Wastewater Treatment by Radiation Technology

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The problems of environmental damage and degradation of natural resources are receiving increasing attention throughout the world. The increased population, higher living standards, increased urbanization and enhanced industrial activities of humankind are all leading to significant water pollution.

Radiation technologies have been widely promoted in industry, agriculture, and research. Ionizing radiation in the form of accelerated particles or electromagnetic waves are capable of ionising water molecules, thereby generating active radicals from the water molecule that react with the harmful organic contaminants in the wastewater. These contaminants then degrade and become simpler chemical forms and are easier to treat through traditional methods. The first studies on radiation treatment of wastes were carried out in the 1950s principally for disinfection. In the 1960s, these studies were extended to the purification of water and wastewater. After some laboratory research on industrial wastewaters and polluted groundwater in 1970s and 1980s, several pilot plants were built for extended research in the 1990s. The first full-scale application was constructed in 2005 for the treatment of textile dyeing wastewater (10,000 m^3/d) in Korea with the support of International Atomic Energy Agency (IAEA), followed by a plant in China in 2020 (30,000 m^3/d) for textile industries. The results of practical applications confirmed this technology is easily and effectively utilized for treating large quantities of wastewater.

Radiation treatment can also be used to treat emerging organic pollutants in ground water such as fertilizers, pesticides, and pharmaceutical residues that can lead to ground pollution and consequent contamination of water resources. The major advantage of radiation technology is that the reactive species are generated in-situ during the radiolysis process without addition of any chemicals and such reactions can be carried out at relatively low temperature, resulting in lower energy cost, less thermal damage to the system and product.

IAEA supports the non-power nuclear applications in the member states, especially for preservation of water resources and environment.

Key Words: IAEA, Nuclear Technology, Wastewater, Radiation, Water Radiolysis

1. Introduction

The International Atomic Energy Agency (IAEA) is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field. It works for the safe, secure, and peaceful uses of nuclear science and technology, contributing to international peace and security, and the United Nations' Sustainable Development Goals [1]. The IAEA was created in 1957 in response to the deep fears and expectations generated by the discoveries and diverse uses of nuclear technology. The IAEA was set up as the world's "Atoms for Peace" organization within the United Nations family. From the beginning, it was given the mandate to work with its Member States and multiple partners worldwide to promote safe, secure, and peaceful nuclear technologies [2]. Nuclear science and technology is the foundation for all the IAEA's activities. The Agency assists Member States with scientific advice, education, training, and technical documents in many nuclear science areas, provides key nuclear data and helps them improve awareness about the wide range of applications of nuclear technology.

Rapid population growth and increased agricultural and industrial development have led to the generation of large quantities of polluted industrial and municipal wastewaters. The recognition that these polluted waters may pose a serious threat to humans has led technologists to look for cost effective technologies for their treatment. A variety of methods based on biological, chemical, photochemical, and electrochemical processes is being explored for decomposing the chemical and biological contaminants present in the wastewaters. Conventional water treatment technologies that incorporate filtration, chemical and biological treatment, are often inherently unable to remove low levels of pollutants. New technologies, based on advanced oxidation reduction process (AORP) involving free radicals, hold promise. Radiation technologies can mitigate the effects of emerging organic pollutants by degrading them alone, or in combination with other treatment technologies [3].

Radiation technologists have been investigating the use of high energy radiation to treat such wastewaters, with the primary advantage being that the reactive species are generated in situ during the radiolysis process without the addition of any chemicals. Several pilot scale and a number of industrial scale wastewater treatment plants based on radiation technology are in operation or under construction. The results of practical applications have confirmed that radiation technology can be easily and effectively utilized for treating large quantities of wastewater. Aqueous effluents that can be treated by irradiation fall into two groups: industrial wastewater, and natural and contaminated water (including effluents from municipal treatment plants). The main differences between the two groups are the concentration of pollutants and the level of microbial infection, both of which are higher for the first group of effluents; however, disinfection is the main focus for the second group.

The first studies on the radiation treatment of wastes, principally for disinfection, were carried out in the 1950s. In the 1960s, these studies were extended to the purification of water and wastewater. Laboratory research on industrial wastewaters and polluted groundwater was conducted in the 1970s and 1980s, and in the 1990s several pilot plants, including mobile electron beam (EB) facilities, were built for extended research.

2. Treatment of Wastewater by Means of Ionizing Radiation

Radiation processing in wastewater treatment is an additive free process that uses the short-lived reactive species formed during the radiolysis of water for efficient decomposition of the pollutants therein. For practical treatment of wastewater, radiation processing offers the following advantages:

- Strong reducing and oxidizing agents;
- Universality and interchangeability of redox agents;
- A variety of paths for pollutant conversion;
- Process controllability;
- A wide choice of equipment and technological regimes;
- Compatibility with conventional methods.

High energy irradiation produces instantaneous radiolytic transformations through energy transfer from high energy photons or accelerated electrons to orbital electrons of water molecules [4]. Absorbed energy disturbs the electron system of the molecule and results in the breakage of interatomic bonds. Hydrated electrons (e^-_{aq}), H atoms, •OH and $HO•_2$ radicals, H_2O_2 and H_2 are the most important products of the fragmentation and primary interactions (radiolysis products). High reactivity is characteristic of water radiolysis products. As a rule, these products' reactions with impurities in water typically require less than 1 microsecond. At the same time, the reactivity of different radiolytic products is quite different. Hydrogen peroxide and •OH and $HO•_2$ radicals are oxidizing species, while H atoms and e^-_{aq} are chemical reducing in nature [5]. The simultaneous existence of strong oxidants and strong reductants within wastewater under treatment is both remarkable and one of the important characteristics of radiation processing. The •OH radical, by virtue of the high radiation–chemical yield of the formation as well as its high oxidation potential, is the most predominant species. In fact, the oxidation power of •OH is much higher than that of conventional industrial oxidants such as Cl_2, O_2, HOCl, $KMnO_4$, $K_2Cr_2O_7$ and O_3.

The typical rate constants for the reactions of •OH radicals with nitriles, amides, carboxylic acids, esters, and carbonyls are from 1 X 10^7 to 1 X 10^9 $dm^3·mol^{-1}·s^{-1}$; however, with saturated hydrocarbons, alcohols, ethers, amines, alkenes, aromatics, pyrimidines, thiols and disulphides, the rate constants can be greater than 1 X 10^9 $dm^3·mol^{-1}·s^{-1}$ [4]. During its reactions with ions, the *OH radical captures an electron to form a hydroxyl ion:

$$^{\bullet}OH + Fe^{2+} \rightarrow OH^- + Fe^{3+}$$
$$^{\bullet}OH + NO_2^- \rightarrow OH^- + NO_2^{\bullet}$$

whereas in reactions with unsaturated hydrocarbons, •OH adds to the double bond:

$$^{\bullet}OH + CH_2 = CH_2 \rightarrow HOCH_2 - \ ^{\bullet}CH_2$$

and, upon reaction with alkyl compound, the captures a hydrogen atom to produce a water molecule:

$$^{\bullet}OH + CH_3COCH_3 \rightarrow H_2O + CH_3CO\dot{C}H_2$$

A hydrated electron is a stronger reductant than a H atom. In reactions involving cations of metals, e^-_{aq} is able to produce neutral atoms and ions having anomalous valency. Typical reactions of e^-_{aq} consist in e^- addition to the reagent, but can be subdivided into two types [5]. The first type includes simple addition such as:

$$e^-_{aq} + Tl^+ \rightarrow Tl^0$$
$$e^-_{aq} + NO_3^- \rightarrow NO_3^{2-}$$
$$e^-_{aq} + C_{10}H_8 \rightarrow C_{10}H_8^-$$

The second type includes the dissociative reactions of e^- addition:

$$e_{aq}^{-} + \mathrm{RCl} \rightarrow R^{\bullet} + \mathrm{Cl}^{-}$$
$$e_{aq}^{-} + C(\mathrm{NO_2})_4 \rightarrow C(\mathrm{NO_2})_3^{-} + \mathrm{NO}_2^{\bullet}$$

Radiation processing aims at the degradation of pollutants at a faster rate than the generally slow rates of conventional processes. The radiation processing of polluted water containing specific contaminants may require the creation of special conditions to achieve the predominant type of transformation — reduction, oxidation, addition or removal of functional groups, aggregation, disintegration, etc. However, in general, pollutant transformation involves the following pathways: chain oxidation, formation of insoluble compounds, coagulation of colloids and enhancement of pollutant biodegradability.

Chain oxidation constitutes one of the most efficient processes realized in radiation processing of wastewater. As a rule, saturation of wastewater with air is needed for chain oxidation. Radiolytic oxidation at a moderate dose leads to the formation of carbonyl, carboxyl, hydroxyl and/or peroxide groups in organic molecules [5, 6]. The conditions of irradiation can be specifically chosen to achieve chain oxidation of various pollutants. The general mechanism of chain oxidation consists of the following stages:

(a) Initiation : $\mathrm{RH} + {}^{\bullet}\mathrm{OH} \rightarrow R^{\bullet} + H_2O$

$\mathrm{R}^{\bullet} + O_2 \rightarrow \mathrm{RO}_2^{\bullet}$

(b) Propagation : $\mathrm{RO}_2^{\bullet} + \mathrm{RH} \rightarrow \mathrm{ROOH} + R^{\bullet}$

$\mathrm{ROOH} \rightarrow \mathrm{RO}^{\bullet} + {}^{\bullet}\mathrm{OH}$

(c) Termination : $\mathrm{RO}_2^{\bullet} + R^{\bullet} \rightarrow \mathrm{ROOR}$

$2\mathrm{R}^{\bullet} \rightarrow R_2$

$2\mathrm{RO}_2^{\bullet} \rightarrow \mathrm{ROOR} + O_2$

The products of radiolytic oxidation differ from the initial pollutants and are essential in terms of their physicochemical properties and increased ability to undergo biodegradation.

Many organic pollutants can be transformed into insoluble or sparingly soluble compounds upon irradiation owing to the formation of high molecular weight products [7, 8]. Usually, organic compounds having a molecular weight of more than 200 amu have low solubility. The formation of large molecules during radiolysis is realized by the recombination of intermediate radicals formed upon radiolytic transformation of pollutants:

$$2\mathrm{R_2HC} - \dot{C}R_2 \left\langle \begin{array}{l} \rightarrow \mathrm{R_2HC} - \mathrm{CR_2} - \mathrm{CR_2} - \mathrm{CHR_2} \\ \rightarrow \mathrm{R_2HC} - \mathrm{CHR_2} + R_2C = \mathrm{CR_2} \end{array} \right.$$

The pollutant radicals formed may undergo dimerization or disproportionation. In water, the dimerization dominates because of the cage effect and the rapid delocalization of excess energy by inner redistribution along C–C bonds or its transfer to molecules of the medium. Recombination of radicals competes with the reaction of radical addition to unsaturated hydrocarbons:

$$\mathrm{R_2HC} - \dot{C}R_2 + R_2C = \mathrm{CR_2} \rightarrow R_2\mathrm{HC} - \mathrm{CR_2} - R_2C - \dot{C}R_2$$

A high concentration of unsaturated molecules in wastewater can result in the formation of a polymer by the chain repetition of the above reaction.

3. Industrial Wastewater Treatment Plant with the Support of IAEA

Since 1990s, the IAEA supports radiation treatment of water, wastewater, and sludges via various programmes – Coordinated Research Projects (CRPs) and Technical Cooperation (TC) projects. The technology has developed in laboratory and pilot scale, and then transferred to member states through TC projects for further implementation in industrial scale. In late 1990s The Agency conducted "Irradiation Treatment of Water, Wastewater and Sludge" and resulted in several pilot scale operation of wastewater and sludge in Republic of Korea, U.S.A., India, and Argentina. The CRP on "Remediation of Polluted Waters & Wastewaters by Radiation Processing" showed the first industrial scale wastewater treatment plant and it is connected to another CRP on "Radiation Treatment of Wastewater for Reuse with Particular Focus on Wastewaters Containing Organic Pollutants" with the dissemination of this technologies to other Members States – Industrial Plants in China, Mobile EB plants in Korea and Brazil [9].

