaknesses listed above, it is recommended that RO be carried forward for further evaluation, as applicable, for the potable water aquifer recharge scenarios (Scenarios A and C).

4.6 Side Stream Salinity Reduction Options (For Non-Potable Reclamation Scenarios A1 and B)

Table 4-5 is a summary of considerations for the evaluation of salinity reduction options for maintaining TDS of less than 450 mg/L.

Table 4-5: Summary of Salinity Reduction Options

Category	Reverse Osmosis (RO)	Electrodialysis Reversal (EDR)
Effectiveness	Highly effective in rejecting a wider range of salts.	Moderately effective in rejecting salts.
Reject/ Side Streams	Some	Some
Footprint	Smaller footprint	Relatively large footprint
Pretreatment Requirements	UF/MF	GMF/MF/UF
Energy, Maintenance, & Capital Cost	Moderate	High

Based on the strengths and weaknesses listed above, it is recommended that RO be carried forward for further evaluation, as applicable, for the non-potable water reclamation scenarios (Scenarios A1 and B).

4.7 Solids and Residuals Handling

4.7.1 Thickening

To minimize foam and scum buildup on the bioreactors, surface wasting will be installed. Waste-activated sludge (WAS) will be removed from the surface of the final aeration zone in the bioreactor. This method is more accurate than return activated sludge (RAS) wasting because it is a volumetric calculation. For example, if a 10-day solids retention time (SRT) is needed, 10% of the bioreactor volume is wasted. It is also an effective means of controlling scum because it is preferentially wasted from the bioreactor.

Of the alternatives available for WAS thickening (dissolved air flotation [DAF], centrifuge, gravity belt, rotary drum), most are hydraulically limited, except for DAF. For example, centrifuge suppliers recommend pre-thickening of mixed liquor prior to centrifuge thickening. DAF on the other hand is solids limiting, and therefore is suitable for high flow, and low concentration of mixed liquor wasting. Therefore, DAF thickening is recommended for the SCWRRF.

4.7.2 Digestion

The primary purpose of digestion is to produce biosolids that are stabilized and suitable for various disposal options. In the case of the SCWRRF, since all the sludge produced will be in the form of secondary waste-activated sludge (i.e., no primary sludge) it is recommended that aerobic digestion be implemented. In the U.S., EPA Part 503 Biosolids Rule regulations require that 35% volatile solids reduction be obtained to meet Class B vector attraction reduction requirements.

For the SCWRRF, it is assumed that the minimum digester temperature will be 26° C. This requires an aerobic digester retention time of 40 days to meet Class B pathogen reduction criteria. The DAF thickener will produce solids at concentration of about 3%. For staged aerobic digester operation (i.e., two digesters) the volume can be reduced by about 30% (40 storage days can be reduced to 28 storage days). Therefore, two 13-meter digesters will be required for the SCWRRF.

4.7.3 Dewatering

Dewatering of digested solids will be accomplished using drying beds. Drying beds are one of the oldest methods of dewatering and are simple to operate and less sensitive to variations in influent loads. They are less automated and have lower capital and operational costs than mechanical systems. However, they do require large areas and are therefore best suited to smaller facilities. Typical loading rates for sludge drying beds range from 50 to 125 kg/m^2-yr for open beds. Based on the solids production for the SCWRRF, this would require a sludge bed area of approximately 75 m x 75 m.

5. Water Reclamation Scenario Project Elements

5.1 Process Flow Diagrams

For all scenarios, there is a common portion of treatment from the headworks through UV disinfection, which is described in the following two paragraphs. The influent flow will be received by the headworks and conveyed to the lift station after undergoing screening and grit removal. From the lift station, the flow will be pumped to the channel upstream of the CAS systems (two operating in parallel), where the flow from the headworks and the RAS will be combined before entering the CAS system. Treatment through CAS will remove a portion of the carbon and nitrogen present in the wastewater. From the CAS, water will flow by gravity to the secondary clarifiers. The secondary clarifiers will remove a large portion of the solids formed during the biological treatment. Through a dedicated pump station, the secondary clarifier underflow will be recirculated to the CAS as RAS. The waste activated sludge will be diverted to a dissolved air flotation (DAF) thickener, and after thickening to the aerobic digester. The sludge from the aerobic digester will be pumped to the drying beds and, after drying, it will be collected for off-site disposal.

The effluent from the secondary clarifier will be conveyed by gravity to tertiary disk filters or diverted to the marine outfall when the flow exceeds 18000 m^3/day. The tertiary filters will remove residual solids from the secondary clarifier. The effluent from the disk filters will flow by gravity to the UV system. The UV system will provide disinfection by inactivating pathogens. Downstream of the UV system, the disinfected water will be collected in an underground basin that will function as a wet well for pumps that will feed the advanced water treatment (AWT) facility. Excess water will discharge to the marine outfall. There will also be the option to feed a storage tank when flows to the treatment plant are low.

Scenarios A Process Flow Diagram

In Scenario A (Figure 5-1), the effluent from secondary and tertiary treatment is processed through the AWT facility for potable aquifer recharge. The UV-treated water will be first pumped through a strainer and then through the MF or UF skids. The strained and MF/UF treatment will remove fine particulates before the RO. After MF/UF treatment, the flow will be collected in an MF/UF break tank that will provide a point for hydraulic control and simplify controls to feed the RO system.

From the MF/UF break tank, water will be pumped through the RO cartridges. The cartridges protect the RO from fine particulate and biological growth that may have developed in the pipes feeding the RO. If needed, RO pretreatment chemicals such as sulfuric acids and antiscalants will be added (an inline static mixer should be provided). A small dose of chloramines is also recommended to limit biological growth in the piping feeding the RO.

After the addition of pretreatment chemicals, the flow will be pumped through another set of high-pressure pumps to the RO skids. The RO removes organic and inorganic constituents, including salts. The reject brine from the RO will be conveyed to the marine outfall. A portion of the RO permeate will be blended with filtered disinfected reclaimed water to achieve TDS of less than 450 mg/L for irrigation end use.

For potable aquifer recharge flows the RO permeate will be injected with sodium hypochlorite and then treated to the UV/ Advanced Oxidation Process (AOP) for the additional removal of recalcitrant organic compounds that may have passed through the RO. After the UV/AOP treatment, the product water will undergo chemical stabilization to restore pH and alkalinity, and to limit corrosive properties. The suggested treatment includes decarbonation (carbon dioxide removal), treatment of a side stream of the RO-treated water through a calcite bed for remineralization, addition of sodium hydroxide for pH control, and final adjustment of sodium hypochlorite (if needed) to provide a chlorine residual through the pipeline.

Treated water after stabilization will be collected in a storage tank that will function as a wet well for the pumps feeding the potable aquifer recharge pipeline.

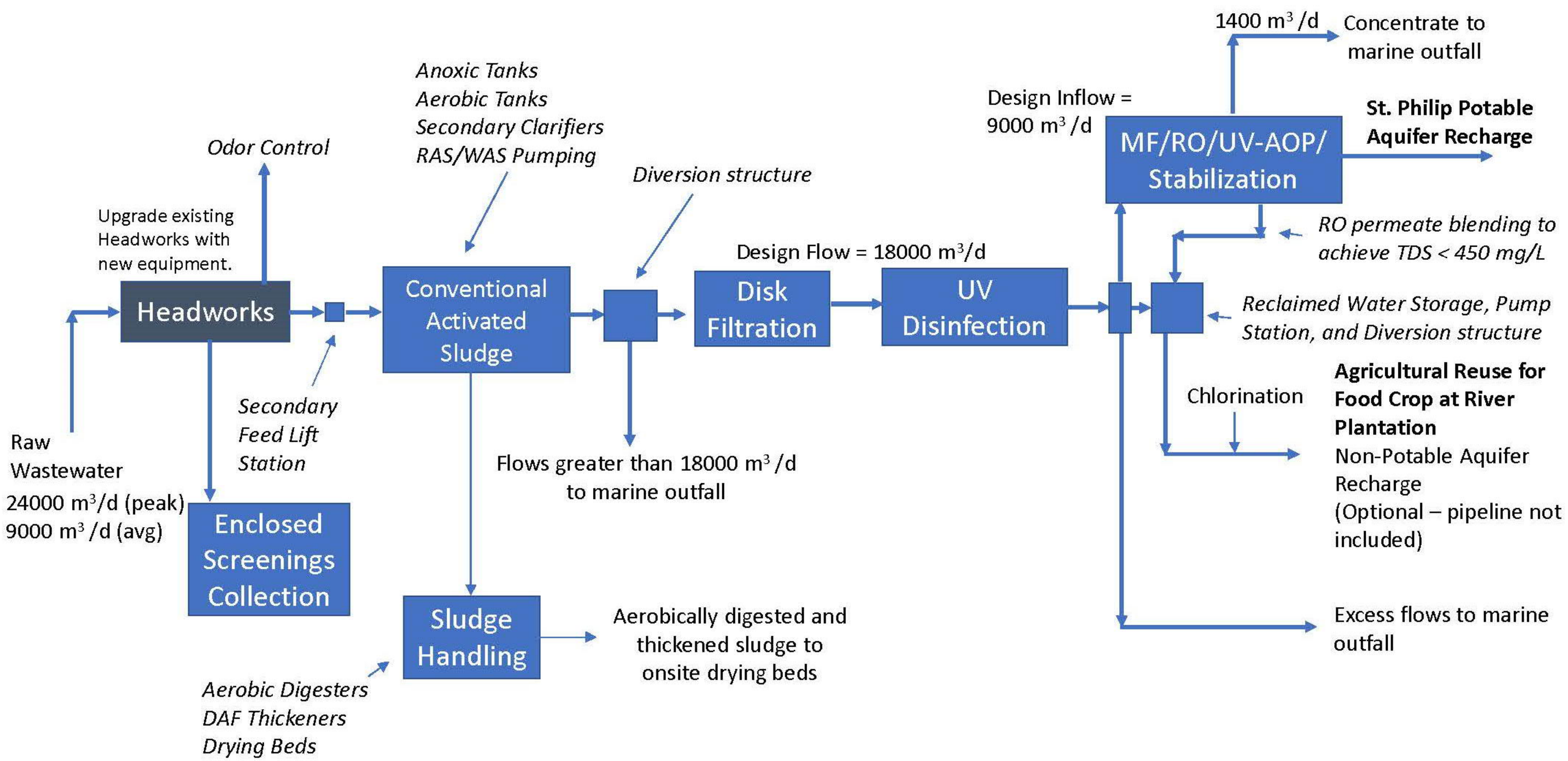


Figure 5-1: Scenario A Process Flow Diagram

Scenarios A1 Process Flow Diagram

In Scenario A1 (Figure 5.2), a side stream will be treated through RO to meet the 450 mg/L TDS limit for the product water. UV-treated water will be first pumped through a strainer and then through the microfiltration (MF) or ultrafiltration (UF) skids. This treatment will remove fine particulates before RO. After MF/UF treatment, the flow will be collected in an MF/UF break tank that will provide a point for hydraulic control and simplify controls to feed the RO system. From the MF/UF break tank, water will be pumped through the RO cartridges. The cartridges protect the RO from fine particulate and biological growth that may have developed in the pipes feeding the RO. If needed, RO pretreatment chemicals, such as sulfuric acids and antiscalants, will be added (an inline static mixer should be provided). A small dose of chloramines is also recommended to limit biological growth in the piping feeding the RO. After the addition of pretreatment chemicals, the flow will be pumped through another set of high-pressure pumps to the RO skids. In this case, the objective of the RO treatment is the removal of salts. The rejected brine from the RO will be conveyed to the marine outfall.

In this scenario, the chemical stabilization of RO permeate may not be required. If any chemical stabilization is required, passing a side stream of the RO-treated water through a calcite bed for remineralization should be sufficient.

In the end, RO permeate and UV-treated water will be blended in the pipe (using a static mixer) in approximated 3 RO / 2 UV ratio (assuming 1000 mg/L TDS in the UV-treated water). Sodium hypochlorite to provide residual disinfection should also be added at this stage. The blended water will be collected in a storage tank that will function as a wet well for the pumps feeding the non-potable aquifer recharge and irrigation pipeline.

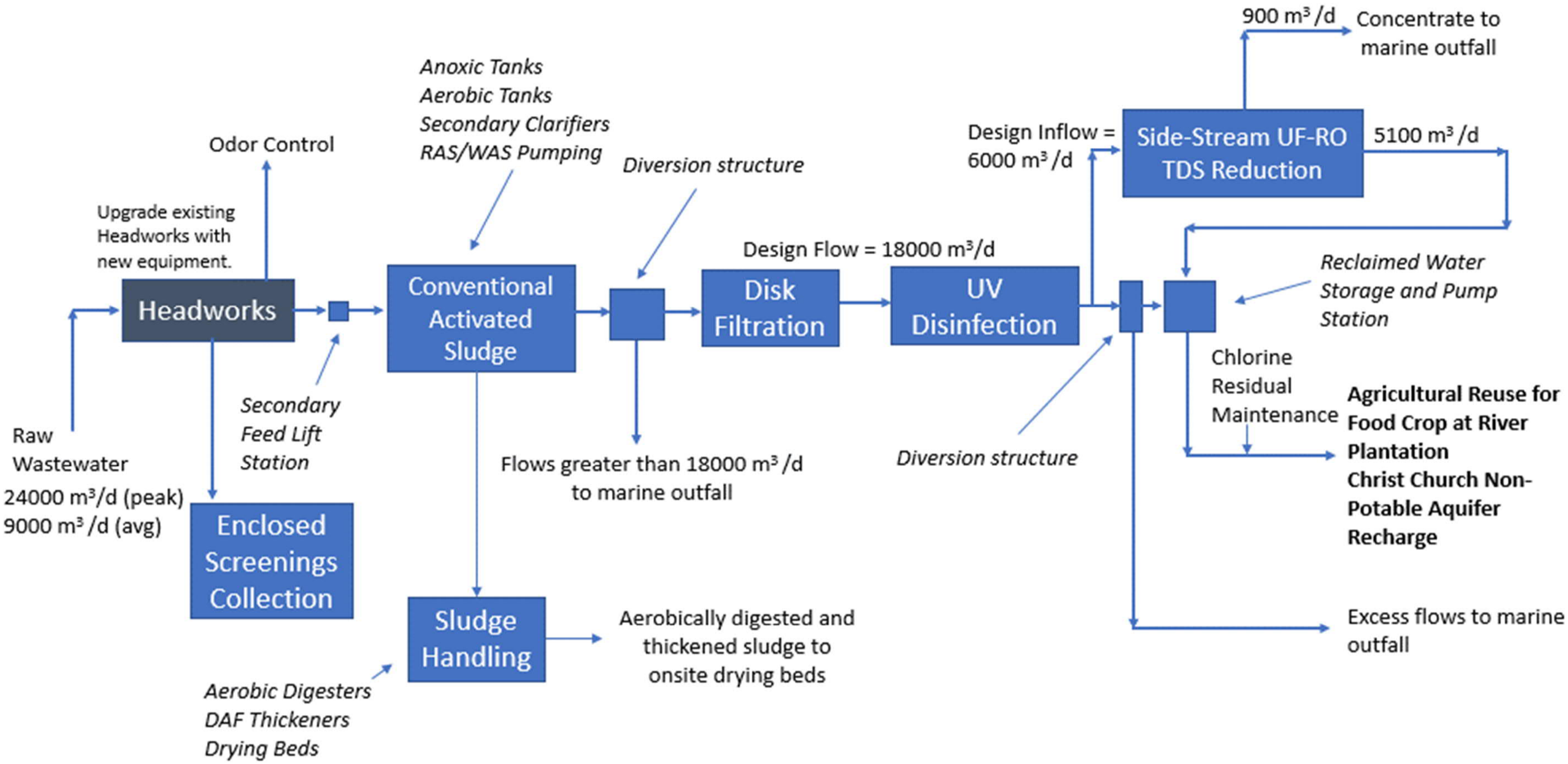


Figure 5-2: Scenario A1 Process Flow Diagram

Scenarios B Process Flow Diagram

In Scenario B (Figure 5-3)a side stream will be treated through RO to meet the 450 mg/L TDS limit, after blending, for the product water. UV-treated water will be first pumped through a strainer and then through the microfiltration (MF) or ultrafiltration (UF) skids. This treatment will remove fine particulates before RO. After MF/UF treatment, the flow will be collected in an MF/UF break tank that will provide a point for hydraulic control and simplify controls to feed the RO system. From the MF/UF break tank, water will be pumped through the RO cartridges. The cartridges protect the RO from fine particulate and biological growth that may have developed in the pipes feeding the RO. If needed, RO pretreatment chemicals, such as sulfuric acids and antiscalants, will be added (an inline static mixer should be provided). A small dose of chloramines is also recommended to limit biological growth in the piping feeding the RO. After the addition of pretreatment chemicals, the flow will be pumped through another set of high-pressure pumps to the RO skids. In this case, the objective of the RO treatment is the removal of salts. The rejected brine from the RO will be conveyed to the marine outfall.