Wastewater treatment using radiation has not yet found wide application and it is used to a lesser extent than conventional chemical, physical or biological methods. However, pilot plants and industrial scale studies, from the Americas to Europe and Asia, have shown that radiation processing could have a bigger impact in the future. With the support of the IAEA, the Republic of Korea established the first industrial plant for treatment of textile dye wastewater using an electron beam in 2005. Located in the Daegu Textile Dyeing Industrial Complex, the facility had the capacity to treat 10,000 m^3 of wastewater per day [10, 11].

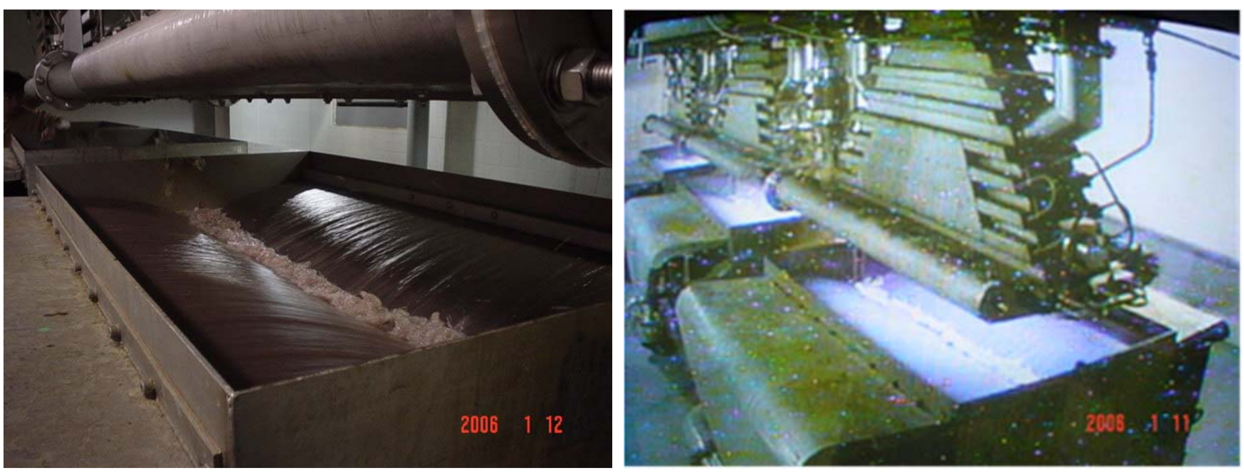

FIG. 1. Industrial electron beam plant for treatment of textile dying wastewater in the Republic of Korea.

Due to the great variety of wastewaters generated by different industries, a universal treatment process is currently not available for industrial wastewater. The focus of radiation processing is to convert non-biodegradable pollutants into biodegradable species. Extensive studies have been carried out on the purification of industrial wastewater by radiation processing, although generally on the laboratory and, to a lesser extent, the pilot plant scale. Convinced of feasibility via a pilot plant, an industrial plant for treating 10,000 m^3/d of textile dyeing wastewater with electron beam (1MeV, 400kW) has been constructed and operated continuously since 2005. This plant demonstrated a reduction of chemical reagent consumption and the reduction in retention time with the increase in efficiency of removal of COD and BOD up to 30~40%. Increase in removal efficiency after radiation treatment is due to radiolytical transformation of biodegradable compounds to more readily digestible forms [11].

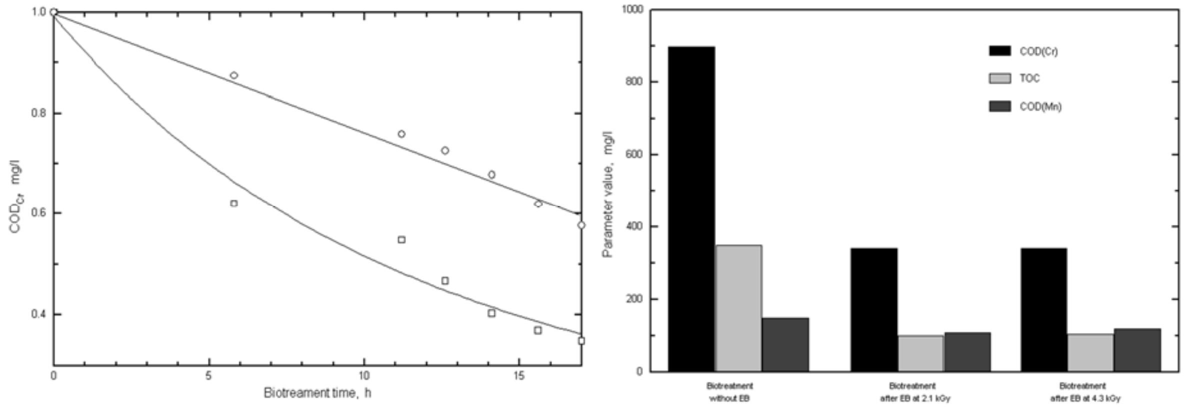

FIG. 2. Effect of electron beam irradiation on biological treatment of wastewater.

Radiation treatment of textile dyeing wastewater and several dyes has also been actively studied in Brazil, Hungary and Turkey [12-14]. A pilot scale wastewater treatment plant was set up at the Institute of Energy and Nuclear Research (IPEN) in Brazil to study the efficiency of removal and degradation of toxic and refractory pollutants present in industrial wastewater. Combined biological and radiation treatment of domestic sewage and sludge was carried out to investigate disinfection. Radiation processing of many other industrial wastewater samples collected at the public wastewater treatment plant in Sao Paulo State was also tested. For industrial wastewater from chemical industries, a dose of 20 kGy was necessary to degrade about 99% of the organic compounds [12].

With the support of IAEA TC project, a pilot facility in Jinhua city, 300 kilometres southwest of Shanghai, was built with a capacity to treat 1,500 m^3 of wastewater per day from a nearby textile factory in 2017 [15]. Two years after the launch of this demonstration project, construction of a commercial treatment plant at the Guanhua Knitting Factory began. Constructed by CGN Nuclear Technology Development Company (CGNNT), a subsidiary of China General Nuclear Power Corporation, the new wastewater plant treats more than 30,000 m^3 of wastewater per day through the operation of seven electron accelerators. It is reported that over 70% of the wastewater that runs through this operation can be reused in the factory, up from the previous reuse rate of 50%. This means less water directly from the nearby river is needed for the operation of the factory, saving 4.5 million m^3 of water every year [16]. Given the growing emphasis on ecological practices, innovative solutions are key for environmental protection, while simultaneously supporting industrial development. This project is a notable example of how a support from IAEA TC projects and CRPs contributes to stimulating the emergence of a sustainable industrial practices in the Member States.

FIG. 3. Treatment plant in China uses electron beam to treat wastewater from textile industries.

4. New Project of IAEA

In 2019, the IAEA launched an international research project to further develop and demonstrate radiation technologies to treat emerging organic pollutants (EOPs) in wastewater [17]. Though low levels of emerging contaminants, such as endocrine-disrupting compounds, antibiotics in water and polyfluorinated compounds in soils may not cause an immediate lethal effect, they could have chronic effects on human and animal health and the ecosystem in general. The four-year project brings together experts from Argentina, Bangladesh, Brazil, China, Egypt, Hungary, Republic of Korea, Malaysia, Myanmar, Poland, Serbia, Slovakia, Tunisia, Turkey, the United States and Viet Nam.

In addition to the research objectives, the project aims to develop standard operating procedures for treating EOPs with different radiation treatment technologies and to establish toxicity measurement assays to determine if the degradation of EOPs by radiation leads to the formation of toxic by-products. Since there is a need to harness radiation technologies to address the environmental pollution caused by EOPs, a multidisciplinary approach that includes the development of new analytical methods to detect pollutants and a deeper understanding of pollutant degradation mechanisms is needed.

The IAEA helps Member States strengthen their capacities in adopting radiation-based techniques that support cleaner and safer industrial processes and for the compositional analysis of materials and objects. It also supports them in applying radiation technology for advanced materials development, nanoscience and the processing of natural polymers into such products, as well as for the management of industrial and agricultural waste and effluents and the decontamination of biological agents.

5. Summary

Radiation technology is quite effective for remediation of contaminated environment. When irradiated with high energy radiation, practically all the energy absorbed initiate the ionization and excitation to result in formation of free radical and molecular species to destroy or to convert the harmful chemicals.

Over the last few decades, extensive work has been carried out on utilizing radiation technology for environmental remediation. This work includes the application of radiation technology for simultaneous removal of SOx and NOx from the flue gases, purification of drinking water, wastewater treatment and hygienization of sewage for use in agriculture.

The IAEA helps Member States strengthen their capacities in adopting radiation-based techniques that support cleaner and safer industrial processes. It also supports them in applying radiation technology for the management of industrial wastes and effluents and the recycling of plastics.

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Efficacy of the compost tumbler as a tool in organic waste management in households in Trinidad and Tobago

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Abstract

In Trinidad and Tobago, organic material comprises a large component of municipal waste, accounting for twenty-seven percent (27%) of waste at national landfills, according to a 2010 waste characterization study. In 2019, the twin island country which is located in the Caribbean was designated as having the second highest fossil CO_2 emissions per capita in Latin America (Alves, 2021). In recognition of home composting as a potential solution to the issue, Central Pathfinders Environmental Foundation (CPEF) posited that an urbanized composting unit (UCU) could ultimately serve as an alternative for organic waste landfilling. CPEF thus commenced a UNDP Global Environment Facility Small Grants Programme-funded project in October 2020 with the design, construction, installation and beta-testing of twelve (12) UCUs, in six (6) households. The objective of this paper is to document the efficacy and efficiency of a locally-produced UCU as a tool for disrupting the flow of organic waste directed to the landfill. Data on the inputs of high nitrogen and carbon materials were analyzed along with temperature, humidity, pH and odour readings. Pre-evaluation survey as well as in-situ feedback was completed in order to collect feedback on the impact of the UCUs on the participating households.

The findings revealed that participating households took on average 17 days to fill the UCU, and a further 59 days to generate mature compost, compared to documented heap composting cases which ranged from 18 days to a year (Raabe, n.d.). Participating households expressed an increased interest in composting at the end of the evaluation period and anticipated that the UCUs would continue to be utilized, given its convenience. The results of the case study indicated that each UCU can potentially remove up to about or 37.12 kg per household per year, from the municipal waste stream and produce compost with a moderate level of efficiency. Households with multiple (5) UCUs can remove as much as 168kg/year. This country generates approximately 189,000 tonnes of organic waste per year based on a 2010 waste characterization study (SWMCOL, 2015). Thus based on these figures, if each household in this country were to implement UCUs, this would significantly reduce organic waste in our landfills.

Keywords: landfill alternative; compost tumbler; composting; Trinidad and Tobago; waste management; NGO

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Introduction

Home composting has the potential to simultaneously disrupt the flow of organic waste to landfill sites and provide a valuable household resource with environmental and economic benefits. An efficient composting process aims to produce a stable organic soil amendment through a controlled decomposition process (Ayilara *et al*., 2020). Composting could reduce the volume of organic waste at landfills, reduce methane emissions and compress the spread of disease, especially due to the illegal dumping. The diversion of organic waste from landfills is also beneficial from a national economic standpoint as it would reduce the cost of waste disposal by authorities (Harir *et al*., 2015; Vásquez and Soto, 2016) and was shown to create more employment opportunities when formulated as a component of a green economy (Tellus Institute, 2010).