In this case, the chemical stabilization of RO permeate may not be required. If any chemical stabilization is required, passing a side stream of the RO-treated water through a calcite bed for remineralization should be sufficient.

In the end, RO permeate and UV-treated water will be blended in the pipe (using a static mixer) in approximated 3 RO / 2 UV ratio (assuming 1,000 mg/L TDS in the UV-treated water). Sodium hypochlorite to provide residual disinfection should also be added at this stage. The blended water will be collected in a storage tank that will function as a wet well for the pumps feeding the non-potable aquifer recharge and irrigation pipeline.

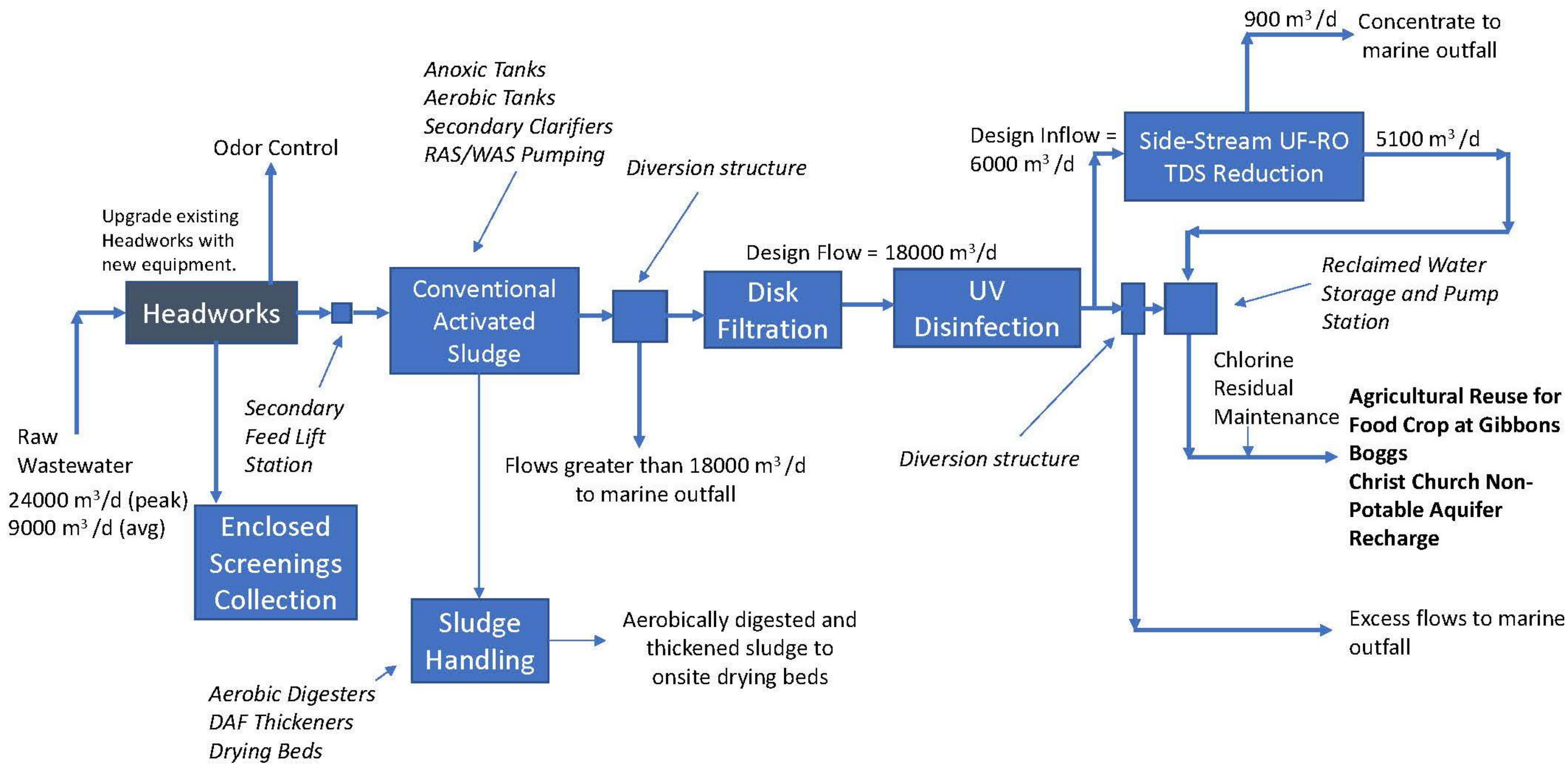


Figure 5-3: Scenario B Process Flow Diagram

Scenarios C Process Flow Diagram

As shown in Figure 5-4, the flow is processed through the AWT facility for potable aquifer recharge. The UV-treated water will be first pumped through a strainer and then through the MF or UF skids. The strained and MF/UF treatment will remove fine particulates before the RO. After MF/UF treatment, the flow will be collected in an MF/UF break tank that will provide a point for hydraulic control and simplify controls to feed the RO system. From the MF/UF break tank, water will be pumped through the RO cartridges. The cartridges protect the RO from fine particulate and biological growth that may have developed in the pipes feeding the RO. If needed, RO pretreatment chemicals such as sulfuric acids and antiscalants will be added (an inline static mixer should be provided). A small dose of chloramines is also recommended to limit biological growth in the piping feeding the RO.

After the addition of pretreatment chemicals, the flow will be pumped through another set of high-pressure pumps to the RO skids. The RO removes organic and inorganic constituents, including salts. The reject brine from the RO will be conveyed to the marine outfall. A portion of the RO permeate will be blended with filtered disinfected reclaimed water to achieve TDS of less than 450 mg/L for irrigation end use.

For potable aquifer recharge flows the RO permeate will be injected with sodium hypochlorite and then treated to the UV/ Advanced Oxidation Process (AOP) for the additional removal of recalcitrant organic compounds that may have passed through the RO. After the UV/AOP treatment, the product water will undergo chemical stabilization to restore pH and alkalinity, and to limit corrosive properties. The suggested treatment includes decarbonation (carbon dioxide removal), treatment of a side stream of the RO-treated water through a calcite bed for remineralization, addition of sodium hydroxide for pH control, and final adjustment of sodium hypochlorite (if needed) to provide a chlorine residual through the pipeline. Treated water after stabilization will be collected in an underground tank that will function as a wet well for the pumps feeding the potable aquifer recharge pipeline.

.

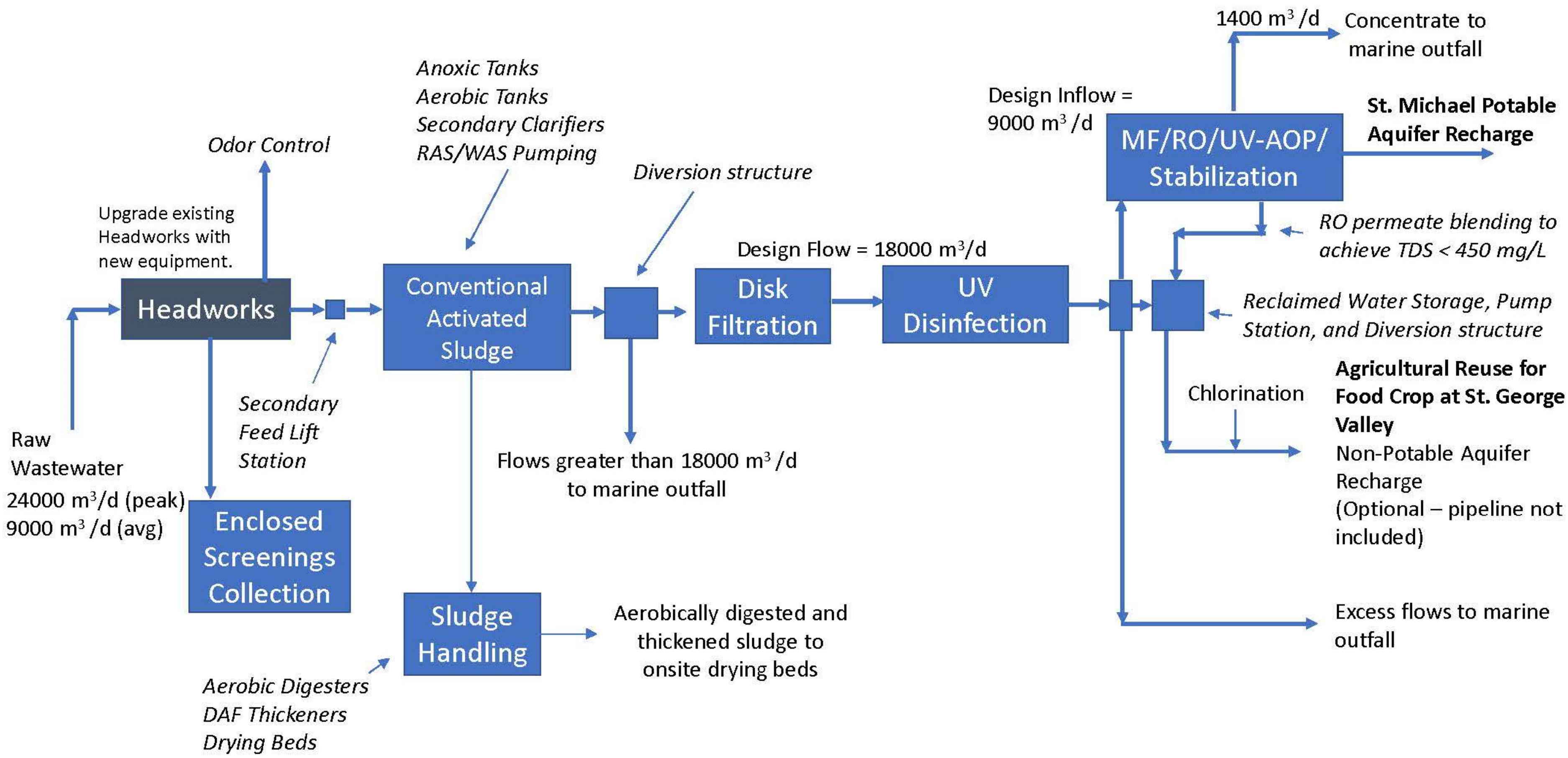


Figure 5-4: Scenario C Process Flow Diagram

5.2 Reclaimed Water Distribution System Concept

The conceptual reclaimed water distribution design for each scenario is summarized in Tables 5-1 through 5-4. Pipeline alignment for all four scenarios are shown in Figure 5-5. Conceptual design values summary includes the details of flowrates, nominal pipe diameter, pipe length, design pressure, pipe material, assumed number of trenchless crossings and an estimated number of appurtenances required.

Table 5-1: Scenario A – Reclaimed Water Distribution Conceptual Design Value

Parameter	Potable Aquifer Recharge Pipeline	Agricultural Irrigation Pipeline
Flow		
Flowrate	9000 m^3/d	9000 m^3/d
Water Quality	Purified water (advanced water treatment effluent)	Reclaimed water (filtered disinfected, blended effluent)
Pipeline		
Nominal Pipe Diameter	400 mm	400 mm
Design Pressure	1065 kPa	1070 kPa
Design Velocity	1.5 m/s	1.5 m/s
Pipe Material	400 mm HDPE DR 9	400 mm HDPE DR 9
Utilities Separation	1.5 m clear from all major utilities and 3 m clear from SS	
Pipe Length	13 km	19 km
Easements	Public ROW, Government ROW, existing easement	
Trenchless Crossing	Three (3) HDD crossings	Three (3)
Typical Pipe Depth	Open-Cut: 1.2 m + pipe diameter & bedding ~ 1.8 m Trenchless: 3 to 7 m	
Pipe Appurtenances	Isolation valves: 24 (every 450 m) ARV: 12 BOV: 5 Flowmeter: 1	40 20 5 1
Access Road		
Time of travel (min)	30	40

Table 5-2: Scenario A1 - Reclaimed Water Distribution Conceptual Design Value

Parameter	Agricultural Irrigation/Non-Potable Aquifer Recharge Pipeline
Flow	
Flowrate	12000 m^3/d
Water Quality	Reclaimed water (filtered, disinfected, blended effluent)
Pipeline	
Nominal Pipe Diameter	450 mm
Design Pressure	1070 kPa
Design Velocity	1.5 m/s
Pipe Material	450 mm HDPE DR 9
Utilities Separation	1.5 m clear from all major utilities and 3 m clear from SS
Pipe Length	18.5 km
Easements	Public ROW, Government ROW, existing easement
Trenchless Crossing	Four (4) HDD crossings
Typical Pipe Depth	Open-Cut: 1.2 m + pipe diameter and bedding ~ 1.8 m Trenchless: 3 to 7 m
Pipe Appurtenances	Isolation valves: 40 (every 450 m) ARV: 20 BOV: 5 Flowmeter: 1
Access Road	
Time of travel (min)	40

Table 5-3: Scenario B - Reclaimed Water Distribution Conceptual Design Value

Parameter	Agricultural Irrigation/Non-Potable Aquifer Recharge Pipeline
Flow	
Flowrate	12000 m^3/d
Water Quality	Reclaimed water (filtered, disinfected, blended effluent)
Pipeline	
Nominal Pipe Diameter	450 mm
Design Pressure	965 kPa
Design Velocity	1.5 m/s
Pipe Material	450 mm HDPE DR 13.5
Utilities Separation	1.5 m clear from all major utilities and 3 m clear from SS
Pipe Length	12.8 km
Easements	Public ROW, Government ROW, existing easement
Trenchless Crossing	Three (3) HDD crossings
Typical Pipe Depth	Open-Cut: 1.2 m + pipe diameter & bedding ~ 1.8 m Trenchless: 3 to 7 m
Pipe Appurtenances	Isolation valves: 24 (every 450 m) ARV: 12 BOV: 5 Flowmeter: 1
Access Road	
Time of travel (min)	30

Table 5-4: Scenario C - Reclaimed Water Distribution Conceptual Design Value

Parameter	Potable Aquifer Recharge Pipeline	Agricultural Irrigation Pipeline
Flow		
Flowrate	9000 m^3/d	9000 m^3/d
Water Quality	Purified water (advanced water treatment effluent)	Reclaimed water (filtered, disinfected, blended effluent)
Pipeline		
Nominal Pipe Diameter	350 mm	350 mm
Design Pressure	830 kPa	830 kPa
Design Velocity	1.5 m/s	1.5 m/s
Pipe Material	350 mm HDPE DR 13.5	same
Utilities Separation	1.5 clear from all major utilities and 3 m clear from SS	1.5 clear from all major utilities and 3 m clear from SS
Pipe Length	8.63 km	8.63 km
Easements	Public ROW, Government ROW, existing easement	Public ROW, Government ROW, existing easement
Trenchless Crossing	Two (2) HDD crossings	Two (2) HDD crossings
Typical Pipe Depth	Open-Cut: 1.2 m + pipe diameter & bedding ~ 1.7 m Trenchless: 3 to 7 m	Open-Cut: 1.2 m + pipe diameter & bedding ~ 1.7 m Trenchless: 3 to 7 m
Pipe Appurtenances	Isolation valves: 16 (every 450 m) ARV: 12 BOV: 5 Flowmeter: 1	Isolation valves: 16 (every 450 m) ARV: 12 BOV: 5 Flowmeter: 1
Access Road		
Time of travel (min)	20	20

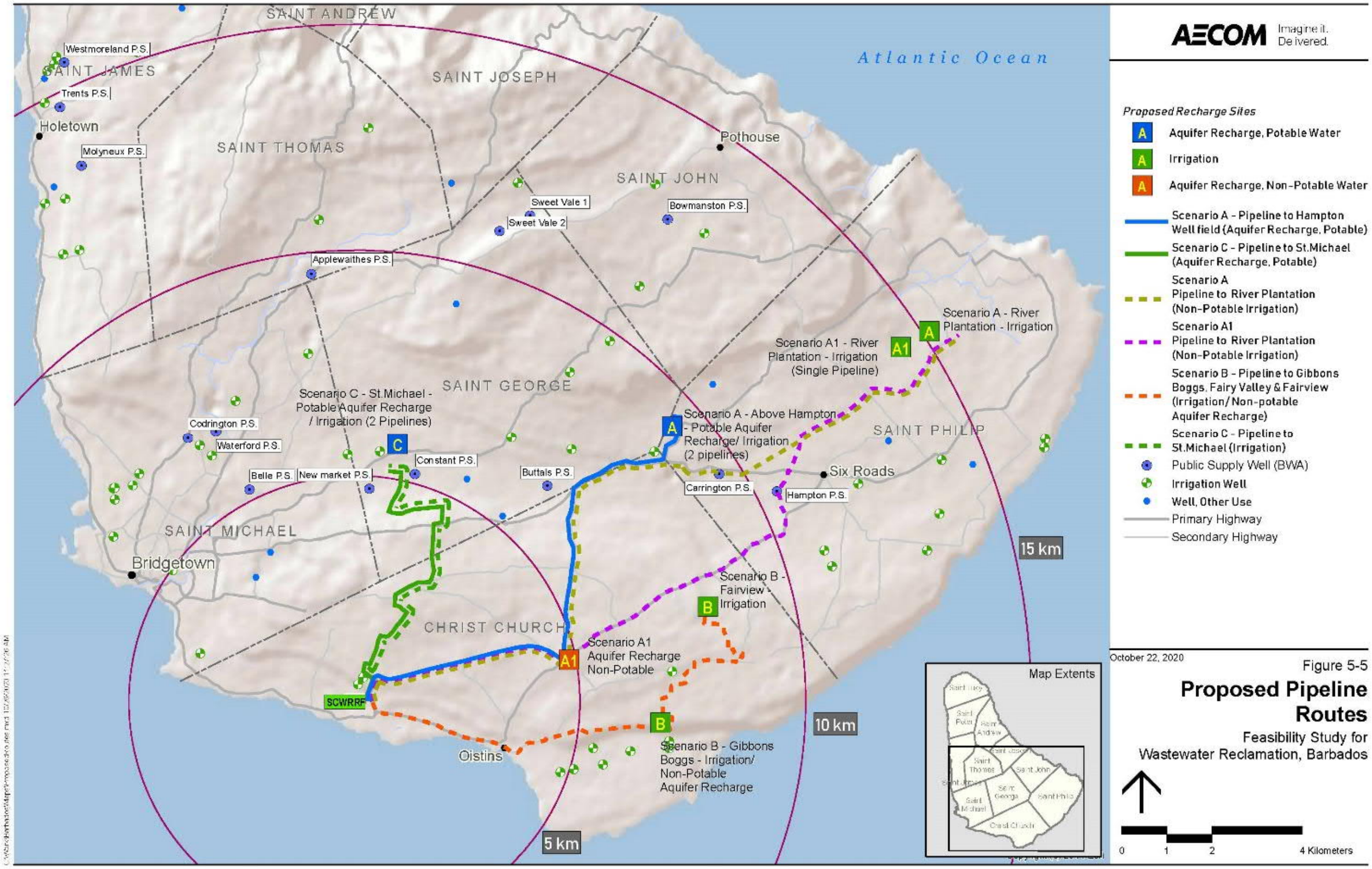


Figure 5-5: Proposed Pipeline Route – Scenarios A, A1, B & C

5.3 Recharge Injection Well Concept

The use of direct aquifer recharge using a recharge well system was determined to be the most efficient because nearly 100% of the reclaimed water can be used to recharge the regional ground water system. Indirect recharge methods, such as infiltration galleries or retention ponds, are not efficient because of high evapotranspiration rates and limitations to infiltration from thick soil with a high clay content (smectite) and the depth to static water levels (-43 m below land surface). Under these conditions, approximately 60% of the reclaimed water could be lost before it reaches the ground water surface.

The conceptual design of the recharge well system was developed using National Sanitation Foundation (NSF), American Water Works Association (AWWA), American Society for Testing and Materials (ASTM) standards, and EPA Class V injection well standards. The recharge wells will consist of a nominal 450-mm (18-inch) diameter polyvinyl chloride casing installed to a depth of approximately 46 m (150 feet), depending on static water levels in the proposed areas. An open wellbore will be completed through the underlying karst aquifer to a total depth of up to 91 m (300 feet), which will provide as much as 46 m (150 feet) of open aquifer material to receive reclaimed water. The proposed recharge wellfield will consist of three primary recharge wells, each receiving approximately 3,000 m^3/day of available reclaimed water. Two additional recharge wells will be installed to provide operational flexibility during long-term recharge operations. This approach will allow individual wells to be rotated or taken offline to be serviced and will maintain an overall recharge capacity of 9,000 m^3/day.

A transfer pump and wet-well system will be used to take reclaimed water from the SCWRRF at the proposed site. This pumping system will be used to convey the water to individual recharge wells, using an optimal operational scheme. The wellhead of each recharge well will be sealed to allow flows to be pumped under low pressure conditions of 138 to 276 kPa (20 to 40 psi). The additional hydrostatic pressure will effectively convey the water into the karst aquifer, creating a mounding effect to the groundwater surface. This approach will allow the recharge water to flow as part of the regional groundwater system. The recharge wells will be backwashed on a regular basis (weekly) using an installed vertical turbine or submersible pump to remove particulate and suspended solids, thereby limiting conditions for biological growth. The produced water from backwashing operations will be routed back to the agricultural irrigation pipeline for reuse. The surface facilities needed to convey and control the water flow from the transfer pump/wet well will consist of steel pipe, automated flow valves, vacuum/air release valves, and flowmeters.

5.4 Flow Basis of Feasibility Evaluation

Table 5.5 shows the flow basis of the feasibility evaluation.

Table 5-5: Flow Basis of Feasibility Evaluation

Parameter	Scenario A	Scenario A1	Scenario B	Scenario C
ADWF, m^3/d	9000	9000	9000	9000
Preliminary/Secondary Treatment Capacity (i.e., PWWF), m^3/d	24000	24000	24000	24000
Filtration/Disinfection Capacity, m^3/d	18000	18000	18000	18000
Adv. Water Purification (UF-RO-UV AOP) Capacity, m^3/d (influent)	9000	N/A	N/A	9000
Side-Stream UF-RO Salinity System Capacity, m^3/d (influent)	N/A	6000	6000	N/A
Potable Recharge System Capacity, m^3/d	7600	N/A	N/A	7600
Potable Recharge System Min Flow, m^3/d	3000	N/A	N/A	3000
Agricultural Reuse System Instantaneous Capacity, m^3/d	Up to 9000	Up to 12000	Up to 12000	Up to 9000
Non-Potable Recharge Capacity, m^3/d	Up to 9000	Up to 12000	Up to 12000	Up to 9000

5.5 Project Elements Summary

Treatment requirements and project elements for four scenarios are summarized in Table 5-6.

Table 5-6: Treatment Requirements and Project Elements Summary

Scenario	Treatment	Conveyance	Recharge Wells
A	Upgraded Headworks; New Secondary Treatment; New Tertiary Filtration/Disinfection; New Advanced Purification System (UF-RO-UV AOP); and New Solids/Residual Handling.	New 400 mm pipeline for Potable Aquifer Recharge New 400 mm pipeline for Agricultural Irrigation.	5 recharge wells in potable aquifer in St. Philip, near Hampton. 4 Monitoring wells
A1	Upgraded Headworks; New Secondary Treatment; New Filtration/Disinfection; New Salinity Reduction System (Side-Stream UF-RO); and New Solids/Residual Handling.	New 450 mm pipeline for Agricultural Irrigation and Non-Potable Aquifer Recharge.	5 recharge wells in non-potable aquifer in Christ Church. 4 Monitoring wells
B	Upgraded Headworks; New Secondary Treatment; New Filtration/Disinfection; New Salinity Reduction System (Side-Stream UF-RO); and New Solids/Residual Handling.	New 450 mm pipeline for Agricultural Irrigation and Non-Potable Aquifer Recharge.	5 recharge wells in non-potable aquifer near Gibbons Boggs. 4 Monitoring wells
C	Upgraded Headworks; New Secondary Treatment; New Filtration/Disinfection; New Advanced Purification System (UF-RO-UV AOP); and New Solids/Residual Handling.	New 350 mm pipeline for Potable Aquifer Recharge New 350 mm pipeline for Agricultural Irrigation.	5 recharge wells in potable aquifer in St. Michael near New Market & Constant. 4 Monitoring wells

6. Relative Life Cycle Costs for Comparison of Water Reclamation Scenarios

6.1 Relative Capital Costs

The American Association of Cost Engineering (AACE) International Cost Classification System - As Applied in the Engineering, Procurement and Construction for the Process Industries has been used for this project. This classification system has now been adopted by the American Society for Testing and Materials (ASTM) and is designated as E 2516-06. The class of cost estimates and the project definition requirements for the new ASTM standard are summarized in Table 6-1.

Table 6-1: ASTM E 2516-06 Cost Estimate Classifications

Estimate Class	Level of Project Definition	End Usage	Methodology	Process Industry Accuracy Range
Class 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	-20% to -50% +30% to +100%
Class 4	1% to 15%	Concept Study or Feasibility	Primarily Stochastic	-15% to -30% +20% to +50%
Class 3	10% to 40%	Budget, Authorization or Control	Mixed but Primarily Stochastic	-10% to -20% +10% to +30%
Class 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	-5% to -15% +5% to +20%
Class 1	50% to 100%	Check Estimate of Bid/Tender	Deterministic	-3% to -10% +3% to +15%

The level of project definition for this pre-feasibility study is consistent with a Class 5 estimate. As such the relative cost estimates relied primarily on stochastic or factored cost estimates in which estimates were derived by applying standard factors or other parametric variables, such as the plant flow rate or pipe length.

The relative capital cost estimates are based on the following assumptions:

- RO concentrate will be disposed of via Needham’s point 1.2 km long sea outfall.
- Dewatered and dried sludge will be hauled away.
- Contingency appropriate for Class 5 estimate has been included.
- BWA’s contingency is not considered.
- BWA costs, such as interest payments on any loans, are not included.
- The impact of tariffs or trade wars on the construction cost are not considered.

There are several factors affecting the cost estimate that cannot readily be forecasted. These include the volume of work in hand or in prospect for contractors and suppliers at the time of the construction work, future labor contract settlements, labor availability, foreign currency exchange rates, import tariffs, and escalation rates.

Relative Operating and Maintenance Costs

As with the relative capital cost estimates, the relative operating costs were derived from stochastic or factored cost estimates, primarily on stochastic or factored cost estimates in which estimates were derived by applying standard factors or other parametric variables, such as the plant flow rate or pipe length. The relative operating costs are equivalent to Class 5, with the same accuracy range. The relative operating and maintenance costs are all in terms of 2020 US dollars and based on assumption that operation commences in 2022.

Relative Life Cycle Costing

The relative life cycle costs were derived from the capital and the operating and maintenance costs, and were based on the following assumptions to develop the present worth:

- Discount rate of 3%
- Time period of 20 years

Table 6-2: Summary of Relative Life Cycle Costs

Item	Scenario A	Scenario A1	Scenario B	Scenario C
Secondary Treatment ADWF	9000 m^3/d	9000 m^3/d	9000 m^3/d	9000 m^3/d
Secondary Treatment PWWF	24000 m^3/d	24000 m^3/d	24000 m^3/d	24000 m^3/d
Filtration and Disinfection Design Flow	18000 m^3/d	18000 m^3/d	18000 m^3/d	18000 m^3/d
Advanced Purification Design Influent Flow	9000 m^3/d	0	0	9000 m^3/d
Potable Aquifer Recharge Pipeline Flow	9000 m^3/d	0	0	9000 m^3/d
Non-Potable Reclamation Flow	9000 m^3/d	12000 m^3/d	12000 m^3/d	9000 m^3/d
Purified Water Pipeline Length	12.7 km	0	0	8.6
Purified Water Pipeline Size	400 mm	0	0	350 mm
Reclaimed Water Pipeline Length	19 km	19 km	12.8 km	8.6 km
Reclaimed Water Pipeline Size	400 mm	450 mm	450 mm	350 mm
Relative Capital Cost	**1.38**	**1.06**	**1.00**	**1.23**
Relative 20-year O&M Cost	**1.24**	**1.03**	**1.00**	**1.21**
Relative Total 20-Year Lifecycled Cost	**1.32**	**1.05**	**1.00**	**1.22**

7. Triple Bottom Line Analysis and Selection of Preferred Options

7.1 Screening-Level Qualitative Triple Bottom Analysis Evaluation Factors

A triple bottom line (TBL) analysis for potential impacts of water reclamation on the region is discussed below. The TBL framework is used to evaluate the social, environmental, and financial impacts of water reclamation scenarios. Evaluation factors used in TBL analysis-based are summarized in Table 7-1.

Table 7-1: Triple Bottom Line Evaluation Factors

TBL Category	Factors Considered
Social	Public Health Risk/Regulatory Compliance
	Economic Boost/Food Security
Environmental	Potential Impacts to Marine Environment
	Potential Impacts to Groundwater Resources
Financial/Institutional	Relative Operation and Maintenance Costs
	Relative Capital Costs of Treatment Facility Upgrades

7.2 Triple Bottom Line Analysis of Water Reclamation Scenarios

Triple bottom line analysis of South Coast Water Reclamation Scenarios was conducted in a collaborative manner involving technical committee members (shown in Table 7-2) from various technical background and expertise.

Table 7-2: Triple Bottom Line Discussion Participant List

Dr. John Mwansa	BWA	Dr. Jamekal Andwele	BADMC
Mr. Roger Elie	BWA	Mr. Avery Green	PIU
Dr. Hugh Sealy	GOB	Mr. Steve Daniel	MOH
Dr. Beverly Wood	MOA/GAS	Dr. Leo Brewster	CZMU
Mr. Phil Beckles	MOA/GAS	Mr. Ricardo Marshall	MFEI
Mr. Alex Ifill Mr. Jaime Paul	BWA	Mr. Anthony Headley	EPD
Mr. Glenn Marshall	MOA	Dr. Vijay Sundaram Mr. Matt McTaggart	AECOM

BWA – Barbados Water Authority

GOB – Government of Barbados

MOA – Ministry of Agriculture and Food Security

MOA/GAS – Ministry of Agriculture and Food Security / Government Analytic Services

PIU – Public Investment Unit

MFEI – Ministry of Finance, Economic Affairs and Investment

CZMU – Coastal Zone Management Unit

MOH – Ministry of Health and Wellness

BADMC – Barbados Agricultural Development and Marketing Corporation

EPD – Environmental Protection Department

The results from the TBL analysis are presented below. Table 7-3 is a summary of the TBL analysis for Scenarios A, A1, B, and C.

Table 7-3:Summary of the Triple Bottom Line Analysis

		Scenario A		Scenario A1		Scenario B		Scenario C	
Potable Aquifer Recharge Location		St. Philip Aquifer		N/A		N/A		St. Michael Aquifer	
Non-Potable Aquifer Recharge Location		Optional		Christ Church Aquifer		Christ Church Aquifer		Optional	
Food Crop Irrigation Location		River Plantation		River Plantation		Gibbons Boggs/Fairy Valley Irrigation		St. George Valley Irrigation	
Social Factors	Potential Health Risks (Regulatory Compliance)	Designed to meet requirements	5	Designed to meet requirements	5	Designed to meet requirements	5	Designed to meet requirements	5
	Food Security (Additional Agricultural Expansion)	Addresses the need for water. Highest potential agricultural acreage	5	Addresses the need for water. Highest potential agricultural acreage	5	Moderate potential agricultural acreage	3	Relatively lower potential agricultural acreage	2
Environmental Factors	Impacts to Marine Environment	Reduces discharge of effluent to marine outfall but generates concentrate	3	Reduces discharge of effluent to marine outfall	4	Reduces discharge of effluent to marine outfall	4	Reduces discharge of effluent to marine outfall but generates concentrate	3
	Groundwater Impacts (Quality & Quantity)	Augments GW quantity, potentially enhances GW quality, and potentially reduces GW pumping	4	Augments GW quantity and potentially reduces GW pumping	3	Augments GW quantity and potentially reduces GW pumping	3	Augments GW quantity, potentially enhances GW quality, and potentially reduces GW pumping	4
Financial	Relative Capital Cost	1.38x	3	1.06x	4.5	1x	5	1.23x	3.5
	Relative Operational Cost	1.24x	3	1.03x	4.5	1x	5	1.21x	3.5
Total			23		26		25		21

7.3 Preferred Water Reclamation Option

Scenario A1 was selected as the preferred water reclamation option based on the triple bottom line analysis. Scenario A1 consists of non-potable water reclamation involving use of reclaimed water for agricultural food crop irrigation in River Plantation area and for non-potable aquifer recharge in Christ Church aquifer.

8. Preferred Water Reclamation Option Preliminary Process Design Criteria Summary

The following Scenario A1 project components will be further evaluated during the next phases of the project:

- Four-Stage Bardenpho process configuration*
- Disk filter**

* Conventional activated sludge biological nitrogen removal design discussions will include a side-by-side comparison of the four-stage and five-stage Bardenpho processes process configurations.

** Tertiary filtration design discussions will include a side-by-side comparison of disk and sand filtration options.

8.1 Preliminary Design Criteria

Preliminary design criteria for plant upgrades required for Scenario A1 are summarized in Tables 8-1 thru 8-11.

Table 8-1: Headworks Preliminary Design Criteria

Parameter	Value or Type	Notes
Design Flow	24000 m^3/d	Retrofit facility – conduct condition assessment.
New Screen (to replace existing medium screen)	6 mm	Replace existing medium screen with new 6 mm screen.