The composting process includes the controlled integration of oxygen, water, microorganisms and a ratio of materials containing nitrogen and carbon. Materials that are high in nitrogen, referred to as “brown materials”, include dried leaves, wood chips and saw-dust whereas materials high in carbon, referred to as “green materials,” include manure, food scraps, vegetables and fruits. Most microorganisms require a ratio of 25 - 30 parts carbon to 1 part nitrogen, taking into consideration the C:N ratio within the components used, however, is equivalent to about 1 - 2 parts brown materials to 1 part green by volume. It is also recommended that oxygen concentration be at least five percent (5%), moisture content between 30 - 65% and with a temperature ranging from 43%. The recommendation for particle size was 5 - 30cm (Meena et al, 2021; Vásquez and Soto, 2017).

According to literature (Ayilara *et al*., 2020; Richard, 2005), compost has proven to improve soil structure, provide nutrients to enhance plant growth and increase soil biodiversity. Accordingly, fields with compost have been shown to have high yields (FAO, 2010). Further, the amelioration of soil may encourage home and community gardening, which can ultimately build stronger food systems and improve the existing supply chain, if adequately managed. The use of compost instead of, or in addition to, synthetic fertilizers could reduce household expenditure dedicated to fertilizers and store-bought produce. It is postulated that home composting could reduce the flow of organic waste to landfills and thus, it becomes necessary to quantify the organic waste processed by home composting (Vásquez and Soto, 2016).

The problem of organic waste in Trinidad and Tobago

According to the National Recycling Policy (2015), a 2010 waste characterization study in Trinidad and Tobago concluded that about 27% of all wastes directed to national landfills were organic in nature. Organic waste comprised the highest percentage of waste at the Beetham and Guanapo Landfills at 32% and 22% respectively, with paper categorized separately. Locally, there has been a significant reduction in the capacity of landfills and furthermore, organic waste in a landfill undergoes decomposition under anaerobic conditions, thereby producing methane gas, a contributor to climate change that is a more potent greenhouse gas than CO_2 (UNECE, 2021). It must be remembered that Trinidad and Tobago is the second largest per capita producer of carbon emissions and hence, any attempts to reduce greenhouse gases will contribute to national objectives on the National Determined Contributions (NDCs). To address such issues, it would be prudent to provide an alternative channel for the reduction of organic wastes to national landfills. Solid waste management has to compete with other pressing national matters (Riquelme, Mendex and Smith, 2016) and in the absence of policy tools and national infrastructure, such as organic waste bans and composting facilities, innovative ways to reduce the amount of organic waste proceeding to the landfill should be bolstered at the household level.

The role of CPEF

The Central Pathfinders Environmental Foundation (CPEF), is a non-governmental organization that aims to promote ecological conservation through sustainable environmental and agricultural awareness and development. In recognition of home composting as a probable partial solution to the waste management issue in Trinidad and Tobago, CPEF posited that the application of an easy-to-use and compact urbanized composting unit (UCU) could encourage home composting and ultimately serve as an alternative to the disposal of organic wastes in the landfills. The UCU, entitled “Captain Turner”, was designed to be enclosed, lightweight, compact, thereby alleviating composting challenges such as offensive odours, pests, high labour intensity and lengthy time for compost maturation and featured a tumbling action to reduce manual labour required for mixing materials. As a result, CPEF embarked on a United Nations Development Programme (UNDP) Global Environment Facility Small Grants Programme-funded (GEF SGP) project to design and beta-test the efficiency of an urbanized composting unit for proof of concept and procedural optimization. The objective of this paper is to document the efficacy and efficiency of a locally-produced UCU as a tool for disrupting the flow of organic waste directed to the landfill.

Materials and methods

Selection of participants

Volunteer sampling was utilized for this project. Six (6) households were selected based on their willingness to voluntarily participate in the programme and having indicated a desire to be more environmentally friendly and an interest in composting. A total of twelve (12) compost tumblers were distributed to six (6) households.

A survey was used to determine the following demographics of the participating households:

- All participants were within the 35 - 60 age group.

- Participant households were located in the communities of Cunupia, Carlsen Field, Freeport, San Fernando and Point Fortin, on the island of Trinidad, as seen in Figure 1.
- There was an equal percentage of male and female participants.
- The average size of the households was three (3) persons, with one household containing four (4) and another household containing seven (7) persons.
- Five (5) households contained meat-eaters whereas one household had only vegetarians.
- Two (3) of the six (6) households actively practiced heap composting.
- None of the participating households previously practiced container composting.

Figure 1: Map showing the location of participating households in Trinidad

Programme of evaluation and operation of the compost tumbler

The project commenced in October 2020 with the design and construction of twelve (12) Urbanized Composting Units (UCU), an example of which is shown in Figure 2. Each participating household was provided with two (2) UCUs so that when one (1) was filled and its content maturing, the other could be used for a new cycle. Notably, Covid-19 impacted the number of participating households as planned participants were no longer willing to interact with individuals unnecessarily. Participants were encouraged to test the compost tumblers for the period of five months, April to August, 2021. This period gave the participants enough time to complete at least one (1) cycle in each UCU and harvest mature composted material. Prior to the commencement of the testing phase, all participants were trained in the composting process using a blended approach, that is, via the Zoom platform as this was conducted during the Covid-19 pandemic and in-person training upon delivery.

Figure 2: Photo of UCU

The participants were advised to only use kitchen scraps as their “green” material and were all provided with sawdust to be used as their “brown” material. Participants were provided with covered buckets and a scale so as to apply 1 - 2 parts brown materials to 1 part green materials by volume. Sawdust was provided to the participants to maintain a level of consistency in the brown materials, though an ideal brown material mix would likely include other materials such as dried grass clippings. Dried grass and hard leaves were not recommended for the UCU as it would take a longer period to decompose. CPEF monitored the progress of the testing participants via weekly communication, and site visits in June and August, 2021, that is, during the middle and end of the evaluation period. Please refer to the Appendix for photos of the UCU and items used in the process.

Determination of the efficacy of the compost tumbler

The efficacy of the units for home composting was evaluated based on the amount and kinds of organic material the participants were able to separate from their kitchen waste and divert to the UCUs as opposed to the landfill. The participating households were required to weigh and record the mass of organic waste each time they added material to the UCU. Each participating household was provided with a digital scale and hygrometer to enable them to record the temperature and humidity within the tumblers. Once per week for the duration of the composting period, the participants were asked to record temperature and humidity readings as well as observe and record changes in colour and odour of the composting material.

To evaluate the time taken to produce mature compost, the tumblers were marked with a “fill line”; the participants were advised to stop adding fresh material to the UCU once the material reached the fill line. At this point, the participants were to rotate the UCU twice weekly and continue recording the parameters identified for observation. Participants were advised to open a tap at the base of the UCU in the event of leachate buildup and upon collection, use it to water their plants. The leachate could also be used as an inoculant to ‘kick-start’ another UCU. When the material was judged to be mature, a pH value was recorded, the material was emptied from the tumblers, weighed, and then spread evenly to air dry. CPEF members advised the participants on compost maturity based on changes in colour, particle size and changes in volume. Compost is considered mature when the raw feedstocks are no longer actively decomposing and thus, volume changes halt, particle size is fine and the colour is dark and no longer red. When completely dried, participants were instructed to again weigh the material and sift through soil sieves that were provided. ANOVAs were used to compare the results of the twelve (12) tumblers to ensure consistency in efficiency.

Results and Discussion

Efficacy of the urbanised composting unit

In theory, the organic waste used as feedstock in the composting process represented waste that was destined for the landfill and is a key aspect in determining the role of the UCU in waste diversion. Table 1 shows the input of green and brown materials by the sample households.

Table 1: Green and Brown material inputs into each UCU for the testing period of April - August, 2021

Household	HH1		HH2		HH3		HH4		HH5		HH6		Total	Av.
Unit#	1	2	3	4	5	6	7	8	9	10	11	12		
Greens (kg)	6.20	6.78	9.16	6.58	6.20	4.96	3.88	11.00	7.40	12.35	6.54	12.85	93.90	7.83
Browns (kg)	3.51	3.80	3.15	2.07	2.14	4.17	0.70	3.64	1.52	3.96	2.49	3.95	35.10	2.93
Total (kg)	9.71	10.58	12.31	8.65	8.34	9.13	4.58	14.64	8.92	16.31	9.03	16.80	129.00	10.75

Source: Authors' compilation

Table 1 shows that through the use of the UCU, 6 households successfully diverted a total of 129.00 kg of organic waste from the landfill over a 5-month period, of which 93.90kg was attributed to kitchen waste. The remainder comprised brown materials, as participants were instructed to weigh brown materials amounting to the equivalent of 1 - 2 times the **volume** of the green materials used. On average, the UCU successfully utilized 10.75kg of organic waste, including 7.83kg of kitchen scraps with a range of 4.58kg to 16.8kg among the participating households. The final volumes varied due to the type of materials added as lighter voluminous materials would fill units faster than denser and more compacted materials. The water content of the green materials would also be a contributor to weight. Of the total number of additions (42), participants reported that vegetable and fruit peels were used in all additions, whereas 33.33% of the total number of additions contained leftover food scraps, 30.95% contained eggshells and 11.91% contained tea and coffee grounds. The figures were not mutually exclusive. ANOVA analysis comparing the twelve (12) units showed no significant difference in their performance (P = 0.91).

Efficiency of compost generation

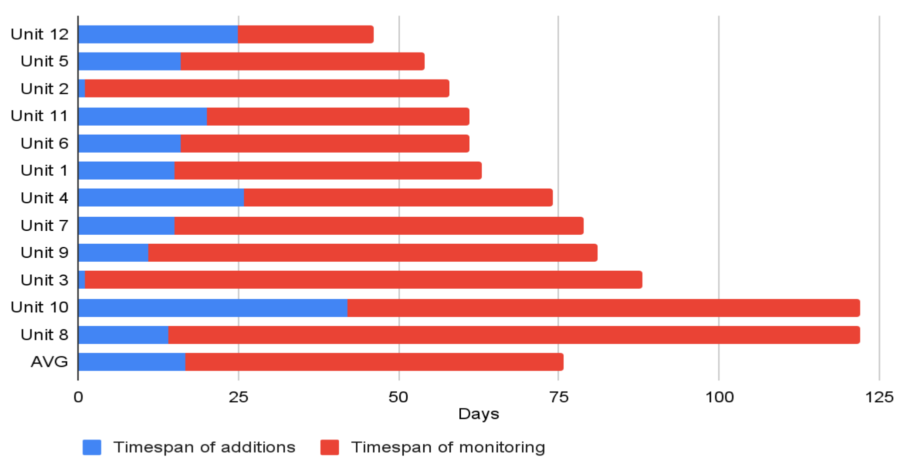

Figure 3: Time taken for additions and maturity and total time per UCU

As seen in Figure 3, the time taken to fill the UCUs was highly variable, ranging from 1 day, in the case of family gatherings, to 42 days, averaging 17 days. Typically, the time taken to fill the UCU would be dependent on the number of persons in the household as well as lifestyle factors such as diet (be it heavily plant-based for example), the number of times per week of home cooking and quantity of leftovers thrown out. Subsequent to the addition of green materials, the time taken for compost maturity ranged from 21 days to 108 days, averaging 60 days. Further data gathering is required from additional testers for validity purposes and to ensure representative data gathering. During the evaluation period, 2 UCUs experienced problems; the contents of UCU #3 become dormant whereas UCU #8 became severely waterlogged. Troubleshooting was required and prolonged the time taken for compost maturation.