Table 8-2: Pre-Engineered Odour Control Unit (Headworks) Preliminary Design Criteria

Description	Unit	Value
Type/ Description		Pre-engineered Odour Control Package with recirculation pumps, foul air fans and a stack
Number of Units		1 Package
Recirculation Pumps		2 (1 Duty + 1 Standby)
Foul Air Fans		2 (1 Duty + 1 Standby)
Approximate Foul Air Flowrate	m^3/min	50
Foul Air Sources		Foul air from 1) influent wet well and pump headspace, 2) screen channels, 3) grit chambers and channels, 4) enclosed screenings and grit collection bins/unit, 5) secondary feed lift station headspace, and 6) other spaces in Headworks with air-raw wastewater interface.
Treatment Stages Required within the Filter		1st Stage – Bio trickling Filter for H_2S removal 2nd State – Biofilter for removal of VOCs and other organic odour causing compounds 3rd Stage – Granular Activated Carbon (GAC) for polishing
Approx. Length	m	13
Approx. Width	m	2.4
Approx. Height	m	2.9
H2S Removal Efficiency	%	99.5
Total Odour Removal Efficiency	%	95
Total Reduced Sulphur	%	90

Table 8-3: WRRF Feed Lift Station Preliminary Design Criteria

Parameter	Value or Type	Notes
Design Flow	24000 m^3/d	New submersible lift station to transfer flow to new WRRF.
Submersible Pumps *Sump Area*	4 x 25 kW 3 m x 5 m	
Influent flow metering	Magnetic flow meter	Influent pipe feeding biological treatment.

Table 8-4: Secondary Treatment Preliminary Design Criteria

Parameter	Value or Type
Design Flow (ADWF)	9000 m^3/d
Design Flow (PWWF)	24000 m^3/d
Total Reactor Volume	4500 m^3/d
Number of Trains	2
Volumes per Train, m^3	2250
Reactor width per train, m^3	10
Reactor length per train, m^3	40
Reactor depth, m^3	5.5
Design SRT, days	8
MLSS average, mg/L	3000
Secondary Clarifier, Number	2
Secondary Clarifier, Diameter	25
Flow metering	Magnetic flow meter

Table 8-5: Pre-Engineered DAF Sludge Thickener Preliminary Design Criteria

Description	Unit	Value
Type/Description		Pre-Engineered DAF Sludge Thickener of Stainless-Steel Construction
Maximum WAS Production	kg/d	1950
Maximum Loading Rate	$kg/m^2/h$	5
Number of DAF Thickener Packages		2
Number of DAF Recirculation Pumps		2 (1 per package unit)
Number of DAF Air Compressors		2 (1 per package unit)
Area per thickener	m^2	8
Length	m	2
Width	m	4

Table 8-6: Aerobic Digester Preliminary Design Criteria

Description	Unit	Value
Maximum WAS Production	kg/d	1950
Sludge Concentration	%	3
Number of Tanks		2
Number of Aeration Blowers		4 (3 duty + 1 standby)
Approx. Air Blower Power Requirements	kW	4 x 75
Diffuser Type		Duckbill
Quality of Biosolids		EPA 503 Class B Standards
SRT	d	28
Depth	m	5.5
Diameter	m	13

Table 8-7: Sludge Treatment Drying Beds Preliminary Design Criteria

Parameter	Unit	Value
Type/Description		Sludge Drying Beds with underdrain system
Digested Sludge Production	kg/d	1400
Loading Rate	Kg/m^2-yr	120
Area Required	m^2	4300

Table 8-8: Tertiary Filtration Preliminary Design Criteria

Disk Filters	Value/ Unit	Criteria/ Notes
Design Flow	18000 m^3/day	
Influent / Effluent Pipes	500 mm	
Configuration	Concrete tanks	Metal components 316 stainless for marine environment.
Number of Filters	3 (1 standby)	
Filter Tanks Dimensions	6 m x 3 m x 3.5 m	Length x width x depth
Cloth disc filters Mesh Size	5 microns	Recommended mesh size
Type	Outside-in cloth	
Number of Disks Recommended	14	Typical
Filter Area	70 m^3	Per Unit - Typical
Total Suspended Solids in Secondary Effluent	20 mg/L (max) / 10 mg/L (average)	Assumed quality for secondary effluent.
Max Solids Loading Rate	4.86 kg TSS/day/m^2	Max flow and TSS/ filter area
Effluent Turbidity	< 2 ntu 5 ntu < 10 ntu	24-hour average Not to exceed more than 5% of time. Not to exceed at any time.
Headloss @ Flow	45 cm (average) / 50 (max)	Preliminary
Maximum Hydraulic Loading Rate @ Average Flow	5.4 m/hr	in accordance with the State of California Title 22 Code of Regulations related to recycled water.
Aluminum Sulfate (Alum) feed System	Feed pump (1+1) 1000 L tote tank	If filter influent exceeds 5 NTU for more than 15 minutes.
Backwash System	Backwash pump and valves	

Disk Filters	Value/ Unit	Criteria/ Notes
Instrumentations	Level transmitter(s) Float switch(es) Vacuum transmitter(s) Turbidity meter(s)	For individual filter
Flow Meter	Magmeter	On combined filtered water effluent line.
Control Panel		Nema 4 x 316 stainless-steel enclosure.

Table 8-9: Disinfection System Preliminary Design Criteria

Parameter	Value or Type	Criteria/ Notes
Ultraviolet Light System		
Design Flow	18000 m^3/day	
Location	Downstream of disk filters	
Type	In-channel	Concrete channels
Number of channels	Two channels	
Lamp type	Low pressure high output	
Redundancy	One additional bank per channel	
Minimum UV Dose, mJ/cm^2	100	California Title 22
Minimum UV transmittance (% at 254 nm)	55	California Title 22
Effluent Total Coliform Concentration, CFU/1 mL	1	Barbados Water Reclamation Standards
Effluent coliphage inactivation	5-log MS2	California Title 22
Tertiary Water (UV Disinfected) Storage	Approximately 3-4 hours storage	Provide sufficient storage to handle daily flow variations.
Chlorine Feed System		
Point of application	Reclaimed water pipeline	Provide chlorine residual to minimize biological growth during conveyance.
Expected Dose	0.5 – 5 mg/L	
Target residual in pipeline	0.1 – 0.2 mg/L – free chlorine	
Chlorine Storage Tanks	TBD	Two tanks (3 weeks shelf life)

Table 8-10: Side-Stream MF/UF Followed by RO Preliminary Design Criteria

Parameter	Value or Type	Criteria/ Notes
MF/UF System		
MF/UF pump from Feed Tank	Centrifugal, end suction, horizontal	1 duty + 1 Standby
Design Flow	6400 m^3/day	
MF Automatic Backwashing Strainer	1 duty	300 microns
Design Flow, Influent/Permeate	6400 / 6300 m^3/day	Assume 99% recovery
Manual Basket Strainer	1 duty	250 microns
MF/UF Skids	2 duty	
Membrane Pore Size (approx.)	0.1 micron	Material PVDF
Design Flow, Influent/Permeate	6300 / 6000 m^3/day	Combined for two skids assume 95% Minimum Recovery
Membrane Filtration Break Tank	1	
Volume	150000 L	
RO System		
RO Transfer Pumps	2	1 per skid
Pump Type	Vertical turbine (can type), in-line	
Capacity of Pump	TBD	
RO Cartridge Filters	2 duty	one per RO skid
Number of Elements per Housing	176	
Element Rating	20 microns	
RO Pretreatment Facilities		
Threshold Inhibitor Addition System	100 %	Solution Strength
Number of Installed Totes	1 duty, 2 standbys	
Sulfuric Acid (if needed)	93%	Solution Strength
Number of Installed Totes	1 duty, 2 standbys	
RO Membrane Feed Pumps	2 duty	One for each skid
Pump Type	Vertical turbine (can type), in-line	VFD
Capacity of Pump	TBD	
RO Membranes and Skids		
Design Capacity, RO Permeate - per Train	85 %	

Parameter	Value or Type	Criteria/ Notes
Number of RO Trains	2 duty	
RO feed / permeate	6000 / 5100 m^3/day	Combined for two skids assuming 85% eff.
RO Reject Brine	900 m^3/day	assuming 85% eff.
RO / Tertiary Blending System		
In pipe static mixer	To mix RO and tertiary water	316 Stainless Steel
Blending tank	Concrete structure	Also used as wet well for agricultural reuse pump station.
Number of Installed Pumps	1	
Operating Configuration	1 duty, 1 standby	
Pump Type	Vertical turbine	
Capacity of Pump	9000 m^3/day	
Total Dynamic Head of Pump	TBD	
Motor Size of Pump	TBD	
Drive System for Pump	--	Variable speed

Table 8-11: Plant Water Pump Station Preliminary Design Criteria

Parameter	Unit	Value
Type/Description		Vertical Turbine
Number of Pumps		2 (1 Duty + 1 Standby)
Approx. Pump Power Requirements	kW	2 x 20
Area Required	m^2	15

Table 8-12: Reclaimed Water (Filtered and Disinfected Effluent) Storage Preliminary Design Criteria

Parameter	Unit	Value
Type/Description		Concrete or steel tank with cover
Approx. Total Storage Volume	m^3	2000
Approx. Storage Time at 8,000 m^3/d	hr	6

In the addition to items mentioned in the preliminary design criteria tables, the SCSTP upgrade to the SCWRRF will require, but will not be limited to, the following:

- Ancillary facilities include:
    - Chemical feed systems
    - Waste handling system
    - Plant drain system
    - Stormwater drain system
    - Emergency standby generator
- Automatic flow-proportional composite samplers (influent and effluent)

8.2 Details of Preferred Water Reclamation Option

A process flow diagram and a conceptual layout of the future SCWRRF site layout are shown in Figure 8-1 and Figure 8-2. The preferred pipe route for Scenario A1 is shown in Figure 8-3.

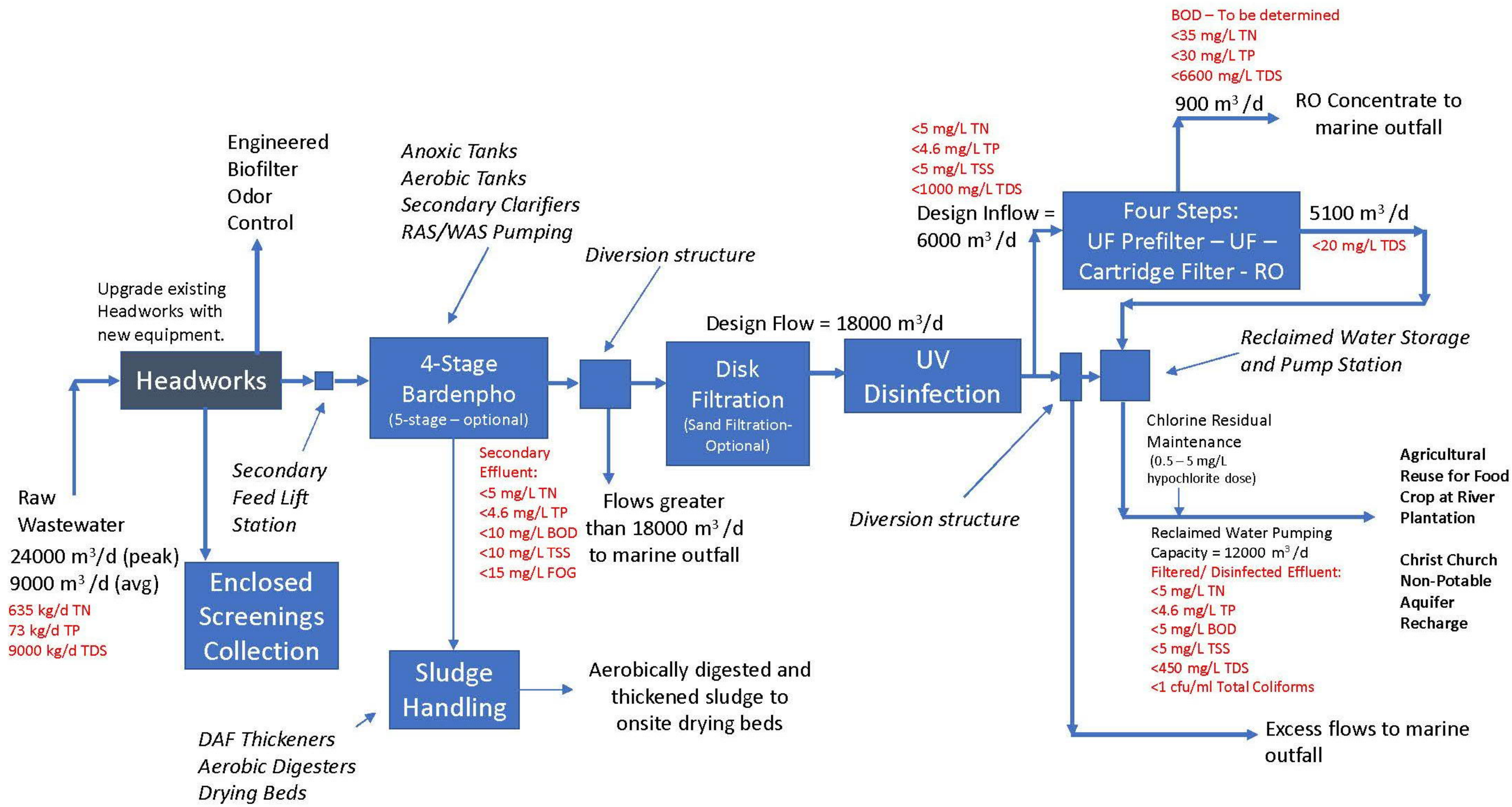


Figure 8-1: Preferred Option (Scenario A1)

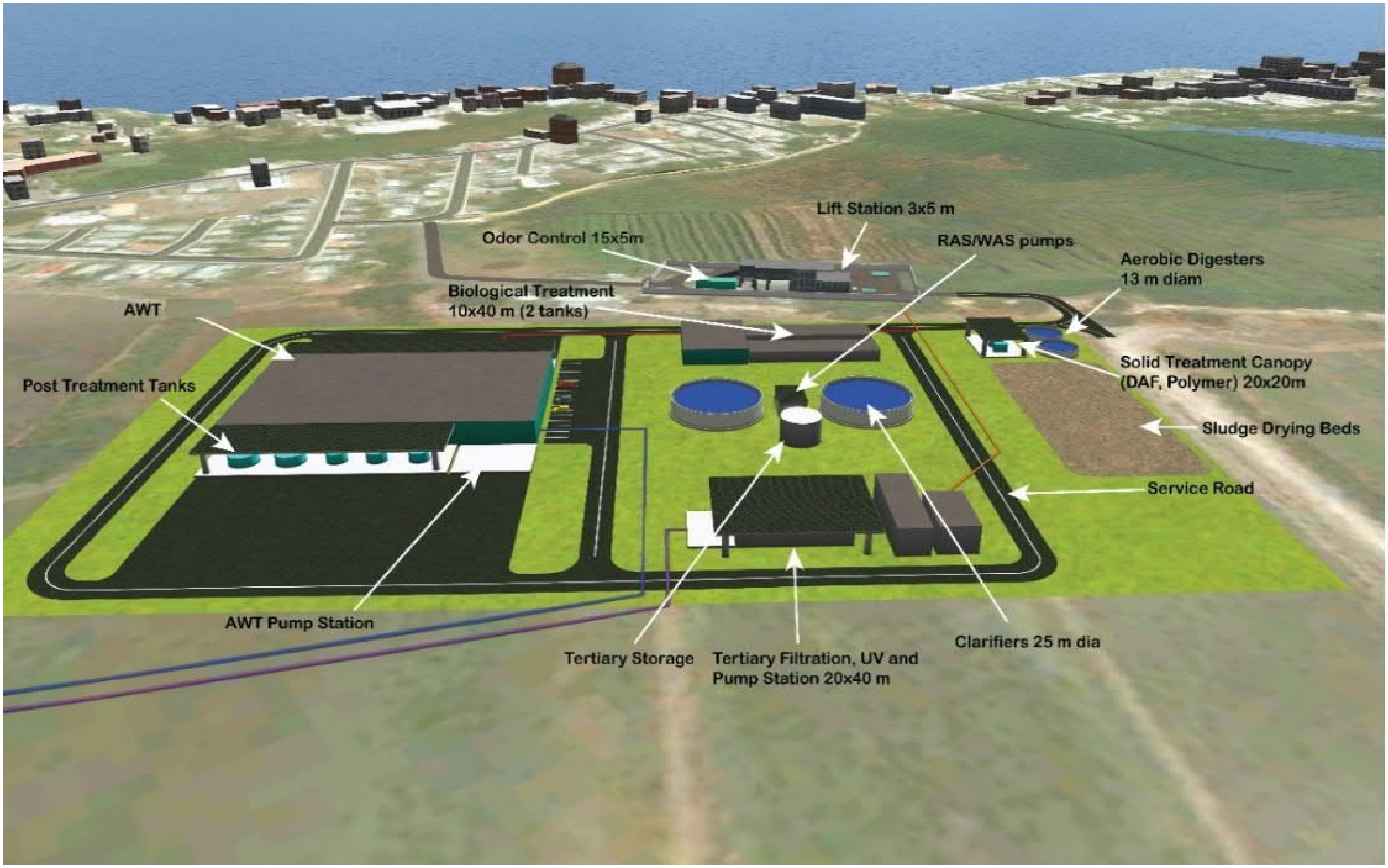


Figure 8-2: Conceptual Site Layout for Preferred Water Reclamation Option (Scenario A1)