If one (1) household were to have only one (1) UCU, then in a 77-day timeframe, the UCU would utilize 7.83kg of kitchen waste, which can be extrapolated to 37.12kg per year, if the household data is representative. However, if households were to have 5 UCUs at their disposal, then one (1) UCU can be used every 17 days to capture all kitchen waste in that household, which would amount to 168kg/year. This country generates 700,000 tonnes of waste every year (SWMCOL 2015; EGARR and Associates, 2013) with organic waste accounting for approximately 189,000 tonnes. Thus based on these figures, if each household in this country were to implement UCUs, this would significantly reduce organic waste in our landfills.

Compost generation

Figure 3 below showcases the output of the urbanized composting tumblers by weight. Wet compost generation per unit is presented below, though individuals were encouraged to fully dry their compost before its final storage or utilization.

Table 2: Compost generated by each UCU for the testing period of April - August, 2021

Household	**HH1**		**HH2**		**HH3**		**HH4**		**HH5**		**HH6**		**Total**	**Avg.**
Unit#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		
Feedstock (kg)	9.71	10.58	12.31	8.65	8.34	9.13	4.58	14.64	8.92	16.31	9.03	16.80	129.00	10.75
Wet compost (kg)	7.81	8.68	7.35	6.75	7.43	6.72	4.02	7.94	6.63	14.02	7.65	14.43	99.43	8.29

Source: Author's compilation

Literature indicates that the time frame for compost maturation is variable, based upon conditions, the type of composting process as well as inputs (Raabe, n.d). Compost is considered mature when the raw feedstocks are no longer actively decomposing and are biologically and chemically stable. Generally however, the Berkeley method generates compost in a 18 - 30 day period whereas passive composting generates composting in 130 days and more. In this regard, the efficiency of generation of compost from the urbanized composting unit in 56 days can be classed as **moderate.**

In the event that the compost is not mature, decomposition will continue to occur thus reducing the availability of nutrients for plant growth and potentially damaging plants via root rot. Another effect of using immature compost is the release of compounds such as carbonic acids and sulfides which could compromise root systems. The chemical components responsible for the lower pH values such as carbon dioxide and the associated carbonic acid are depleted naturally once metabolic activity ceases, which indicates the completion of composting. The theoretical pH range for finished compost is above 7, which was attained by all participants upon completion of the composting process. It should be noted that the pH of materials also affects the composting rate and varies as the compost approaches maturity.

Participants used their generated compost as potting soil and as soil amendments. Most participants gave positive feedback in terms of being able to produce their own compost as well as the quality of the compost, which resulted in positive growth of their plants and seedlings.

Potential and resulting considerations

Participants expressed positive feedback on the initial Zoom training, rating their new knowledge as useful and very useful. Moreover, through interviews, it was found that testers had an continued interest in composting given the convenience and ease of use of the UCU. Based on interview responses, the participants were particularly pleased that the UCU was enclosed and did not encourage pests. However, participants stated that problems faced were unpleasant odours and leachate issues. Observations indicated that waterlogging appeared to be the major problem, which then led to lowered temperatures and prolonged compost generation times; participants were advised to leave the leachate drain open and open the cover periodically as a solution. All participants expressed interest in continuing to use the UCU at the end of the evaluation period, thereby indicating a reduction of organic wastes from 6 households being directed towards the landfill. The response that participants would continue to use the UCU was promising as it signified that the easy-to-use and compact design could result in behavioural change as it relates to organic wastes. Notwithstanding, further research into this aspect is required.

Pending further data collection, through an increase in number of users over a longer period of time, the community and/or national benefit can be obtained on an annual basis by multiplying the estimated number of households by the quantity of organic waste utilized by time frame ratio (to obtain an annual rate).

Composting process characteristics

Given that specific ranges of temperatures and humidities are recommended as optimal, Figures 4 and 5 represent the recorded values during the period by the participating households. A mixed microbial community is integral to composting, involving aerobic mesophilic organisms which dominate the initial and final stages of composting that represent the lower temperature stages and thermophilic organisms which produce the highest temperatures.

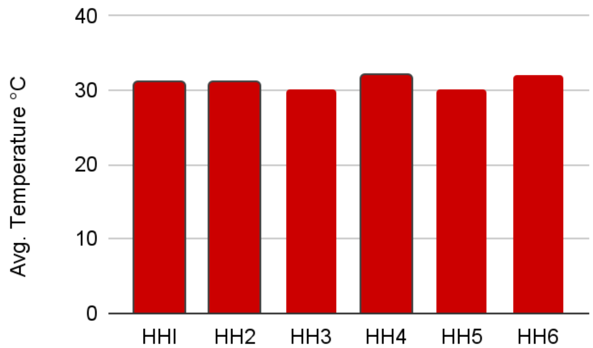

Figure 4: Avg. UCU temperature per household

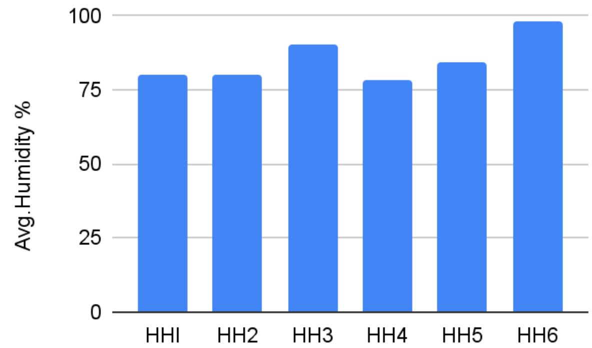

Figure 5: Avg. UCU humidity per household

The temperatures in Figure 4 were measured at the surface, not internally and ranged from 28℃ - 36.2℃. Internal temperature readings were taken periodically with a compost thermometer and confirmed that internal temperatures were higher than that of the surface temperatures. A consistent programme of internal monitoring was difficult to adhere to based on limited site visits due to Covid-19 considerations, however, provided a range of temperatures from 37℃ - 43℃.

Nonetheless, the surface temperatures recorded were no higher than 32℃. Vásquez and Soto (2017) proposed that the moisture content in a home composting unit constrained the temperature of the compost itself. From the experimental data gathered and experience in household compost heap maintenance, the size and shape of a compost heap is better suited for drainage whereas it is possible that the size and shape of the UCU dissipated heat more readily, leading to a stable mesophilic phase of composting. The relative humidity of the UCUs were over 75%, likely due to respiration by microorganisms and limited drainage. Waterlogging may occur from excessive additions of water, low amounts of dried brown materials and the emergence of water from moisture rich foodstuff.

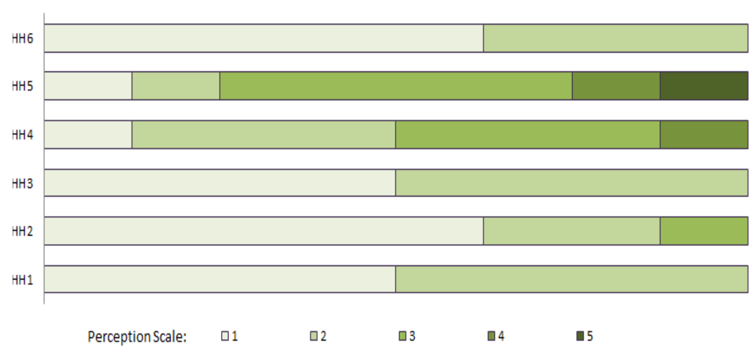

Figure 6: UCU odour perception per household

Odour rating was set to a subjective 1 - 5 scale: 1 being relatively odourless and 5 being a highly offensive scent. Odours are an indication that the decomposition has moved from aerobic to anaerobic

(Colon *et al*, 2010). During aerobic composting the main gases produced are carbon dioxide and water vapour with trace amounts of other gases. Anaerobic composting generates malodorous compounds such as hydrogen sulfide and ammonia, along with odourless greenhouse gases such as methane, carbon monoxide and nitrogen dioxide. The subjective detection of the malodorous compounds indicated that the tumbler was possibly waterlogged and required immediate attention. As seen in Figure 6, households 4 and 5 witnessed the emergence of malodorous gases and a possible shift to anaerobic composting whereas the remaining households had low to no odours.

Challenges and Limitations

Limitations of the evaluation process are as follows:

- Covid-19 regulations limited regular in-person interactions which would have been useful to make more frequent site visits to the testers to verify their internal temperature and humidity readings. Also to monitor the state of the UCUs with respect to waterlogging and or microbial inactivity to thereby better advise the testers on corrective actions.
- Data gathering on the efficacy and efficiency of the UCU is required from additional testers for validity purposes and to also determine further adherence issues as well as problems which require troubleshooting.

Challenges regarding the composting process included:

- The design of a cost-effective design for an enclosed leachate recovery process.
- The occurrence of waterlogging, which leads to a reduction in the diffusion of oxygen and in turn reduces the metabolic activities of the organisms appeared to be an issue. To counter the issue, instructions were changed so that participants would leave the drain-tap on the ‘on’ position, rather than vent when necessary.
- Maintenance of required temperatures. Further research and iterative design improvements may be required to ensure sufficient oxygenation and maintenance of the required temperatures.
- The UCU appeared to be functional for households of 4 individuals and under.
- Potential opportunities for further research to disrupt the flow or organic waste to the landfill include a larger composting unit. This would be especially useful and welcomed given the fast rate at which the designed UCU was filled.

Marketing Strategy

Upon completion of the beta-testing phase, CPEF embarked on a plan to market and sell the tumblers to the general public. Branded as ***“Captain Turner - the household compost tumbler”***, CPEF created an email address and pages on social media platforms, Facebook and Instagram, to provide information on this novel product and allow interested persons to place orders to purchase. Figure 7 showcases an example of a published flyer. The product is priced at $500.00 - 600.00TTD. In Trinidad and Tobago, the average cost of a 45kg bag of compost is currently $60.00 - 75.00TTD; Captain Turner affords its owner the ability to produce compost indefinitely for less than the cost of 10 bags of commercial compost. CPEF provides an added value proposition to its customers, knowing that when they purchase Captain Turner they support a local non-governmental organization which has created an upcycled product, which can efficiently recycle their organic kitchen scraps into a medium they can use in their kitchen gardens and potted plants to add nutrients and improve soil structure. After-sales support is also a feature of the product as CPEF via text communication will provide troubleshooting advice to its customers.

Figure 7: Marketing flyer for the UCU

Recommendations and Conclusion

Based on the data collected on the beta-testing, the following can be concluded about the UCU:

1. The UCU is an effective method of reducing household organic waste and converting it into a viable household product (compost);
2. The UCU works well under the local climatic conditions and allows the production of mature compost within 60 days (2 months). This is a lower timeframe than other research on passive heap composting which can take as long as a year (Raabe, n.d.).
3. It is important that users of the UCU reduce the water content of the material going into it in order to reduce water logging and foul smells as well as allow leachate to drain as much as possible.
4. The produced compost has proven to be useful to the beta-testing participants who used it for their home gardens and potted plants.

The following recommendations are hereby suggested to aid the improvement of the UCU and the monitoring process:

- A programme of further research to gain additional data on the current process as well as mitigate challenges encountered. Research and observations would also serve to introduce information for other aspects such as the determination of an ideal brown material mix.

- More research is also required to determine the impact of wider-scale composting activities. For example, compost can retain excess water that may contribute to flash flooding and assist in conserving water to maintain larger-scale crop yield (Kirchhoff *et al*., 2003).
- It is especially acknowledged that public education campaigns are critical to inform households of the need to reduce their organic waste disposal and redirect it towards a beneficial resource in order to achieve large-scale behavioural change. Due to its compact size, the UCU tumblers can serve as an educational tool showing how the composting process is carried out.
- The expansion and replication of the use of the UCU in communities on a large-scale basis can culminate in a significant disruption of organic waste directed to landfills while promoting sound agricultural practices and improving environmental and human health.

In conclusion, home composting may be a viable solution to reduce a proportion of the organic waste stream that is directed to landfills in Trinidad and Tobago. CPEF continues to advocate for change in waste management locally by educating the public on the need to integrate home composting into their lifestyle and by promoting useful waste management tools and techniques, such as the UCU. The UCU has proven to be advantageous over the traditional method of compost for some individuals, due to its rate of compost generation, enclosed and compact design. The UCU was found to have a moderate efficiency and the potential to disrupt about 7.83kg of organic kitchen waste every 17 days and produce compost in a further 60 days. A shift in behaviour from dumping organic waste to the utility of a waste management tool, namely the UCU, may serve to improve environmental and human health.

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Appendix

Figure A1: Photos showing participants with UCUs

Figure A2: Photo showing some of the items that were distributed to participating households

Figure A3: Photo showing inside of a UCU in use, with humidity and temperature recorder

Figure A4: Photo showing matured compost

TITLE: OPTIONERING AND DESIGN OF SMALL-SCALE PILOT GREYWATER COLLECTION, TREATMENT AND REUSE SYSTEM, COLLEGE STREET GHAUT, ST KITTS.

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Abstract

This paper focuses on a pilot study for collection, treatment and reuse of greywater in the College Street Ghaut in St. Kitts and Nevis which is part of a large IWEco Project. The design of the greywater treatment system was informed via an extensive literature review.
The review of the technologies for greywater treatment and reuse was conducted. It revealed that the traditional treatment of wastewater, i.e., via unit operations such as sedimentation, filtration, disinfection is relevant. Various commercial options were also considered.
The volume of greywater generated was estimated based on the per capita water consumption and the number of persons per household.
Samples were collected and analyzed by the Bureau of Standards of SKN. The parameters determined were Biological Oxygen Demand, (BOD_5^{20}) =111 mg/l, Total Dissolved Solids (TDS) = 352 mg/l, Total Suspended Solids (TSS) = 200 mg/L, Nitrates = 48.10 mg/l and Phosphates = 0.56 mg/l.
The above-mentioned options were not recommended due to the lack land area required, the fact that some are energy intensive, and the skills-set required to operate and maintain these systems may not be found among householders.
The most appropriate technology was determined to be a Vertical flow constructed wetland (VFCW). The required land space ranges from 0.1 to 1.5 m^2/P. E. For a household of 5 persons (5 P.E), the area required is 3 m^2 (33 sq. ft). This treatment method requires pre settling of the greywater. Tropical ornamental flowering plants (OFP) such as *Canna spp., Iris spp., Heliconia spp*., *Zantedeschia spp*. (Calla lilies) and *Hedychium coronarium* (ginger lilies) were included since it is a good economic option and their flowers add to the esthetic appearance of CWs. The treated effluent can be reused for irrigation. The effluent quality reported: reduction in COD 90%, TSS 95%, and nitrates of 85%.

Key Words: greywater, reuse, constructed wetland, Canna spp., Heliconia spp., Hedychium coronarium

1.0 Introduction

The Waterwise group (2021) defines greywater or sullage is the water that is created from activities such as showering, bathing, or doing laundry. It gets its name from its somewhat murky, cloudy appearance. While not nearly as dark as sewage, greywater is easily distinguishable from tap water. Greywater contains lower amounts of contaminants than black water and can therefore serve a variety of useful purposes in and around the home.

2.0 Grey Water Management Strategies

2.1 Grey water is not wastewater but a valuable resource

The choice of a greywater management strategy depends on the end use of the effluent. The planning of such management systems should be done with the reuse in mind and should be adapted to a specified purpose, such as agricultural reuse, ground water recharge or discharge into inland or coastal waters.
Greywater reuse provides several benefits including:
Reducing potable water demand
Reducing the amount of wastewater discharged into the environment
A well-watered, healthy garden
Reduces household water bills as well as the water footprint.

2.2 Grey Water Recycling

The simplest and cheapest greywater recycling system is to capture shower and bath water in a bucket and use it to flush a toilet. Another simple way is to collect the water from a washing machine in a tub by connecting the outlet to the tub and using this water for irrigating a garden. Greywater can be used for other purposes like washing vehicles and driveways, mopping or cleaning sideways/staircases.
The contaminant elements present in greywater are soap, shampoo, toothpaste, shaving cream, food scraps, organic matters, and nutrients (e.g., nitrogen, potassium). These constituents do not necessarily harm the garden soils and plants if used for irrigation purposes. However, care must be taken to remove pollutants such as powdered laundry detergents which have high salt and phosphorus concentrations. These can stunt plants with low phosphorus tolerance if the greywater is used for irrigation purposes. (Marshall, 1996; Erguder *et al*.,2009).

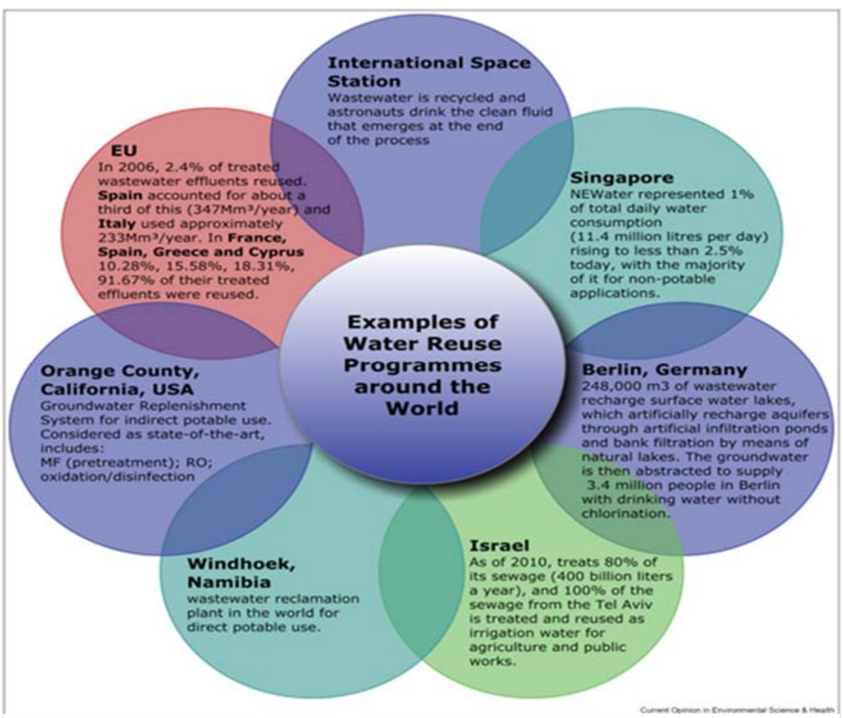

Figure 1 - Examples of Wastewater recycling around the world (Courtesy Environmental Source & Health, 2018)

3.0 Centralized verses Decentralized Wastewater Treatment Systems
In reviewing the mandate given in the Terms of Reference of this project, it begs the questions, "Why does the city of Basseterre do not have a central sewerage system?" Why does the same situation exist in the neighboring St. John's in Antigua? Why was a central sewerage system built in the early 1930's in St. George's, Grenada but still serves less than 5 % of the population? Why does the central sewerage system in the Castries harbor, for the last 30 years, have a broken sea outfall that is yet to be repaired? The short answer to these questions is that centralized systems are too expensive!
The traditional wastewater management concept, i.e., centralized system includes sewage collection and its treatment at the central treatment plant is difficult to adopt in developing countries mainly due to prohibitive costs. To overcome this limitation of the centralized system, decentralized wastewater management systems have evolved, with the wastewater treated close to where it is generated.
Successful decentralized treatment system should possess the following characteristics:
Produce a good quality effluent for reuse and increase wastewater reuse opportunities;
Able to deal with high flow and load variations and is adaptable to different discharge requirements;
Simple and easy operation and reduced risks associated with system failure;
Low overall cost - i.e., capital, installation, and operating & maintenance cost;
O & M must be accomplished by people who are specially trained for the job to be accomplished.
Minimal aesthetic impact; Small footprint of the treatment plant and allows incremental development and investment of the system; and Long useful life.
The present project focused on the development of a highly efficient, compact, user friendly and economical system which is nature-based in order to serve the needs of developing countries in general and the people of St. Kitts around the College Street Ghaut in particular as it relates to greywater management.

4.0 Greywater constituents

4.1 Chemical parameters & Nutrients in greywater
General features of greywater are that it contains lower concentrations of organic matter, of some nutrients (e.g., nitrogen, potassium) and microorganisms than blackwater. The concentrations of phosphorus, heavy metals and xenobiotic organic pollutants are around the same levels. The main sources for these pollutants are chemical products such as laundry detergents, soap, shampoo, toothpaste, and solvents.
The content of biological oxygen demand (BOD) and chemical oxygen demand (COD) in greywater indicate the risk of oxygen depletion due to the degradation of organic matter during transport and storage and the risk of sulphide production which causes a mal odour. (Ledin et al., 2001a).

Table 1: Measured values of nutrients in greywater (Ledin et al., 2001a)

Nutrients [mg/l]	**Laundry**	**Bathroom**	**Kitchen sink**
Ammonia (NH_3-N)	< 0.1- 3.47	<0.1- 25	0.2 - 23.0
Nitrate and nitrite as N*	0.10 - 0.31	<0.05 - 0.20	-
Nitrate (NO_3-N)	0.4 - 0.6	0 - 4.9	-
Phosphorus as PO_4	4.0 - 15	4- 35	0.4 - 4.7
Nitrogen as total	1.0 - 40	4.6 - 20	15.4 - 42.8
Tot- N	6 - 21	0.6- 7.3	13 - 60
Tot- P	0.062- 57	0.11- 2.2	3.1 - 10

*** = per 100ml;**

4.2 Ground elements in greywater & Heavy metals in greywater

Laundry wastewater was found to contain elevated sodium levels compared to other types of greywater. The sodium in the laundry wastewater may be caused by the use of sodium as a counter-ion to several anionic surfactants used in powder laundry detergent and the use of sodium chloride in ion-exchangers (Eriksson et al., 2002).
Plastic and metal piping release compounds, such as Xenobiotic Organic Compounds (XOCs) and heavy metals, into the water supply and to greywater generated. Chemical products, resulting from water use, the type of pipes used for transmission and the quality of the water supply when it leaves the water works. Materials such as Arsenic, cadmium, iron, lead, mercury, etc. The Xenobiotic organic compounds (XOCs) that could be expected to be present in greywater constitute a heterogeneous group of compounds. They originate from the chemical products used in households such as detergents, soaps, shampoos, perfumes, preservatives, dyes, and cleaners. Kitchen wastewater contains lipids (fats and oils), tea, coffee, soluble starch, dairy products, and glucose, while the wastewater produced from laundry will contain different types of detergents, bleaches and perfumes (Eriksson et al., 2002).

4.3 Physical parameters

Greywater temperatures are often higher than the temperature of the water supply due to hot tap water used for personal hygiene and laundry. High temperature favors microbial growth and leads to precipitation of e.g., calcite in supersaturated waters (Eriksson et al., 2002).
The measurements of turbidity and suspended solids give information about the content of particles and colloids that could cause clogging of soil pores and installations. Generally highest values are found in greywater generated in kitchen sinks and washing machines as shown in Table 2.

Table 2: Physical properties of greywater (Ledin et al., 2001a)

Physical properties [mg/l]	Laundry	Bathroom	Kitchen sink
Colour (Pt/Co units)	50 -70	60 - 100	
Suspended solids	79 - 280	48 - 120	134 - 1300
TDS		126 - 175	
Turbidity [NTU]	14 - 296	20 - 370	
Temperature [°C]	28 - 32	18 - 38	

4.4 Microbiological parameters

Generally, very little is known about the presence of microorganisms in any specific greywater. The types and quantities may vary depending on a myriad of factors. Four types of pathogens may be present: viruses, bacteria, protozoa, and intestinal parasites (helminths). It can, however, be expected, when evaluating microbiological parameters, that microbial populations of faecal origin in greywater cause the major health risks (Ledin et al., 2001a).