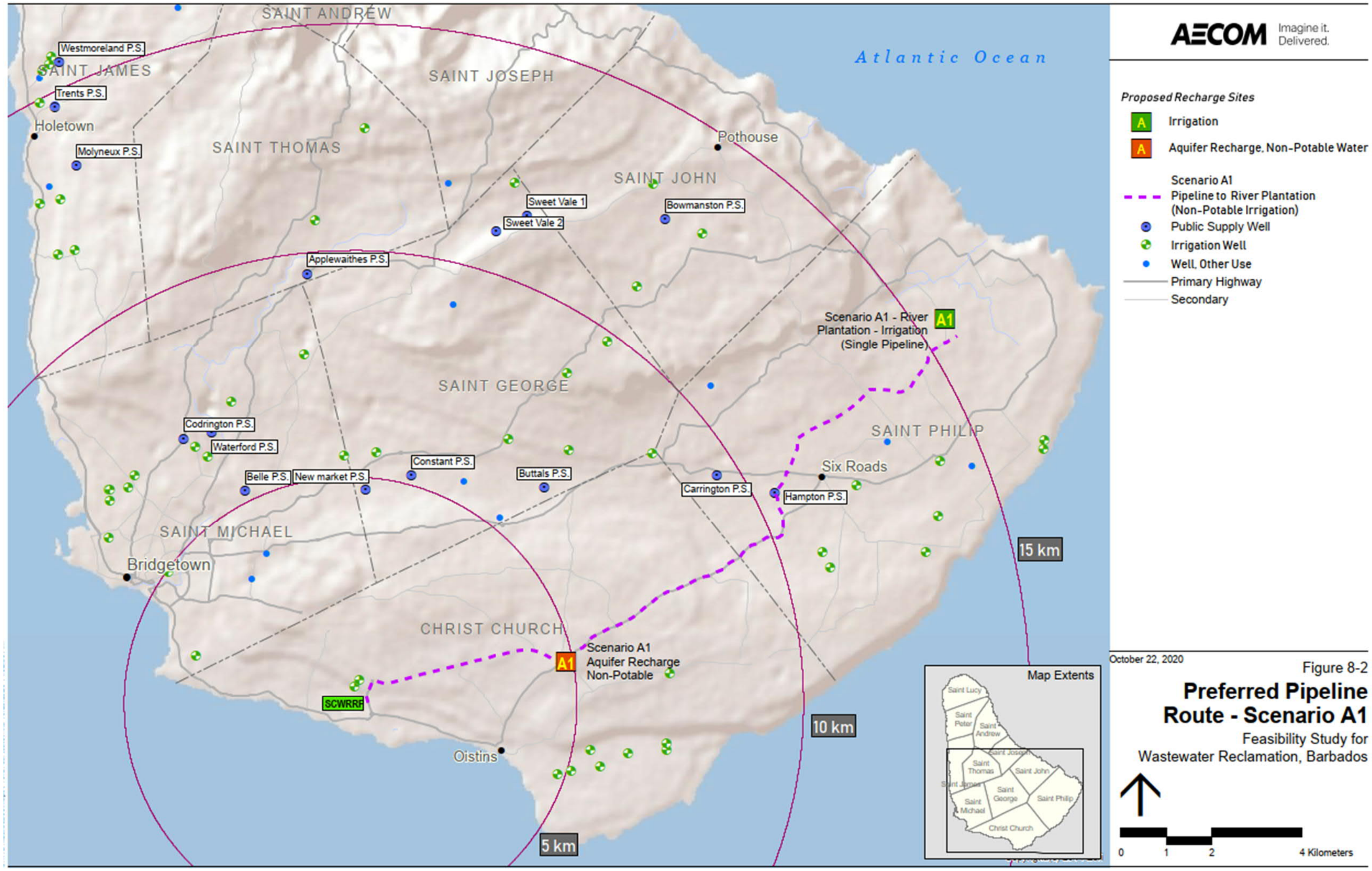


Figure 8-3: Preferred Pipeline Route – Scenario A1

8.3 Example Pictures of Treatment Units included in the Preferred Water Reclamation Option

Examples for various treatment units that could potentially be utilized in SCWRRF are shown below.

Headworks Treatment

Pre-Engineered Odour Control Units

Figure 8-4: Pre-Engineered Odour Control Unit (Source: Biorem)

Figure 8-5: Pre-Engineered Odour Control Unit (Source: Biorem)

Figure 8-6: Pre-Engineered Odour Control Unit (Source: Biorem)

Figure 8-7: Pre-Engineered Odour Control Unit (Source: BioAir)

Secondary Treatment

Figure 8-8: Secondary Treatment Facility (Ref: Lincoln Placer, USA)

Figure 8-9: Bioreactor – Aeration Zone (Diffused Air)

Figure 8-10: Bioreactor – Anoxic Zone

Figure 8-11: Secondary Clarifiers (Ref: SFWWTP, Trinidad)

Figure 8-12: Secondary Clarifiers (Ref: USA)

Figure 8-13: Dissolved Air Floatation (DAF) – Sludge Thickening (Ref: SFWWP, Trinidad)

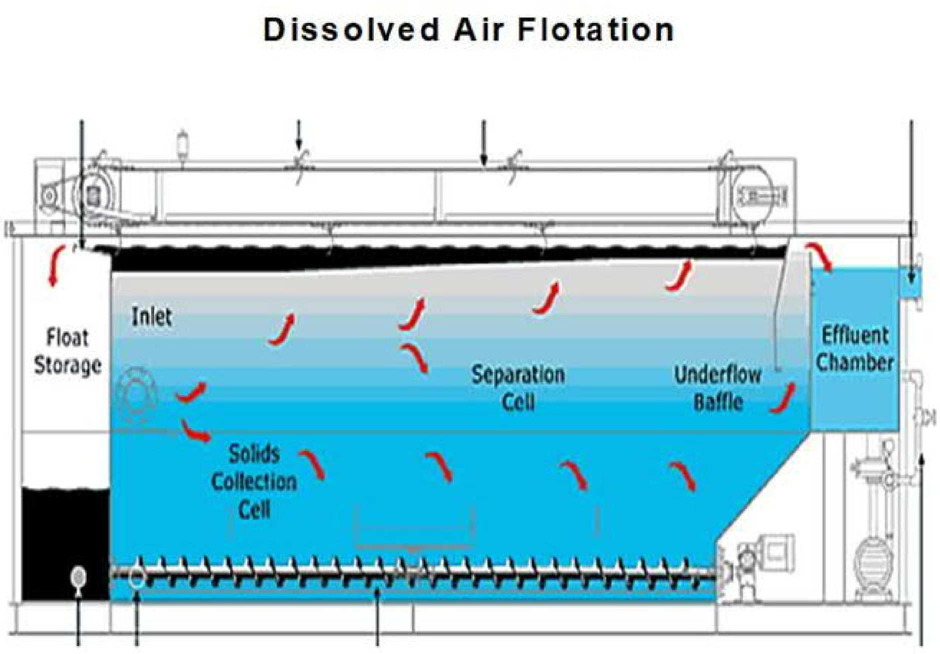


Figure 8-14: DAF Thickener Schematic

Figure 8-15: DAF Sludge Thickener

Figure 8-16: Aerobic Digester Retrofit (Trinidad)

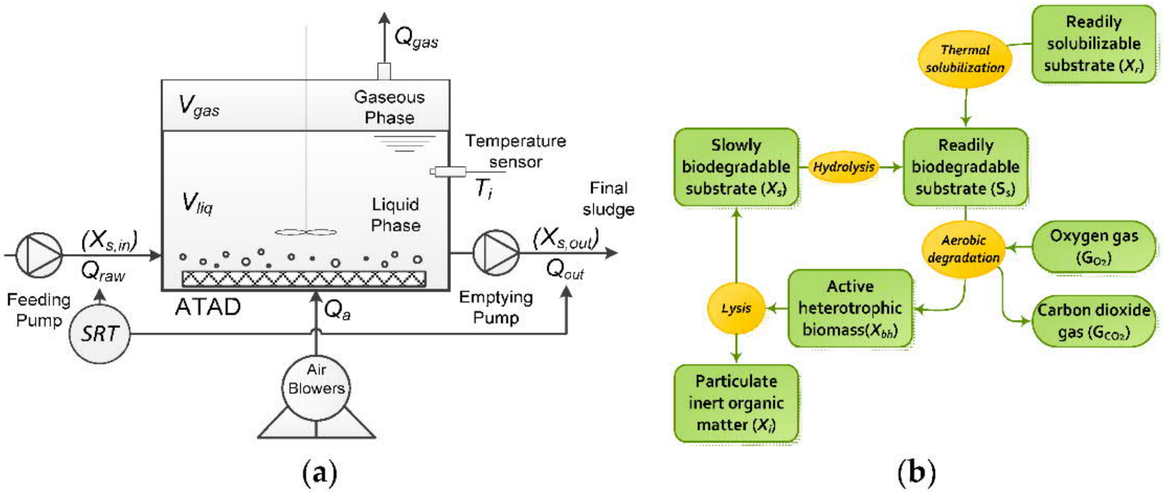


Figure 8-17: A Schematic of Aerobic Digester

Figure 8-18: Sludge Drying Beds

Tertiary Treatment

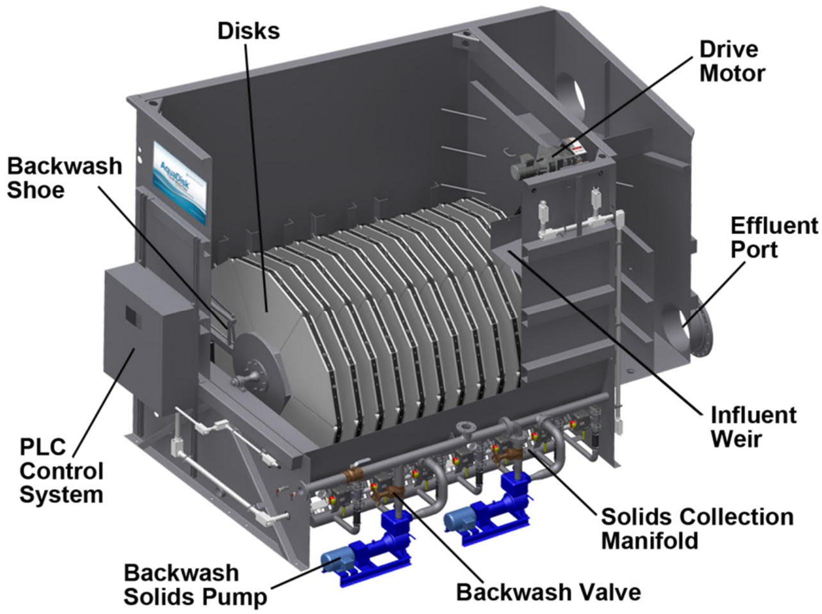


Figure 8-19: Disk Filter (Source: Aqua-Aerobics)

Figure 8-20: Disk Filter (Ref: SFWWP, Trinidad)

Figure 8-21: UV Disinfection (Ref: City of Merced, USA)

Figure 8-22: UV Disinfection

Advanced Water Treatment

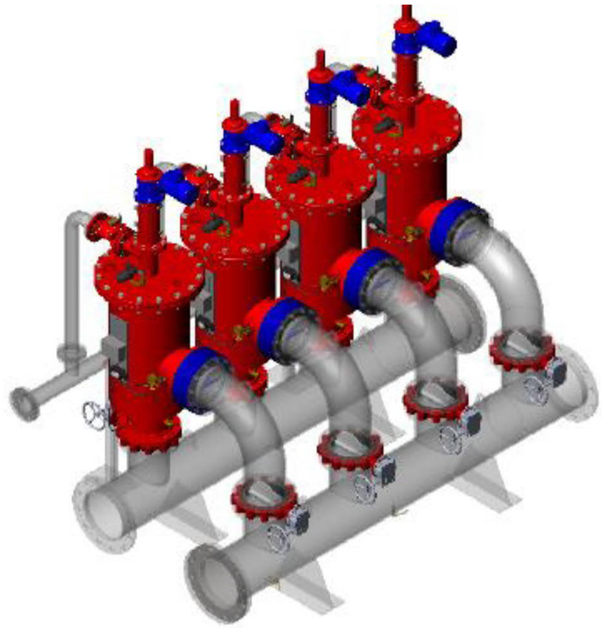


Figure 8-23: Example of automatic strainer Pre MF/UF (Amiad)

Figure 8-24: Example of MF/UF Skid (H2O Innovation)

Figure 8-25: RO Filter Cartridge (Parker)

Figure 8-26: Example RO Skid (AECOM)

Figure 8-27: Example of RO skids (Desalitech)

9. References

[1] *Draft Final Report, Barbados Regional Groundwater Model – Developed for Planning Purposes, XCG Consultants Ltd, (January 2010)*

[2] *Comprehensive Review and Overhaul of Barbados' Groundwater Protection Zoning Policy and System," Volume 3 – Water Resources and Hydrogeology, R.J. Burnside International, Ltd, (June 2011).*

[3] "*Geochemical Evolution of Groundwater in the Pleistocene Limestone Aquifer of Barbados" PhD Thesis of Ian Jones, University of Texas at Austin, (December 2002)*

[4] *"Hydrogeologic and climatic influences on spatial and interannual variation of recharge to a tropical karst island aquifer," Jones, I. and J. Banner, Water Resources Research / Volume 39, Issue 9, (September 2003).*

[5] *South Coast Sewerage Scheme Final Report, Reid Crowther Inc. (1989)*

Appendix A

Water Reclamation Standards from Other Jurisdictions

AECOM Imagine it. Delivered.

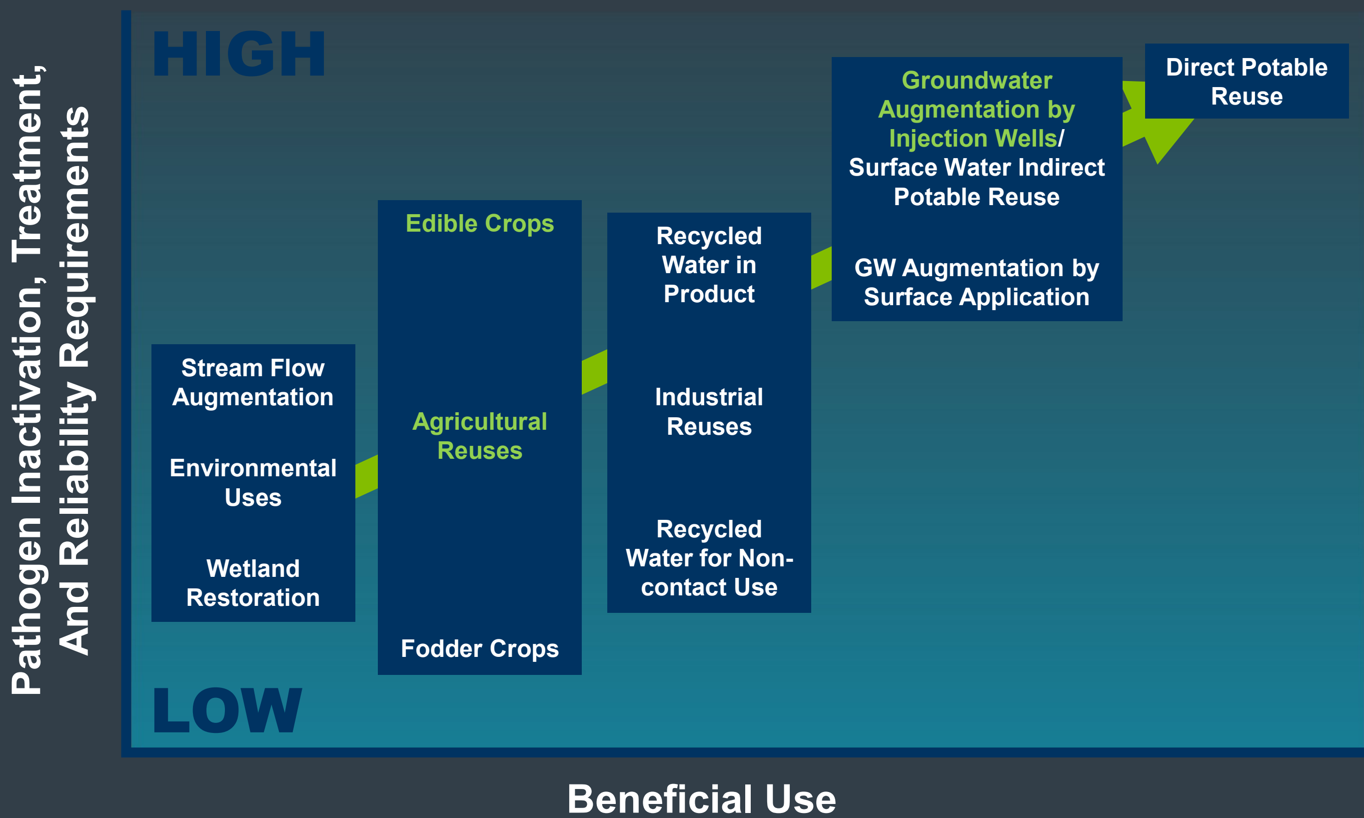
Water Reclamation Standards from Other Jurisdictions

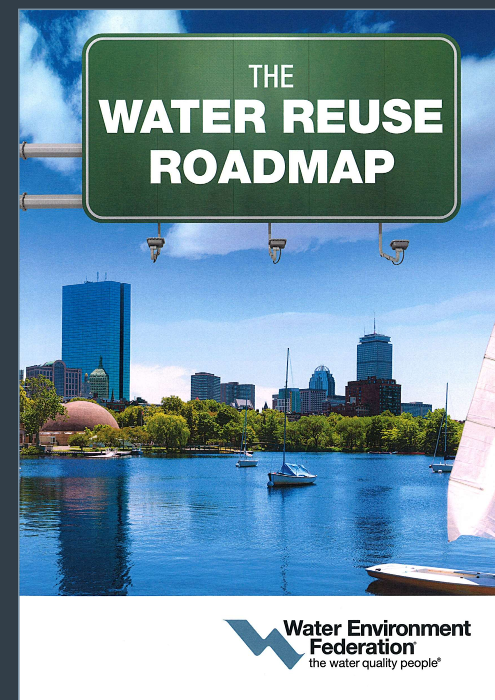
BWA South Coast Water Reclamation Pre-Feasibility Study Project

Vijay Sundaram, PhD, PE
Water Reuse Practice Leader
Vijay.Sundaram@aecom.com

Indirect Potable Reuse Water Quality Standards

The Water Reuse Spectrum





Source: The WEF Water Reuse Roadmap, 2018

Potable Reuse Types and Terminologies

Municipal Water Reuse of Biological Secondary Effluent

Non-Potable Reuse

Filtration (GMF or MF/UF) and Disinfection (UV or Chlorine)

Landscape Irrigation, Environmental Restoration, & Industrial Uses

Potable Reuse

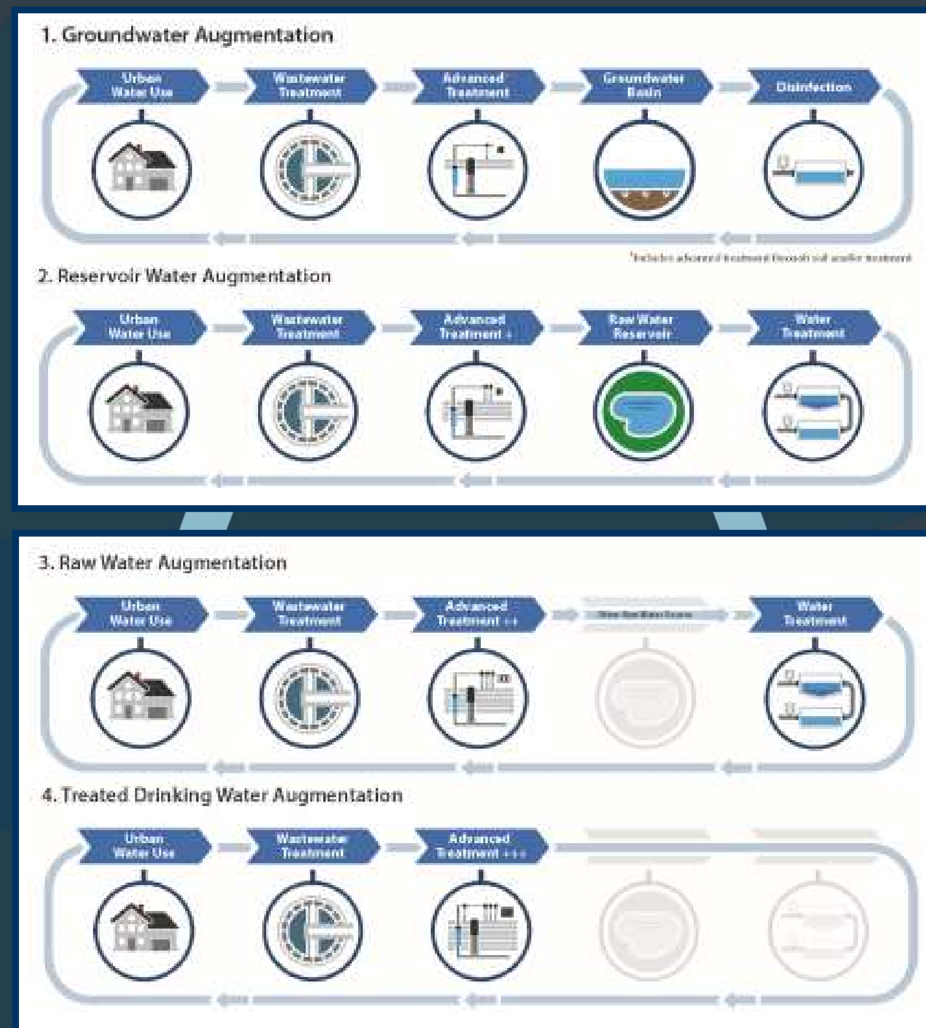
Advanced Water Treatment (AWT) including CFCGMF, MF/UF, Ozone-BAC, RO, GAC, UV AOP and Others

Indirect Potable Reuse (IPR):

- Groundwater Augmentation
- Reservoir Augmentation

Direct Potable Reuse (DPR):

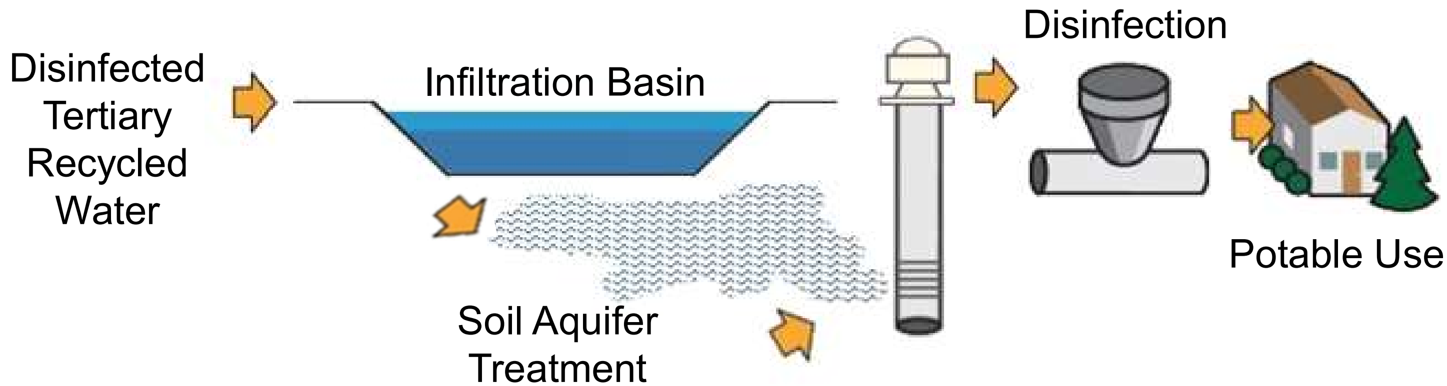
- Raw Water Augmentation
- Treated Drinking Water Augmentation



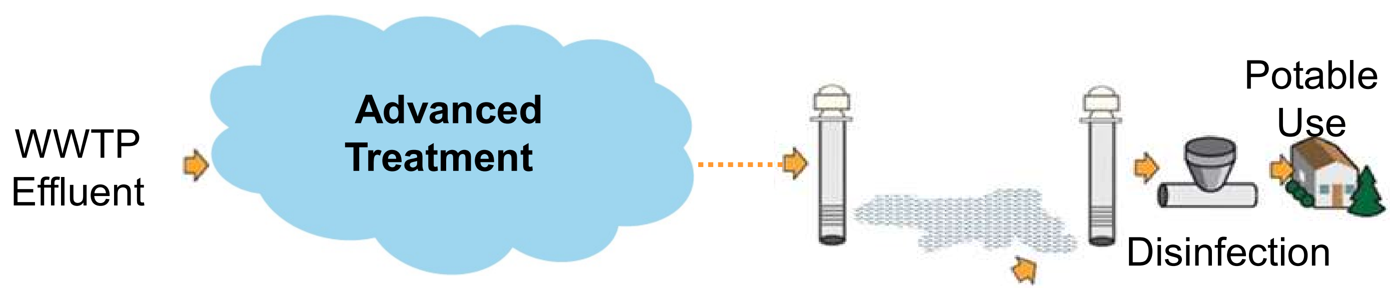
AECOM

Groundwater Augmentation (Indirect Potable Reuse) Methodologies

Spreading Basins



Injection Wells



State of Nevada

Nevada Reclaimed Water Category A+ Requirements

- Injection Wells or Spreading Basins
- Water Quality Requirements NAC 445A.27612
  - Primary Drinking Water Regulations (NAC 445A.4525)
  - Secondary Maximum Contaminant Levels (NAC 445A.455)
  - 12 Log Reduction Value (LRV) for Enteric Virus
  - 10 Log Reduction Value (LRV) for *Giardia lamblia*
  - 10 Log Reduction Value (LRV) for *Cryptosporidium* oocysts
  - Unregulated Constituent Monitoring Plan
- Treatment Requirements for Injection Wells
  - Minimum of three (3) barriers for each pathogen removal/inactivation
  - Maximum of six (6) pathogen log removal credit for an individual treatment unit process

An Example Unregulated Constituents/Contaminants of Emerging Concern (CECs) Monitoring Plan developed for OneWater Nevada Project

Constituent	Method Reporting Limit (MRL)	Units
1,4-Dioxane	0.07	µg/L
17-β-estradiol (Estradiol)	10	ng/L
Atenolol	5	ng/L
Caffeine	10	ng/L
Carbamazepine	5	ng/L
Cotinine	10	ng/L
N,N-diethyl-metatoluamide (DEET)	10	ng/L
Estrone	10	ng/L
Ethinyl estradiol (17α-ethinyl estradiol)	10	ng/L
Gemfibrozil	5	ng/L
Iohexol	10	ng/L
Meprobamate	5	ng/L
N-nitrosodimethylamine (NDMA)	2	ng/L
N-Nitrosomorpholine (NMOR)	2	ng/L
Perfluorooctanoic acid (PFOA)	2	ng/L
Perfluorooctane sulfonate (PFOS)	2	ng/L
Phenytoin (Dilantin)	20	ng/L
Primidone	5	ng/L
Sucralose	100	ng/L
Sulfamethoxazole	5	ng/L
Tris (2-chloroethyl) phosphate (TCEP)	10	ng/L
Triclosan	20	ng/L

Source: OneWater Nevada Engineering Report, 2020

State of California

California Groundwater Augmentation Requirements

- Provide Treatment
  - Spreading Basins: Title 22 Disinfected Tertiary Recycled Water (Turbidity + Total Coliforms)
  - Injection Wells: Full Advanced Treatment (RO-UV AOP) or equal
- Meet recycled water contribution requirements
  - Spreading Basins: Provide diluent water, at least initially at a ratio of up to 4 parts diluent water for each part of effluent
  - Injection Wells: 100% effluent can be injected if TOC <0.5 mg/L
- Comply with 12-10-10 pathogen reduction, TOC, and drinking water standards
- Meet underground travel time requirements based on pathogen credit criteria
- Conduct extensive monitoring
- Develop contingency plan

State of Florida

Florida Groundwater Augmentation Requirements

Florida	Groundwater Recharge to a Potable Aquifer via Injection	▪ Secondary ▪ Filtration ▪ Disinfection ▪ Multiple barriers for control of pathogens and organics ▪ Pilot testing required	**Injection to groundwater with TDS < 3,000 mg/L:** ▪ Primary and secondary drinking water standards ▪ TSS < 5 mg/L ▪ TOC < 3 mg/L ▪ No detectable total coliforms/100 mL ▪ TOX < 0.2 mg/L ▪ Total N < 10 mg/L ▪ $CBOD_5$ < 20 mg/L
		▪ Secondary ▪ Filtration ▪ Disinfection	**Injection to groundwater with TDS between 3,000 -10,000 mg/L:** ▪ Primary and secondary drinking water standards ▪ TSS < 5 mg/L ▪ No detectable total coliforms/100 mL ▪ Total N < 10 mg/L ▪ $CBOD_5$ < 20 mg/L

Source: EPA Water Reuse Compendium, 2017

Note: Revisions to Chapter 62-610, F.A.C., are being considered to ensure proper regulation for the use of reclaimed water in the State of Florida. The proposed revisions add clarity to both substantive and administrative aspects of Chapter 62-610, F.A.C.

Non-Potable (Agricultural) Reuse Water Quality Standards

State of Nevada

Nevada Reclaimed Water Category A Requirements

Category A Reclaimed Water Requirements:

- Coliforms:
  - 2.2 m.p.n or c.f.u/100 ml Total Coliform - 30-day geometric mean
  - 23 m.p.n or c.f.u/100 ml Total Coliform - Daily Max.
- BOD: Less than 30 mg/L (5-day)
- TSS: Less than 30 mg/L
- pH: 6.0-9.0

Nevada Reclaimed Water Category A End Uses

Category A Reclaimed Water Uses:

- Spray irrigation of lawn, golf course, greenbelt, and park. Public access unrestricted.
- Snowmaking and irrigation of food crops (may require additional requirements)
- Outdoor decorative water features
- Commercial toilet and urinal flushing
- Commercial window and pressure washing

– Any other activity approved for Reuse Category B, C, D or E

Nevada Reclaimed Water Categories B through E Water Quality Requirements

Category B Reclaimed Water Uses:

Coliforms: 2.2 m.p.n or c.f.u/100 ml Fecal Coliform - 30-day geometric mean. 23 m.p.n or c.f.u/100 ml Fecal Coliform - Daily Max.

BOD: Less than 30 mg/L (5-day)

TSS: Less than 30 mg/L

pH: 6.0-9.0

Category C Reclaimed Water Uses:

Coliforms: 23 m.p.n or c.f.u/100 ml Fecal Coliform - 30-day geometric mean. 240 m.p.n or c.f.u/100 ml Fecal Coliform - Daily Max.

BOD: Less than 30 mg/L (5-day)

TSS: Less than 30 mg/L

pH: 6.0-9.0

Category D Reclaimed Water Uses:

Coliforms: 200 m.p.n or c.f.u/100 ml Fecal Coliform - 30-day geometric mean. 400 m.p.n or c.f.u/100 ml Fecal Coliform - Daily Max.

BOD: Less than 30 mg/L (5-day)

TSS: Less than 30 mg/L

pH: 6.0-9.0

Category E Reclaimed Water Uses:

Coliforms: No Limit

BOD: Less than 30 mg/L (5-day)

TSS: Less than 30 mg/L

pH: 6.0-9.0

Nevada Reclaimed Water Categories B through E End Uses

Category B Reclaimed Water Uses:

Spray irrigation of lawn, golf course, greenbelt, and park. Public access is restricted.

Subsurface irrigation of commercial lawn and greenbelt

Cooling tower applications

Fire-Fighting operations

Commercial chemical mixing

Hydroseeding

Street sweeping

Any other activity approved for Reuse Category C, D or E

Category C Reclaimed Water Uses:

Spray irrigation of lawn, golf course, greenbelt, and park. Public access is restricted, and minimum 100 ft buffer zone is required.

Watering of nursery stock if public access is restricted

Wetland restoration if public access is restricted

Washing and processing aggregate for concrete production

Feed water for boiler

Impoundment if public access is restricted

Fire fighting of forest fires or other wildland fires

Any other activity approved for Reuse Category D or E

Category D Reclaimed Water Uses:

Spray irrigation of agricultural purposes if public access is prohibited and minimum 400 ft buffer zone is maintained

Subsurface irrigation of land if public access is prohibited.

Subsurface irrigation of agricultural purposes if public access is restricted

Dust control

Soil compaction

Flushing sewer lines

Impoundment if public access is prohibited

Any other activity approved for Reuse Category E

Category E Reclaimed Water Uses:

Spray irrigation of agricultural purposes if public access is prohibited and minimum 800 ft buffer zone is maintained

State of California

California Recycled Water Quality Requirements

CA Title 22 Disinfected Tertiary Recycled Water

Organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

For Sand Filtration: Shall not exceed 2 NTU – Average within 24-hr period. Shall not exceed 5 NTU more than 5 percent of the time within 24-hr period. Shall not exceed 10 NTU any time.

For Micro/Ultrafiltration & RO: Shall not exceed 0.2 NTU more than 5 percent of the time within 24-hr period. Shall not exceed 0.5 NTU any time.

For Chlorine Disinfection: CT not less than 450 mg-min/L and modal contact time of at least 90 minutes

For Other Disinfection: 5-log removal of F-specific MS2 Bacteriophage or polio virus

All Disinfection Process:

- **2.2 m.p.n or c.f.u/100 ml Total Coliform - 30-day geometric mean**
- **23 m.p.n or c.f.u/100 ml Total Coliform - Daily Max.**

CA Title 22 Disinfected Secondary-2.2 Recycled Water

Organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

2.2 m.p.n or c.f.u/100 ml Total Coliform - 30-day geometric mean

23 m.p.n or c.f.u/100 ml Total Coliform - Daily Max.