5.0 WHO Guidelines for Agricultural Use of Wastewater

Standards developed 40-50 years ago (1969-1979) tended to be very strict, as they were based on an evaluation of potential health risks associated with pathogen survival in wastewater, in soil and on crops, and on technical feasibility. The technology of choice for pathogen removal at that time was effluent chlorination. Evaluation of the credible epidemiological evidence; (an appraisal of the actual, as opposed to potential, health risks) – indicated that these standards were unjustifiably restrictive. As a result, a meeting of experts held in Engelberg, Switzerland, in July 1985, recommended the guidelines shown in table 4 (WHO, 1989b).

Table 4: Tentative microbiological quality guidelines for treated wastewater reuse in agricultural irrigation
(WHO, 2000b (adapted from WHO,1989b))

Reuse process	Intestinal nematodes (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted use: irrigation of trees, fodder crops, industrial crops, fruit trees and pasture	≤ 1	Not applicable
Unrestricted use: irrigation of edible crops, sport fields and public parks	≤ 1	≤ 1000

For developing countries, it is therefore more feasible to rely on the WHO guidelines for their own legislation than on USEPA or FAO guidelines.

6.0 The concept of Reuse/ Recycle and Green, and Circular Economies

The Water Supply and Sanitation Collaborative Council (WSSCC) created an Environmental Sanitation Working Group (ESWG) which in turn developed the Household Centered Environmental Sanitation Approach (HCES) (SANDEC/WSSCC, 1999). The HCES recommended among other things:

People and their quality of life should be at the centre of any advanced Urban Environmental Sanitation System (UESS); Solutions of UESS problems should take place as close as possible to the place where they occur. "Waste", whether solid or liquid, should be regarded as resources; UESS system should be "circular"- designed in such a way as to minimize inputs and reduce outputs.

It must be noted the HCES approach consist of two main components: (a) the household centered planning approach which deals with consultation with the stakeholders among the households, problems are solved as close as possible to their sources and (b) the circular system of resource management which seeks to minimize waste transfer across circle boundaries by minimizing waste-generating inputs and maximum recycling/reuse activities in each circle.

The project consultants have pursued these concepts in the "Design, Collection, treatment and recycling of Greywater system for the College Street Ghaut" which falls within the above-mentioned context. The Consultants were also mindful that the solution needed to be simple, i.e., easy to design, economical and sustainable operations and maintenance; should be nature-based; and that available land space is a limiting factor; hence the use of constructed wetlands in wastewater treatment was investigated thoroughly.

7.0 Constructed Wetlands in treatment of wastewater

Constructed wetlands (CWs) are systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters. The first experiments aimed at the possibility of wastewater treatment by wetland plants were undertaken by Käthe Seidel in Germany in the early 1950s at the Max Planck Institute in Plön (Seidel, 1976). Danish Studies were carried out in 1960's with emergent species such as: Phragmites australis (common reed), Typha latifolia (bulrush, common bulrush, common cattail). These systems known initially as reed beds gave excellent removal ratios for BOD520 (80 - 95%) & Total Dissolved Solids (TSS) (> 85%). The first fully constructed wetland was built with free water surface (FWS) in the Netherlands in 1967 (Kadlec and Tilton, 1979).

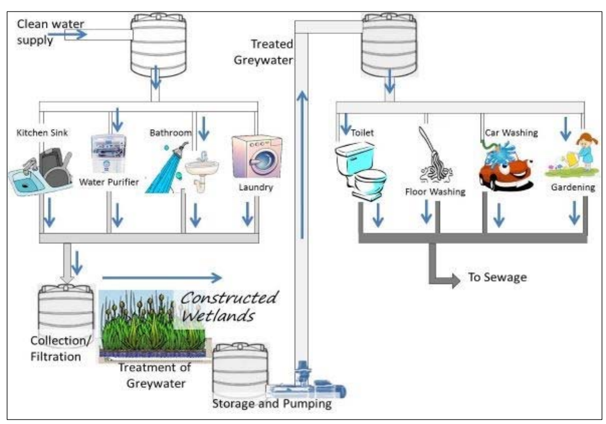

*Figure 2 - **Schematic of the concept of greywater recycling***

https://www.iamrenew.com/environment/grey-water-recycling-solution-catches-eyes-in-water-deficit-kerala/

However subsurface-flow type prevailed in the 1980s and 1990s (Vymazal and Kröpfelová ,2008).

In North America, FWS CWs began with the ecological engineering of natural wetlands for wastewater treatment at the end of the 1960s. Subsurface-flow technology spread slowly in North America applicable to the treatment of various types of wastewater. At present, thousands of CWs of this type are in operation (Kadlec and Wallace, 2008).

Figure 3 – Constructed Wetland, Grenada

In Grenada there are three Horizontal Subsurface-Flow wetlands systems which were constructed since 2006. The first was a demonstration pilot Model Liquid Waste Wetland Treatment under the GEF-IWCAM Project in 2006. It was constructed to treat domestic wastewater from an office block/restaurant, events/theater complex. The second was to serve a three-bedroom house in 2019 (See Figure 3). The third was constructed in 2020 to serve a three-bedroom dwelling & three single-bedroom apartment complex. These systems were planted with the following ornamental flowering plants: heliconia, ginger lily, ornamental banana and bird of paradise. They have been giving excellent effluent quality.
Molle et al., (2005) & (Seidel, 1976) in their study concluded that Vertical flow systems, if well designed, can achieve an effluent level that will meet the most stringent class, 95% removal of BOD, 90% removal of total-P and 90% nitrification. (Brix et al., 2003 & Arias et al, 2003) reported that these systems can give effluent quality of 60 mg/l COD, 15 mg/l SS, and 8 mg/l TKN with an area of 2 - 2.5 m2/P.E.

7.1 The role of Constructed Wetlands in the treatment of Greywater Use of Ornamental Flowering Plants in Constructed Wetlands for Wastewater Treatment

Gorky, (2015), has proven through experiments that constructed wetland treatment systems have been an effective method for treatment grey water for recycling. In her research, the effectiveness of the wetland plant Colocasia esculenta in the treatment of grey water by vertical subsurface-flow constructed wetland system was studied. It was seen that the reed bed unit had reduced the concentrations of TSS, TDS, BOD, COD by 66%, 89%, 85%, 82% respectively on an average. These results indicated that this method of treatment is well suited for greywater.
Sandoval et al, (2019) reported after carrying out a review of the application of CWs in fifteen (15) countries, that the four most used flowering ornamental plants in constructed wetlands were Canna, Iris, Heliconia and Zantedeschia. This survey is very relevant to the Caribbean, it being part of The Tropics. Canna spp. (Canna Lily or Indian Shot Plant) are commonly found in Asia, Zantedeschia spp. (Arum Lily, Calla Lily or Pig Lily) is frequent in Mexico, Iris has been most used in Asia, Europe and North America. Species of the Heliconia genus (Lobster Claw Plants) are commonly found in Asia and parts of the Americas (Mexico, Central and South America & the Caribbean).
They reported removal efficiency of biochemical oxygen demand (BOD) (51–82%), chemical oxygen demand (COD) (41–72%), total suspended solids (TSS) (62–86%), total nitrogen (TN) (48–72%), total phosphorous (TP) (49–66%), ammonium (NH4-N) (62–82) & nitrates (NO3-N) (63–93%). Excellent removal efficiencies were also recorded for coliforms and some heavy metals (Cu, Zn, Ni and Al).

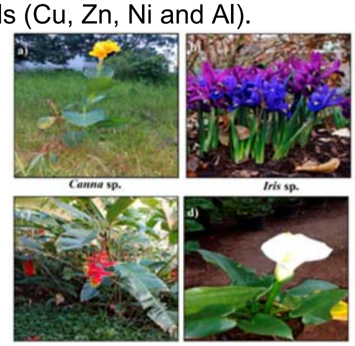

Figure 4

In general, the mean TN and TP removal when using ornamental plants in CWs were less than the mean removal of the other pollutants (TSS, CDO, BOD, NH4-N or NO3-N). Such removal is influenced not only by the plants, but also by other parameters, such as filter media; or operational parameters, such as hydraulic and influent loading, which are related with the removal of pollutants in CWs and need to be considered in system designs (Yan et al., 2007).
The use of Ornamental Flowering Plants (OFP) (especially species with different colours) in CWs provides an aesthetically pleasing appearance in the systems making it more probable for adoption and replication. In CWs with high plant production, OFP harvesting can be economical for operators/owners of CW, providing social and economic benefits. Such benefits include improvement of system landscapes, and improved

environmental quality. The flowers could be sold as bouquets, as plants with attached roots for use in gardens, or for crafts made with parts of the plants. These are pertinent issues to be addressed for the project under consideration.

8.0 Costs

The literature reviewed indicates that the basic investment costs for constructed wetlands include land, site investigation, system design, earthwork, liners, filtration (HF and VF CWs) or rooting (FWS CWs) media, vegetation, hydraulic control structures and miscellaneous costs (e.g., fencing, access roads) (Wallace and Knight, 2006). However, the proportions of individual costs vary widely in different parts of the world. Also, larger systems demonstrate greater economies for scale (Wallace and Knight, 2006). For example, (Vymazal and Kröpfelová, 2008) summarized available data from HF CWs in U.S., Czech Republic, Portugal, Spain and Portugal and found out that excavation costs varied between 7% and 27.4% of the total capital cost, while gravel varied between 27% and 53%, liner (13%–33%), plants (2%–12%), plumbing (6%–12%), control structures (3.1%–5.7%) and miscellaneous (1.8%–12%). The total investment costs vary even more, and the cost could be as low as 29 USD per m^2 in India (Billore et al., 1999) or 33 USD per m^2 in Costa Rica (Dallas et el., 2004), or as high as 257 EUR per m^2 in Belgium (Rousseau et al, 2004). In Grenada these systems were constructed with a concrete envelop and were preceded with septic tanks and up flow filters. The cost of a system for a typical three-bedroom house is $4,780.00 US, i.e., $ 357 US per m^2. The media was ¾" minus crushed stones and were planted with ornamental flowering plants. Constructed wetlands have very low operation and maintenance costs, i.e., maintenance of access roads and berms, pretreatment maintenance (including regular cleaning of screens and emptying septic and grit chambers), vegetation harvesting (if applicable). The basic costs are much lower than those for competing concrete and steel technologies, by a factor of 2–10 (Doherty et al., 2015) & (Kaldec and Wallace, 2008). In addition, because wetlands have a higher rate of biological activity than most ecosystems, they can transform many of the common pollutants that occur in conventional wastewaters into harmless byproducts or essential nutrients that can be used for additional biological productivity. These transformations are accomplished by virtue of the wetland´s land area, with the inherent natural environmental energies of sun, wind, soil, plants, and animals. Due to the natural environmental energies at work in constructed treatment wetlands, minimal fossil fuel energy and chemicals are typically needed to meet treatment objectives (Kaldec and Wallace, 2008).

9.0 Conclusions

Based on general considerations, public health, environmental, financial, and technological criteria the varying treatment trains all present some disadvantages. the main of which are as follows:
not enough available land space to accommodate these systems on residential lots along the College Street Ghaut,
the necessary skills set to operate and maintain these systems may not be found among householders,
the commercial systems are energy intensive and moving parts may render them not sustainable,
These commercial systems are not nature-based so they were not considered as sustainable solutions.
Stakeholder consultations were a critical component of this review. Residents and commercial interests in the study area, operators of motor vehicles, pedestrians and government organisations were interviewed. Interviews were conducted face to face, via telephone and social media. A consultation of government organisations was conducted virtually via zoom.
The consensus from individuals, businesses and government organisations was that the greywater flowing down College Street Ghaut posed a threat to human health, was not aesthetically pleasing, had the potential to impact the near shore marine environment and negatively affected both vehicular and pedestrian traffic through College Street. There was also consensus that the government should make control and or treatment of greywater a priority, but interviewees offered varied solutions to the problem. Table 5 below presents a comparative analysis of Pros and Cons of the systems considered as possible solutions for greywater treatment at College Street Ghaut.