CA Title 22 Disinfected Secondary-23 Recycled Water

Organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

23 m.p.n or c.f.u/100 ml Total Coliform - 30-day geometric mean

100 m.p.n or c.f.u/100 ml Total Coliform - Daily Max.

CA Title 22 Undisinfected Secondary Recycled Water

Organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

California Recycled Water End Uses

CA Title 22 Disinfected Tertiary Recycled Water

1. Surface Irrigation:
 (a) Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop,
 (b) Parks and playgrounds,
 (c) School yards,
 (d) Residential landscaping,
 (e) Unrestricted access golf courses, and
 (f) Any other irrigation use not specified in this section and not prohibited by other sections of the California Code of Regulations.
2. Supply for nonrestricted recreational impoundments
3. Industrial or commercial cooling or air-conditioning that creates a mist
4. Flushing toilets and urinals
5. Priming drain traps
6. Industrial process water that may come into contact with workers
7. Structural fire fighting
8. Decorative fountains
9. Commercial laundries
10. Consolidation of backfill around potable water pipelines
11. Artificial snow making for commercial outdoor use
12. Commercial car washes, including hand washes if the recycled water is not heated, where the general public is excluded from the washing process.

CA Title 22 Disinfected Secondary-2.2 Recycled Water

1. Surface irrigation of food crops where the edible portion is produced above ground and not contacted by the recycled water.
2. Supply for restricted recreational impoundments.
3. Industrial or commercial cooling or air-conditioning that does not create a mist.

CA Title 22 Disinfected Secondary-23 Recycled Water

1. Surface Irrigation:
 (a) Cemeteries,
 (b) Freeway landscaping,
 (c) Restricted access golf courses,
 (d) Ornamental nursery stock and sod farms where access by the general public is not restricted,
 (e) Pasture for animals producing milk for human consumption, and
 (f) Any nonedible vegetation where access is controlled so that the irrigated area cannot be used as if it were part of a park, playground or schoolyard.
2. Supply for landscape impoundments that do not utilize decorative fountains.
3. Industrial boiler feed,
4. Nonstructural fire fighting,
5. Backfill consolidation around non-potable piping,
6. Soil compaction,
7. Mixing concrete,
8. Dust control on roads and streets,
9. Cleaning roads, sidewalks and outdoor work areas and
10. Industrial process water that will not come into contact with workers.

CA Title 22 Undisinfected Secondary Recycled Water

1. Surface irrigation:
 (a) Orchards where the recycled water does not come into contact with the edible portion of the crop,
 (b) Vineyards where the recycled water does not come into contact with the edible portion of the crop,
 (c) Non food-bearing trees (Christmas tree farms are included in this category provided no irrigation with recycled water occurs for a period of 14 days prior to harvesting or allowing access by the general public),
 (d) Fodder and fiber crops and pasture for animals not producing milk for human consumption,
 (e) Seed crops not eaten by humans,
 (f) Food crops that must undergo commercial pathogen-destroying processing before being consumed by humans, and
 (g) Ornamental nursery stock and sod farms provided no irrigation with recycled water occurs for a period of 14 days prior to harvesting, retail sale, or allowing access by the general public.
2. Flushing sanitary sewers.

State of Florida

Non-Potable Reuse: Florida Vs. California Requirements

Parameter	Unrestricted urban reuse		Restricted urban reuse		Agricultural food crops		Agricultural non-food crops	
	CA	FL	CA	FL	CA	FL	CA	FL
Treatment	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and	Secondary – 23, oxidized, and disinfected	Secondary treatment, filtration, and	Oxidized, coagulated, filtered, and dis infected	Secondary treatment, filtration, and high-	Secondary - 23, Oxidized,	Secondary treatment, basic disinfection
		high- level disinfection		high- level disinfection		level dis infection	and disinfected	
BOD_5	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$	Not Specified	20 mg/l $CBOD_5$
TSS	NS	5.0 mg/l	Not Specified	5 mg/l	Not Specified	5.0 mg/l	Not Specified	20 mg/l
Turbidity	2 NTU (Avg)	Not Specified	Not Specified	Not Specified	2 NTU (Avg)	Not Specified	Not Specified	Not Specified
	5 NTU (Max)				5 NTU (Max)			
Coliform	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal
	2.2/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	200/100 ml (Avg)
	23/100 ml (Max in 30 days)	25/100 ml (Max)	240/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (M ax in 30 days)	25/100 ml (Max)	240/100 ml (Max in 30 days)	800/100 ml (Max)

Source: Chaudhary, J., Application of Reclaimed Water for Irrigation: A Review, 2019.

Appendix B

WHO Agricultural Reuse Guidelines

WHO GUIDELINES FOR THE

SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER

VOLUME II

WASTEWATER USE IN AGRICULTURE

World Health Organization

UNEP

United Nations Environment Programme

FIAT PANIS

plants may require high quantities of nitrogen (in the earliest stages of growth, plants require lots of nitrogen, but may be too small to usefully assimilate all that is applied), but in the later flowering and fruiting stages, they may require less. In some cases, nitrogen levels will need to be adjusted by blending water supplies (Ayers & Westcot, 1985). This is also an important consideration to reduce leaching of nitrate into groundwater supplies, which would pose a potential health risk to consumers of the drinking-water (see chapter 3).

Table A1.1 Water quality for irrigation

Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity EC_w[a]		dS/m	<0.7	0.7–3.0	>3.0
TDS		mg/l	<450	450–2000	>2000
TSS		mg/l	<50	50–100	>100
SAR[b]	0–3	meq/l	>0.7 EC_w	0.7–0.2 EC_w	<0.2 EC_w
SAR	3–6	meq/l	>1.2 EC_w	1.2–0.3 EC_w	<0.3 EC_w
SAR	6–12	meq/l	>1.9 EC_w	1.9–0.5 EC_w	<0.5 EC_w
SAR	12–20	meq/l	>2.9 EC_w	2.9–1.3 EC_w	<1.3 EC_w
SAR	20–40	meq/l	>5.0 EC_w	5.0–2.9 EC_w	<2.9 EC_w
Sodium (Na^+)	Sprinkler irrigation	meq/l	<3	>3	
Sodium (Na^+)	Surface irrigation	meq/l	<3	3–9	>9
Chloride (Cl^-)	Sprinkler irrigation	meq/l	<3	>3	
Chloride (Cl^-)	Surface irrigation	meq/l	<4	4–10	>10
Chlorine (Cl_2)	Total residual	mg/l	<1	1–5	>5
Bicarbonate (HCO_3^-)		mg/l	<90	90–500	>500
Boron (B)		mg/l	<0.7	0.7–3.0	>3.0
Hydrogen sulfide (H_2S)		mg/l	<0.5	0.5–2.0	>2.0
Iron (Fe)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Manganese (Mn)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Total nitrogen (TN)		mg/l	<5	5–30	>30
pH			Normal range 6.5–8		
Trace elements (see Table A1.2)					

TDS, total dissolved solids; TSS, total suspended solids
Sources: Ayers & Westcot (1985); Pescod (1992); Asano & Levine (1998).
[a] EC_w means electrical conductivity in deciSiemens per metre at 25 °C.
[b] SAR means sodium adsorption ratio ($[meq/l]^{1/2}$); see section A1.5.

Sodium chloride, boron and selenium should be monitored carefully. Many plants are sensitive to these substances. Boron is frequently present in wastewater because it is used in household detergents. Many types of trees (e.g. citrus and stone fruits) will have impaired growth even when low boron concentrations are present in the water (Ayers & Westcot, 1985). Selenium can be toxic to plants in very low concentrations and can accumulate in plant tissue to toxic concentrations — for example, in alfalfa grown for forage (Tanji & Kielen, 2002). Concentrations of these elements in the irrigation water may be improved by blending water supplies if other water sources are available. See FAO Publication 61, chapter 6, on details regarding blending of water supplies for irrigation (Tanji & Kielen, 2002).

Water quality is also a factor in selecting the type of irrigation method. For example, sprinkler irrigation with water that contains relatively high concentrations of sodium or chloride ions can cause leaf damage to sensitive crops, especially when climatic conditions favour evaporation (i.e. high temperatures and low humidity) (Ayers & Westcot, 1985). Similar damage to crops occurs when wastewater with high levels of residual chlorine (>5 mg/l) is sprayed directly onto leaves (Asano & Levine, 1998).

Municipal wastewater may contain a range of other toxic substances, including heavy metals, as a result of industrial effluents entering the municipal wastewater stream (Pescod, 1992). Some of these substances may be removed during wastewater treatment processes when available, but others may remain in quantities large enough to cause toxicity to the crops. In cases where industrial wastes are released into the general wastewater stream or where crops exhibit signs of trace element toxicity, it may be necessary to test the water and soil for these elements. Heavy metals are usually fixed by the soil matrix and tend to be mobile only in the topmost soil layers. When water containing toxic trace elements is applied to crops, these elements may be concentrated in the soil as the water is lost into the atmosphere (Tanji & Kielen, 2002). Table A1.2 shows the threshold values for plant toxicity for selected trace elements.

Table A1.2 Threshold levels of trace elements for crop production

Element		Recommended maximum concentration[a] (mg/l)	Remarks
Al	Aluminium	5.0	Can cause non-productivity in acid soils (pH <5.5), but more alkaline soils at pH >7.0 will precipitate the ion and eliminate any toxicity.
As	Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be	Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd	Cadmium	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	Cobalt	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	Chromium	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu[b]	Copper	0.20	Toxic to a number of plants at 0.1–1.0 mg/l in nutrient solutions.
F	Fluoride	1.0	Inactivated by neutral and alkaline soils.
Fe[b]	Iron	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.

Table A1.2 (continued)

Element		Recommended maximum concentration[a] (mg/l)	Remarks
Li	Lithium	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn[b]	Manganese	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo	Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	Nickel	0.20	Toxic to a number of plants at 0.5–1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	Lead	5.0	Can inhibit plant cell growth at very high concentrations.
Se	Selenium	0.02	Toxic to plants at concentrations as low as 0.025 mg/l, and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. Essential element to animals, but in very low concentrations.
V	Vanadium	0.10	Toxic to many plants at relatively low concentrations.
Zn[b]	Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH >6.0 and in fine textured or organic soils.

Source: Adapted from Ayers & Westcot (1985); Pescod (1992).

[a] The maximum concentration is based on a water application rate that is consistent with good irrigation practices (5000–10 000 m^3/ha per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3/ha per year. The values given are for water used on a continuous basis at one site.

[b] Synergistic action of Cu and Zn and antagonistic action of Fe and Mn have been reported in certain plants species' absorption and tolerance of metals after wastewater irrigation. If the irrigation water contains high concentrations of Cu and Zn, Cu concentrations in the tissue may increase greatly. In plants irrigated with water containing a high concentration of Mn, Mn uptake in the plants may increase, and, consequently, the concentration of Fe in the plant tissue may be reduced considerably. Generally, metal concentrations in plant tissue increase with concentrations in the irrigation water. Concentrations in the roots are usually higher than in the leaves (Drakatos, Kalavrouziotis & Drakatos, 2000; Drakatos et al., 2002; Kalavrouziotis & Drakotos, 2002).

A1.4 Soil characteristics

Soil infiltration

The infiltration rate of the soil determines how much water will reach the crop root zone and eventually percolate to the subsoil and is dependent upon soil texture and structure and the structural stability of the soil. The infiltration rate is also dependent upon both the salinity of the water and the sodium adsorption ratio (SAR) of the soil (see Table A1.1). The SAR is a measure of the ratio of sodium ions to calcium and magnesium ions in the soil. The SAR can be calculated using the following formula:

$$SAR = Na^{+}/[(Ca^{++} + Mg^{++})/2]^{1/2}$$

where the ionic concentrations of Na, Ca and Mg are expressed in meq/l.

Water with a low salinity content (<0.5 dS/m) leaches soluble minerals and salts. If calcium is leached, soil structure can be destabilized and fine soil particles become

Table 3-4 Guidelines for interpretation of water quality for irrigation[1]

Potential Irrigation Problem		Units	Degree of Restriction on Irrigation: None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*[2]					
	EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS	mg/L	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil; evaluate using EC_w and SAR together)*[3]					
SAR	0 – 3	**and EC_w =**	> 0.7	0.7 – 0.2	< 0.2
	3 – 6		> 1.2	1.2 – 0.3	< 0.3
	6 – 12		> 1.9	1.9 – 0.5	< 0.5
	12 – 20		> 2.9	2.9 – 1.3	< 1.3
	20 – 40		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*					
	Sodium (Na)[4]				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	meq/l	< 3	> 3	
	Chloride (Cl)[4]				
	surface irrigation	meq/l	< 4	4 – 10	> 10
	sprinkler irrigation	meq/l	< 3	> 3	
	Boron (B)	mg/L	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects *(affects susceptible crops)*					
	Nitrate (NO_3-N)	mg/L	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)	meq/L	< 1.5	1.5 – 8.5	> 8.5
	pH		**Normal Range 6.5 – 8.4**		

[1] Adapted from FAO (1985)
[2] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25°C (dS/m) or in millimhos per centimeter (mmho/cm); both are equivalent.
[3] SAR is the sodium adsorption ratio; at a given SAR, infiltration rate increases as water salinity increases.
[4] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

Appendix C

List of Prohibited Concentrations

Public Consultation

List of Prohibited Concentrations

Produced for:

Environmental Engineering Division and Coastal Zone Management Unit,

Ministry of Housing, Lands and the Environment,

Government of Barbados.

Prepared by:

University of the West Indies

In association with:

October 2004

FOREWORD

It is with great pleasure that I present this public consultation document to the Barbadian public on behalf of the staff at the Environmental Engineering Division and the Coastal Zone Management Unit. It is anticipated that the Coastal Zone Management Act and Marine Pollution Control Act will greatly enhance Government's ability to manage and protect our coastal resources for this and future generations. The coast and the many activities that take place within the Coastal Zone are fundamental to our society and economy and it is imperative that we protect it so that it may continue to be a source of pride to our Nation.

The tables included in this document give the preliminary compliance standards for each pollutant as well as the reasons for including them and where the standard originated. The Government cannot achieve its aims of protecting the coast without the assistance of the Barbadian public and the companies operating here. It is for this reason that the Consultation is taking place; to ensure that a system is put in place and that everyone understands the role they play in protecting our environment.

I encourage you to read the document and provide us with any feedback so that we can all work together to protect and manage our resources for the benefit of all.

Jeffrey Headley
Chief Environmental Engineer.

Table of Contents

Glossary of Terms.

μg/l –	micrograms/litre ≡ 1000 mg/l ≡ parts per billion.
μg P/l or μg N/l –	The mass of the phosphorous or nitrogen in a litre rather than the mass of the atoms they are attached to, e.g. oxygen in nitrates.
% Saturation –	The measured concentration compared with the normal atmospheric equilibrium concentration at that temperature.
Best Available Technology -	The most accurate and available methods of detection.
Bioaccumulation –	The retention and accumulation of a chemical within the tissues of a biological organism.
Geometric mean –	The list of values are multiplied together and then the taken to the power 1/n, where n is the number of values.
Half-life –	The time period required for a process to remove half of the original quantity.
Organic/inorganic –	Organic compounds contain Carbon. Inorganic compounds do not contain carbon.
psu –	Practical Salinity Units, numerically equivalent to parts per thousand or grams/kilogram.
NTU –	Nephelometric Turbidity Units. Turbidity is measured using a Nephelometer that measures the amount of sediment in the water by measuring the light that is scattered at a 90-degree angle by the suspended material. This measurement generally provides a very good correlation with the concentration of particles in the water.
Toxic –	Poisonous to biological organisms.
Volatile –	Prone to evaporate rapidly.

Table 1. List of Pollutants and Ambient Standards.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
General Parameters and Nutrients				
Chlorophyll *a*	An indicator of the presence of algae, which can be an indicator of high nutrient levels.	Elevated levels detected occasionally, up to 3.23 at the Careenage.	Anzecc, 2000 for tropical marine systems.	0.5
Dissolved Oxygen[1]	Essential for aquatic life. Requirements vary depending on species, life stage, and life processes. Many compounds become more toxic as Dissolved Oxygen decreases; so can have an indirect effect.	Oxygen levels are often supersaturated, but can dip quite low where there is an outfall with high oxygen demand.	Anzecc, 2000 for tropical marine systems.	90 (% saturation) -actual concentration varies with temperature.
Faecal streptococci / enterococci	Public health indicator of sewage pollution in seawater. This is generally the preferred indicator of health risk.	Priority pollutant that has previously been detected at high levels.	US EPA, 2002. UNEP, 1999 - LBS Protocol.	Geometric mean of min. 5 samples should not exceed 35 colonies/100ml in any 30-day period.
Faecal coliform	Public health indicator of sewage pollution in freshwater, but historically used in seawater as well.	Priority pollutant that has previously been detected at high levels.	UNEP, 1999 - LBS Protocol.	Geometric mean of min. 5 samples not exceed 200 colonies/ 100ml in any 30-day period. No more than 10% of samples exceed 400 colonies/100ml.
Phosphate (Filterable Reactive)	Primary nutrient causes high algal growth, which then impacts on coral by blocking light and smothering.	Priority pollutant. The recommended level is often exceeded.	Delcan, 1994	2.48 (µg P/l)
Oxides of Nitrogen (nitrate/nitrite)	Primary nutrient causes high algal growth, which then impacts on coral by blocking light and smothering.	Priority pollutant. The recommended level is often exceeded.	Delcan, 1994	9.8 (µg N/l)
Ammonia	Form of nitrogen most easily used by plants. Causes high algal growth, which then impacts on coral.	Priority pollutant. Not regularly measured, but	Delcan, 1994	9.8 (µg N/l)

[1] Dissolved Oxygen – is measured as a concentration then the saturation level is calculated based on the Normal Atmospheric Equilibrium Concentration (NAEC). At 35psu and 24°C the NAEC for oxygen is 5.5ml/l. Around Barbados we typically measure 6.5-7mg/l, which is equivalent to approximately 4.6-4.9ml/l assuming these measurements were taken at standard pressure.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
		the recommended level is exceeded.		
Total nitrogen (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well.	Not measured.	Anzecc, 2000 for tropical marine systems.	100
Total phosphorous (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well.	Not measured.	Anzecc, 2000 for tropical marine systems inshore.	15
pH	General indicator of acidity/alkalinity. Change in pH can be either toxic directly or indirectly by changing the toxicity of other pollutants.	Rarely measured.	CCME, 1999	7.0-8.7
Salinity	General parameter describing the total salt content of seawater. An indicator of the presence of freshwater or hyper saline discharges.	Ambient levels generally within the range although not always measured.	Delcan, 1994.	30-38 (psu)
Temperature	Indicator of thermal pollution from, for example, cooling water discharges. Changes in temperature can affect the toxicity of chemicals or kill coral directly through bleaching.	Isolated cases, but typically between 26-29°C.	Delcan, 1994.	<31°C
Total Suspended Solids (TSS)	Suspended solids increase turbidity, reduce light penetration, and decrease photosynthetic activity – the basis of coral growth. Also important in the transport of other pollutants that are strongly associated with the solids, such as metals.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Occasionally exceeds standard.	Delcan, 1994 standard is 4mg/l, but given observations, the standard is set at 5mg/l.	5 (mg/l)
Sedimentation Rate	Indicator of the amount of solids that settles on the seabed. Settling solids can smother a reef. Bank reefs are more susceptible than fringing reefs.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Not frequently measured, but can exceed standard.	Delcan, 1994.	Fringing reefs: 25 $mg/cm^2/day$ Bank Reefs: 5 $mg/cm^2/day$

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
Turbidity	Aesthetic impact; reduced water clarity; impact on photosynthetic capacity of corals. Another measure of the amount of sediment in the water column.	Typically <1NTU	Delcan, 1994.	1.5 (NTU)
Non-metallic Inorganics				
Chlorine (Total Residual Chlorine)	Chlorine is commonly used as a disinfectant in potable water and in sewage treatment, toxic to many marine species.	Not measured.	Delcan, 1994.	2
Cyanide (un-ionised HCN)	Used in metal plating / metal finishing and photo-processing. Toxic. HCN (hydrocyanic acid) is the most toxic form of cyanide as it can cross biological membranes.	Not detected in past samples.	Anzecc, 2000. 95% protection level[a].	4
Metals				
Cadmium	Used in metal plating, in batteries, and in the manufacture of semiconductors. Toxic. Bio-concentration can be significant for bivalves. If shellfish from the area are consumed an even lower trigger value of 0.2 µg/l is recommended. Causes kidney damage in humans.	Not detected in past samples.	Anzecc, 2000. 99% protection level[b].	0.7
Chromium III (trivalent)	Used in metal plating, leather industry and as a corrosion inhibitor in cooling systems. Toxic. Chromium III less toxic than Chromium VI.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	27.4
Chromium VI (hexavalent)	Used in metal plating, leather industry and as a corrosion inhibitor in cooling systems. Toxic.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	4.4
Copper	Commonly used metal, specifically by the rum industry. An essential trace element, but toxic at higher concentrations. Readily accumulated by plants and animals. Copper toxicity to marine species generally increases as salinity decreases. Long-term exposure causes liver and kidney damage in humans.	Detected occasionally.	Anzecc, 2000. 95% protection level[a].	1.3
Lead	Historically added to paint and gasoline; used in old	Detected occasionally,	Anzecc, 2000. 95%	4.4

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	water pipes. Toxic.	primarily in Careenage and Port.	protection level[a].	
Mercury (inorganic)	Used in switches, thermometers, and dentistry. Can be converted by microorganisms in sediment to methyl mercury. Methyl mercury is soluble, more toxic than inorganic mercury and bio-accumulates.	Not detected in past samples.	Anzecc, 2000. 99% protection level[b].	0.1
Nickel	Used in metal plating, present in batteries. Nickel toxicity increases with decreasing salinity. The 95% protection level not deemed to provide sufficient protection to juvenile mysids and molluscs.	Low values have been detected.	Anzecc, 2000. 99% protection level[b].	7
Silver	Used in the electronics and photography industries. The acute toxicity of silver to marine fish is considerably lower than to freshwater fish. Toxicity to most species increases with decreasing salinity.	Historically present in at least one local industrial effluent. Low values have been detected.	Anzecc, 2000. 95% protection level[a].	1.4
Vanadium	Occurs in 4 valency states. Vanadium +5 (Vanadate) is the most common in water and the most toxic.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	100
Zinc	In greater than trace concentrations, harmful to aquatic organisms. Zinc uptake and toxicity generally decrease as salinity increases.	Low values have been detected, primarily in Careenage.	Anzecc, 2000. 95% protection level[a].	15
Organotins				
Tributyltin	Highly toxic to marine bivalves. Present in marine antifouling paints and wood preservative.	Used in Barbados, but not detected.	Anzecc, 2000. 95% protection level[a].	0.006
Organic Alcohols				
Ethanol	Present in alcohol distillery waste. Volatile and completely mixable with water. Large inputs can significantly reduce Dissolved Oxygen levels. Limited marine toxicity data. Anzecc present a low reliability value taken from the freshwater value, which should be considered only as an interim working value. It is recommended for inclusion due to the known presence	Not measured.	Anzecc, 2000. 95% protection level[a] in freshwater.	1400

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	of ethanol in marine waters off of the west coast of Barbados.			
Chlorinated Alkanes and Alkenes				
1,1,2- trichloroethane	Volatile and relatively soluble in water. Commonly used industrial solvent. Not expected to bioaccumulate significantly.	Not measured.	Anzecc, 2000. 95% protection level[a].	1900
1,1,2,2-tetrachloroethylene (perchloroethylene)	Commonly used in the dry cleaning industry in Barbados. Not expected to bioaccumulate or to bind to sediment. Volatile with a half-life of 1-6 days in water. Due to its known use in Barbados the Anzecc marine low reliability value is recommended as an interim working value. Anzecc considers that there is insufficient data to generate a marine medium reliability trigger value.	Not measured.	Anzecc, 2000. Low reliability value.	70
Aromatic Hydrocarbons				
Benzene	Benzene, toluene, ethyl benzene and xylene (BTEX) are the simplest aromatic hydrocarbons. Products of oil refining and important common aromatic solvents. Commonly associated with contaminated petroleum sites (e.g. Needham's Point). BTEX compounds are highly volatile, have low water solubility and have low bioaccumulation potential. However, water managers should be aware of possible additive effects (mixture toxicity). Anzecc 99% protection level is recommended to provide protection against chronic toxicity to crabs.	Rarely measured. Below detectable limits.	Anzecc, 2000. 99% protection level[b].	500
Toluene	Insufficient data. Low reliability value recommended as an interim value.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95% protection value.	180
Ethyl benzene	Insufficient data. Low reliability value recommended as an interim value.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95%	80

Parameter	**Rationale**	**Current Status in Barbados**	**Basis of Standard**	**Ambient Water Quality Standard (µg/l) unless otherwise stated.**
			protection value.	
Xylenes	Insufficient data. Low reliability value recommended as an interim value for m-xylene.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95% protection value.	75
Naphthalene	Naphthalene is the simplest polycyclic aromatic hydrocarbon (PAH), used as an insect-proofing agent for stored materials and clothes. Will absorb strongly to sediment. UV light increases the toxicity. Only PAH that Anzecc considers there are sufficient data to generate a moderately reliable guideline value. Due to chronic toxicity to the crab *C. magister*, the Anzecc 99% protection level is recommended.	Rarely measured. Below detectable limits.	Anzecc, 2000. Moderate reliability 99% protection level[b].	50
		Polychlorinated Biphenyls		
PCBs	Used as a dielectric fluid in transformers and capacitors. No longer used by the Barbados Light & Power Company Ltd. High persistence and potential to bioaccumulate. Moderate reliability trigger values have been derived for Arochlors 1242 &1254 in freshwater. These numbers have been converted to marine low reliability figures and should be considered as interim values.	Not detected.	Anzecc, 2000. Moderate reliability 99% protection level[b] in freshwater.	Arochlor 1242: 0.3 Arochlor 1254: 0.01
		Phenols		
Phenol	Commonly used raw material in the manufacture of a wide range of products. A common by-product of oil refining. Readily soluble in water and low bioaccumulation potential. Imparts taste and odour in fish and shellfish at low concentrations. Variable toxicity.	Not detected.	Anzecc, 2000. Moderate reliability 95% protection level[a].	400
Pentachlorophenol (PCP)	A biocide, disinfectant, pesticide and wood	Not detected.	Anzecc, 2000.	11

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	preservative. Found in chlorinated effluents from sewage treatment plants. Impair taste, more toxic at lower pH. The Anzecc 99% protection level is recommended in the absence of local bioaccumulation data.		Moderate reliability 99% protection level[b].	
	Pesticides, Insecticides, Herbicides and Fungicides			
All organochlorine (OC) pesticides	The use of OC pesticides was phased out in Barbados more than a decade ago. However, the compounds are persistent with high bioaccumulation potential. The detection limits for most OC's are greater than the standards, so it is recommended that OC's should not be detectable in marine waters.	Some have been detected at low levels, but not in exceedance of guidelines.	Anzecc, 2000.	Not detectable, based on Best Available Technology.
All organophosphate (OP) pesticides	Commonly used in Barbados. Toxic to most species. Detection limits in the order of 0.02 µg/l in water. Recommended standards are lower. Therefore, it is recommended that OP's should not be detectable in marine waters.	Some have been detected at low levels, but not in exceedance of guidelines.	Anzecc, 2000.	Not detectable, based on Best Available Technology.
Other Insecticides, Herbicides and Fungicides	Insufficient data currently exists to allow Anzecc to generate moderate reliability trigger levels for other pesticides at this time. To be precautionary, it is recommended that a No Detection limit be used as a default in the absence of other data.	Some have been detected at low levels, but not in exceedance of guidelines.	Anzecc, 2000.	Not detectable, based on Best Available Technology.

[a] The 95% protection level means that at this concentration it is expected that 95% of species will be protected.
[b] The 99% protection level means that at this concentration it is expected that 99% of species will be protected.

Table 2. Domestic Waste End of Pipe Standards.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
Biochemical Oxygen Demand	When there is a large quantity of biological matter in the water bacteria will break it down but use up oxygen at the same time. This is a measure of that oxygen demand and will lead to a drop in dissolved oxygen levels.	This can be high for specific types of discharge such as sewage effluent and rum distillery waste.	UNEP, 1999 - LBS Protocol.	Class 1 – 30mg/l Class 2 – 150mg/l
Total Suspended Solids (TSS)	Suspended solids increase turbidity, reduce light penetration, and decrease photosynthetic activity – the basis of coral growth. Also important in the transport of other pollutants that are strongly associated with the solids, such as metals.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Occasionally exceeds standard.	UNEP, 1999 - LBS Protocol.	Class 1 – 30mg/l Class 2 – 150mg/l
Total nitrogen (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well. The end-of-pipe standards have been set to meet the ambient standard in Class 1 waters within a 50:1 mixing zone.	Not measured.	Class 1 based on 50:1 dilution with nutrient removal. Class 2 based on no or advanced preliminary treatment.	Class 1 – 5mg/l Class 2 – 45mg/l
Total phosphorous (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well. The end-of-pipe standards have been set to meet the ambient standard in Class 1 waters within a 50:1 mixing zone.	Not measured.	Class 1 based on 50:1 dilution with nutrient removal. (CEHI, 1998) Class 2 based on no or advanced preliminary treatment.	Class 1 – 1mg/l Class 2 – 10mg/l
pH	General indicator of acidity/alkalinity. Change in pH can be either toxic directly or indirectly by changing the toxicity of other pollutants.	Rarely measured.	EEC, 1976 and World Bank, 1999.	6-9 in Class 1 and 2 waters.
Faecal streptococci	Public health indicator of sewage pollution in seawater. This is generally the preferred indicator of health risk.	Priority pollutant that has previously been detected at high levels.	US EPA, 2002. UNEP, 1999 - LBS Protocol.	Class 1 - Geometric mean of min. 5 samples should not exceed 35 colonies/100ml in any 30-

Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
				day period.
Faecal coliform	Public health indicator of sewage pollution in freshwater, but historically used in seawater as well.	Priority pollutant that has previously been detected at high levels.	UNEP, 1999 - LBS Protocol.	Class 1 - Geometric mean of min. 5 samples not exceed 200 colonies/ 100ml in any 30-day period. No more than 10% of samples exceed 400 colonies/100ml.
Total Residual Chlorine	Chlorine is commonly used as a disinfectant in potable water and in sewage treatment, toxic to many marine species.	Not measured.	CEHI, 1998.	Class 1 - 0.1mg/l
Fats, Oils and Grease	Found in urban runoff and domestic waste. Smothers shoreline ecosystems. Can be toxic.	Not measured as a general group. Generally below detectable limits.	UNEP, 1999 - LBS Protocol.	Class 1 – 15mg/l Class 2 – 50mg/l
Floatables	Plastics and other materials that are not easily removed by natural processes. They can smother or be ingested by organisms.	An important problem.	UNEP, 1999 - LBS Protocol.	Not visible in Class 1 and 2 waters.

Table 3. Petroleum Hydrocarbons End of Pipe Standards for Class 1 Waters.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
Total Petroleum Hydrocarbons (TPH)	Important chemicals used in the production of oils and fuels. Found in industrial discharges and urban runoff. Smothers shoreline ecosystems. Lighter fractions are most toxic.	Not measured as a general group. Generally below detectable limits. Longer chain hydrocarbons found at detectable limits in Careenage and at tanker moorings, but below standards.	Max - State of Wyoming, 2000. Av. Daily value is interim value recommended by consultants to allow some flexibility.	Max. daily discharge (mg/l): 10 Av. Daily concentration over 30 consecutive days (mg/l): 5
Total Oils & Greases	Found in industrial discharges and urban runoff. Smothers shoreline ecosystems. Can be toxic.	Not measured as a general group. Generally below detectable limits.	Max - World Bank, 1999. Av. Daily value is interim value recommended by consultants to allow some flexibility. Based on US EPA, 1995.	Max. daily discharge (mg/l): 10 Av. Daily concentration over 30 consecutive days (mg/l): 5
Total Organic Carbon	The level of organic carbon can influence the availability of other pollutants. Directly non-toxic.	Not measured.	Max - US EPA, 1995. Av. Daily value is interim value recommended by consultants to allow some flexibility.	Max. daily discharge (mg/l): 110 Av. Daily concentration over 30 consecutive days (mg/l): 55

References.

ANZECC and ARMCANZ, 2000. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand Guidelines for fresh and marine water quality. National Water Quality Management Strategy. Available at http://www.ea.gov.au/water/quality/nwqms

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Publication No. PN1299: ISBN 1-896997-34-1. Summary available at www.ccme.ca/publications/can_guidelines.html#108.

CEHI, 1998. Guidelines for Sensitive Waters. Caribbean Environmental Health Institute.

Delcan, 1994. Nearshore Marine Water Quality of the West and Southwest Coasts of Barbados: Present Status and Management Recommendations. Government of Barbados Coastal Conservation Project Unit.

EEC, 1976. Bathing Water Directive 76/160/EEC. Available at http://europa.eu.int/water/water-bathing/directiv.html

State of Wyoming, 2000. Department of Environmental Quality/Water Quality Division Public Notice. August 31, 2000.

United Nations Environment Program, 1999. Protocol Concerning Pollution from Land-Based Sources and Activities to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region. Available at http://www.cep.unep.org/law/lbsmpnut.php

US EPA, 1995. CFR Title 40 – Protection of the Environment. Subchapter N – Effluent Guidelines and Standards, Part 419.22, Petroleum Refining Point Source Category. http://www.epa.gov/epacfr40/chapt-I.info/chi-toc.htm

US EPA, 2002. Implementation Guidance for Ambient Water Quality Criteria for Bacteria. May 2002. Draft.

World Bank, 1999. Pollution Prevention and Abatement Handbook 1998: Toward Cleaner Production. ISBN: 0-8213-3638-X SKU: 13638