Table 5. A Comparative Analysis of Suitability of Different Wastewater Systems Applicable to the Treatment of Greywater in College Street Ghaut Based on Various Criteria

	TYPE OF WASTEWATER TREATMENT SYSTEM

Criteria	Traditional septic tank and filtration	Typical package/ mechanical systems	Waste Stabilization Ponds	Settling Tank and Constructed Wetlands
General Considerations				
Decentralized	Yes	Yes	Yes	Yes
Appropriate	Yes, only if disinfection is added	Yes	Yes	Yes
Innovative	No (Traditional)	Yes	No	Yes
Nature-Based	No	No	Yes	Yes
Treatment Efficiencies	Moderate	Very good	Excellent	Excellent
Social Acceptance	Good	Yes, in developed countries where electricity is cheap	Yes, where cheap land is available	Yes, in the countries where they were constructed which includes Developing Countries
Land Availability	No. Septic Tank and filters take up too much land space. (Require.23 Sq M/5 P.E)	Yes (Require 2.5-3 Sq. M/5 P.E)	No (Require 30-40 Sq. M /5 P.E.)	Yes (Require up to 5 Sq. M/ 5 P.E)
Environmental Criterion				
Nutrient Recycling (P, N)	No	yes	yes	yes
Organic matter recycling	no	no	yes	yes
Occupied area	protected	protected	Open and can attract birds and may emit offensive odours if overloaded	Open but the subsurface- flow ensure that the water level is below the media, hence no proliferation of mosquitos or attraction of birds
Energy Use	Nil	High	Moderate to nil. (Aerated ponds use up energy for aerators and pumps if gravity flow between the different ponds is not possible)	Nil
Quantity of Sludge and biosolids production	Medium to large after 4 to 5 years of operation	Small to medium	Large quantities after 3 to 4 years of operation	Nil
Sludge quality	stabilized	Partially stabilized	Stabilized	Not Applicable
Eutrophication potential of effluent	Medum to high	Low	Very low	Very low or nil if recycling for irrigation is considered
Disinfection Consumption of effluent	Medium to high	high	Very low since substantial die off of bacteria has been recorded	Very low since up to 96% removal of coliforms is reported

Public Health				
Contact Risk	Medium to high	Low to medium	Very low	Very low
Treated Effluent Quality	Satisfactory to good	Good to very good	Very good to excellent	Excellent
Public Acceptance	Good	Very good to excellent	Very Good	Very good to excellent
Potential for reuse of treated effluent for irrigation and other uses	Median	Excellent	Excellent once they are not over loaded	Excellent
Financial				
Capital Cost	$3,680.00	$13,600.00	$10,200.00	$3,995.00
O&M Cost	$100.00	$1,000.00	$2,000.00	$450.00
Expected Lifetime	40 - 60 years	10 - 15 years	50 - 80 years	50 - 80 years
Operation and Maintenance Requirements	Low to medium. Medium because of the filtration	Very high, these are mechanical systems are energy intensive	Low to medium (especially if aerators are used for oxygenation. Desludging after years of operation can be time consuming and messy)	Maintenance activities are minimal. (The harvesting of plant material when they are overgrown. The system recommended will be planted with ornamental flowering plants that will have commercial value)
Technological				
Ability to adapt to hydraulic fluctuation	Good	Low to medium	Low to medium	Very good
Ability to adapt to changes in organic load	Good	Good	Low to medium	Very Good
Vulnerability to natural disasters and climate change	Medium since the system will be covered and generally the envelop will be made of reinforced concrete	High	High	High

Financial: Capital costs were based on prevailing, land, labour and materials prices in St. Kitts. The design assumed a household of 5 in the urban setting, prices are quoted in $US.

Constructed wetlands have evolved during the last five decades into a reliable treatment technology which can be applied to greywater. Pollution is removed through controlled conditions. All types of constructed wetlands are very effective in removing organics and suspended solids, whereas removal of nitrogen is lower but could be enhanced by using a combination of various types of CWs. Removal of phosphorus is usually low unless special media with high sorption capacity are used. Constructed wetlands require very low or zero energy input and, therefore, the operation and maintenance costs are much lower compared to conventional treatment systems. Under this pilot project a Vertical Flow Constructed Wetland system is proposed. We recommend that enough land space be acquired to construct three parallel trains. These trains can be planted with different species or combinations of ornamental plants so that samples of the effluent can be collected, analyzed, and be compared to ascertain which is the most efficient system.

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APPENDIX I

Preliminary Design of constructed wetland system for treatment of greywater in the College Street Ghaut

The Initial conditions are as follows:

Greywater: 50% - 80% of total domestic water use

The per capita water consumption of SKN: Q = 50 Imp. Gallons/day, water consumption = $Q_{\text{water avg.}}$

Considering a single household of **5 P.E (5 persons)**

Wastewater generated = $Q_{\text{waste avg.}}$ = (0.8 – 0.9) of water consumption

= (0.8 – 0.9) $Q_{\text{water avg.}}$

=0.9 (50 gpcpd) x 5 persons

=225 gallons/d

From this figure, (50% - 60%) is greywater.

Therefore, $Q_{\text{greywater}}$ = 0.6 * 225 Imp. gallons/d

=135 Imp. gallons/d * 4.5

=613.7 litres/d

=614 l/d

The hydraulic loading rate of VFCWs is much higher than HFCWs.

Experiments in France/ Europe show that a total area of 1.2m² per P.E is adequate.

(Min – max): (0.1 – 4.7m²/P. E)

Literature reports suggest that the area needed per capita or P.E:

1.5 – 2m²/PE

2 – 2.5m²/PE

2.5 – 3m²/PE, depending on the strength of the wastewater.

VFCW is very appropriate for small communities because treatment is extremely efficient >90% for COD (Chemical Oxygen Demand), 95% for SS (Suspended solids) and 85% for nitrification.

There are various methods of approach for the design of constructed wetlands, using the approach with common hydraulic loading rate (HLR), typically 50 – 130 l/m²/d and up to max 200 l/m²/d,

HLR = Q/A, where Q = $Q_{\text{greywater}}$ = 614 litres/day, A= area required.

Therefore A = 614 l/d ÷ 200 l/m²/d = 3m² or 33 sq. ft

<u>Area required = 33 sq. ft</u>

Appendix II

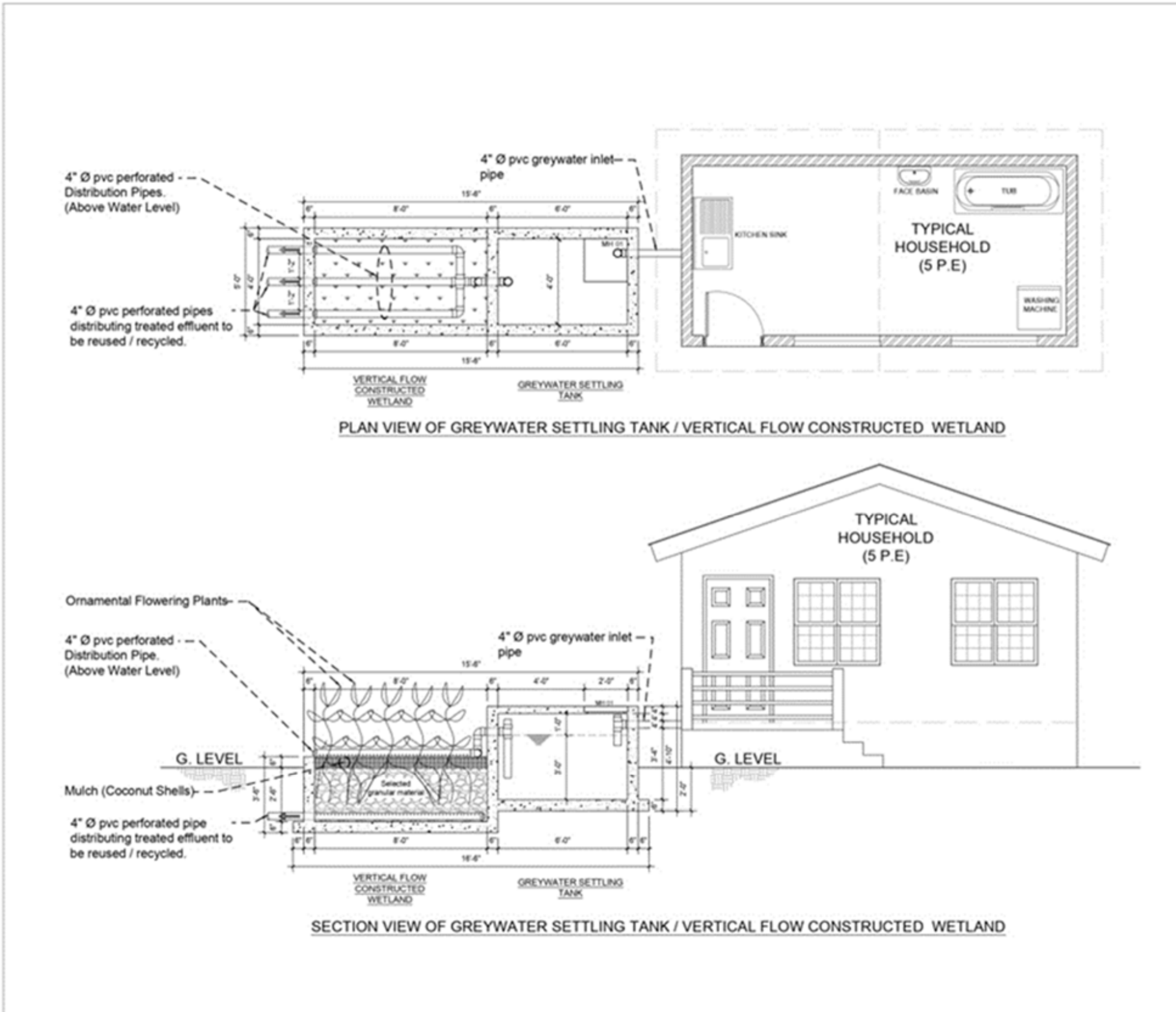
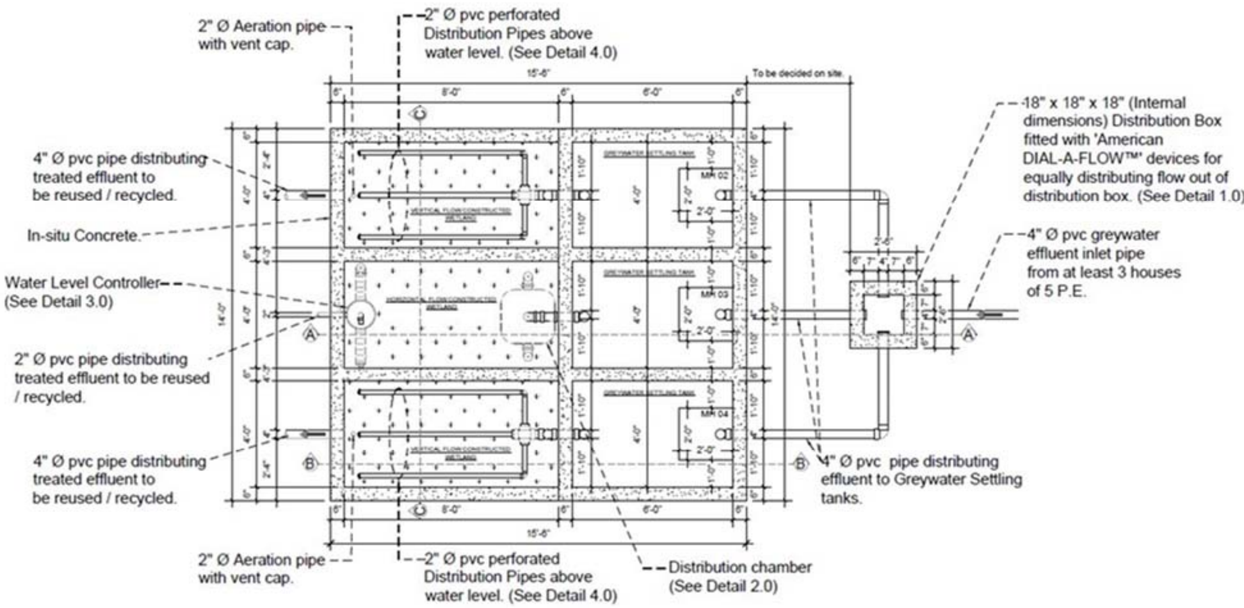


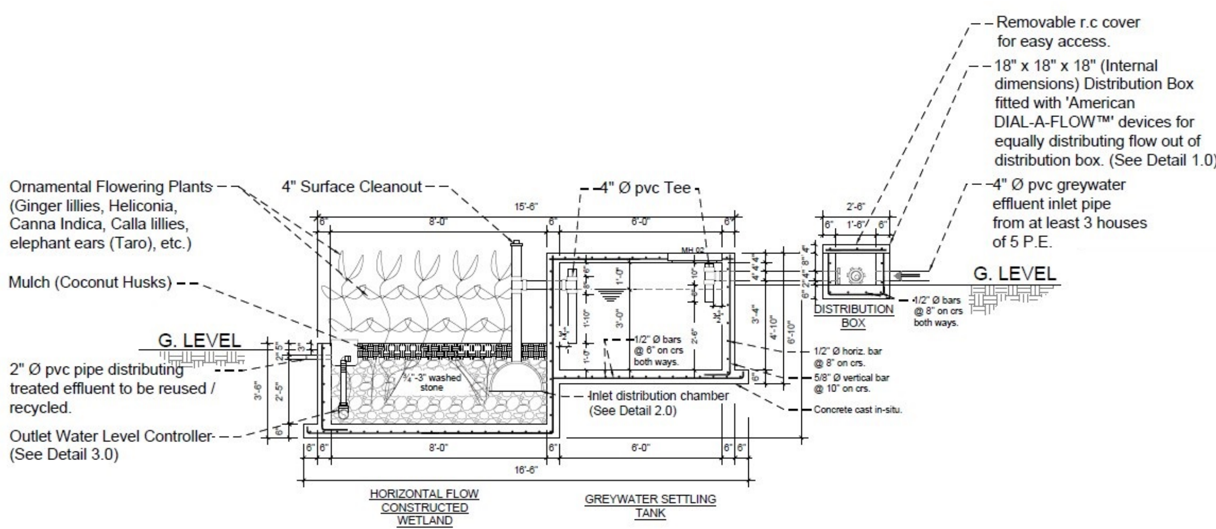
Figure I Typical layout of Greywater Treatment system – Setting Tank and Vertical Constructed Wetland

Appendix III

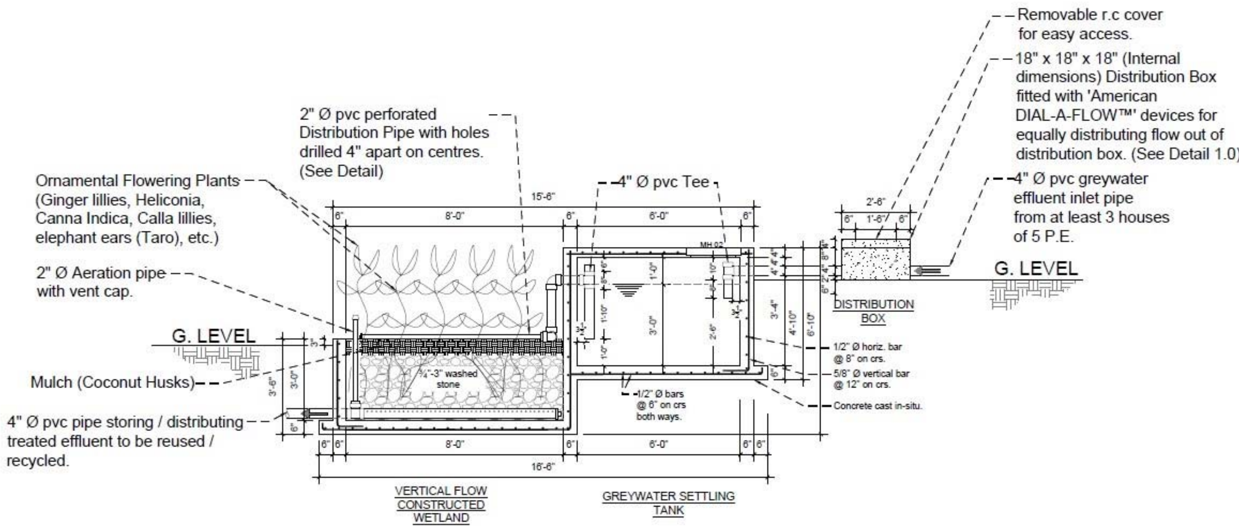
Final design of Greywater Pilot treatment plant with three parallel optional treatment Trains



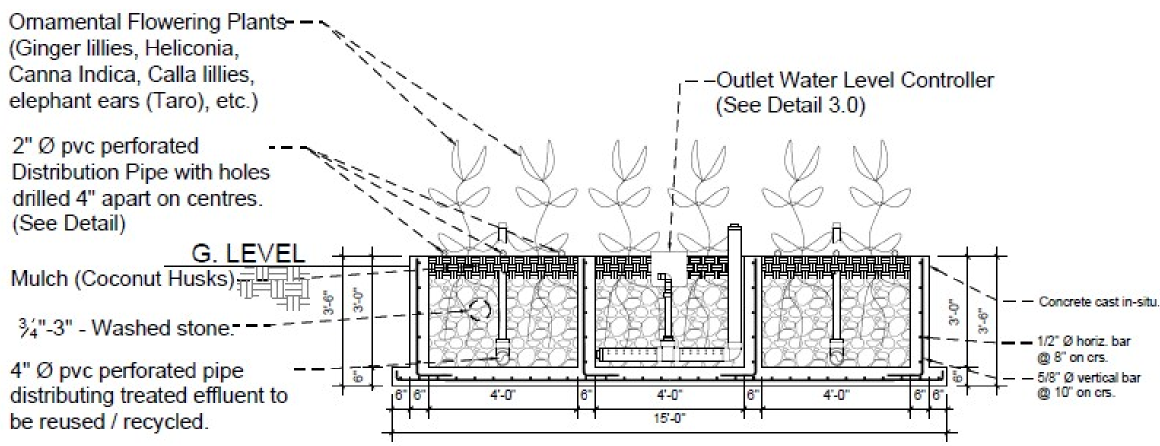
PLAN VIEW OF GREYWATER SETTLING TANK /
VERTICAL & HORIZONTAL SUBSURFACE-FLOW CONSTRUCTED WETLANDS



SECTION A-A - VIEW OF GREYWATER SETTLING TANK /
HORIZONTAL SUBSURFACE-FLOW CONSTRUCTED WETLAND



SECTION B-B - VIEW OF GREYWATER SETTLING TANK /
VERTICAL SUBSURFACE-FLOW CONSTRUCTED WETLAND



SECTION C-C - VIEW OF GREYWATER SETTLING TANK /
VERTICAL & HORIZONTAL SUBSURFACE-FLOW CONSTRUCTED WETLANDS

Pipe Bursting- Improving the Cayman Islands Waste Water Collection System

Abstract:

Pipe bursting is a relatively new method of replacing pipes underground. The method of pipe bursting is cost effective, less invasive and relatively quick in comparison with cut and fill methods of pipe replacement. The concept of pipe bursting was originally developed on the basis of pneumatic piercing. When DJ Ryan and Sons Ltd. and British Gas successfully ran one through an existing gas line in England in 1981, pipe bursting was born. Years on, it is the preferred method of pipe replacement by contractors and local authorities due to, less digging (entry & exit pit is only needed), ability to minimally disturb soil as new pipe is laid and its cost effectiveness all around. This paper examines pipe bursting from a sewerage collection system improvement point of view. In particular the improvements made to the waste water collection system as a direct result from Inflow/Infiltration (I&I).

I&I is huge problem for waste water treatment systems. I&I adds clear water to sewer systems increasing the load on the system. When clear water enters sanitary sewer systems, it must be transported and treated like sanitary waste water. Water Authority Cayman has been using pipe bursting technology for the past three years and it is now its main method of sewer pipe replacement. The material that currently serves our sewer network system is mostly clay pipe which is susceptible to vibration, brittleness and ultimately collapse. The main advantages of HDPE pipe are its continuity, flexibility, and versatility. The continuity, which is obtained by butt fusing together long segments in the field, allows for a smoother interior surface (relative to other pipe material) reduces the friction between the flow and the pipe wall, which allows higher flow speed and increased flow capacity. The HDPE pipe does not erode, rot, corrode, or rust; it also does not support bacteriological growth. The main challenge found with the installation of the HDPE pipe and the use of pipe bursting technology is Caymans high water table, and tidal influence.

Key Words:

Pipe bursting

Trenchless technologies

Lift stations

Forced mains

Inflow & Infiltration

HDPE Pipe

FIPP & CIPP

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1.0 Introduction

Sewer systems form part of modern-day infrastructure. Before Community waste water management systems, cities had open sewers where waste flowed openly throughout canals and onto city towns and streets. This wastewater contaminated the local environment and drinking water supply, thereby leading to increase in the risk of disease transmission. Therefore, to improve health, it is vital to develop an adequate system to manage community wastewater.

Much research has been conducted into the historical development of fully functioning sewer systems worldwide, but essentially these networks started with sewer cesspits, wooden stave pipes, clay pipes, and cast iron. In the late 60's and early 70's, PVC became the material of choice. Modern day collection systems use HDPE as part of the network (Anon., 2016).

The Cayman Islands waste water collection system is no different to any other modern day Urban collection system. It comprises of a network of pipework that extends from each house or building, and flows into a sewer main that usually runs alongside a road or underneath it. These pipes meet inspection manholes with a dropped assembly at regular intervals. These inspection manholes eventually flow into progressively larger pipes where the waste then gets diverted to a Waste Water Treatment Plant, managed by Water Authority Cayman. In the situation where a gravity system is too "low lying", the system needs to be pumped in order to lift the waste back to an elevation whereby it can be diverted by gravity again. This is done with the use of lift stations.

The development of trenchless technologies has been adopted primarily in both in the United States and Europe for water and sewer mains rehabilitation programmers. These techniques ranged from renovation of part of the fabric, upgrading performance of the pipe network, rectification of damage and installation of a new pipeline system. The use of trenchless technology has however been limited to a few projects within the English-speaking Caribbean Region, such as the case of the Barbados South Coast Sewerage Project, and now Grand Cayman (Boyce, 2015).

Pipe bursting is a means of pipe replacement, which is one of the methods within the trenchless technology field. With this method, Grand Cayman has seen the benefits, first hand, what this technology has to offer. The statement of "trenchless technology being a truly "no dig operation", does not stand entirely true for this particular method of pipe replacement, but rather, a more localized digging approach is needed. With the need to upgrade Grand Caymans waste water collection system, the rationale behind using this method of pipe replacement can be explained with the following points in mind.

- An ageing waste water system across the Island.
- Population growth and increase in developments and buildings.
- Population of the Island expected to rapidly expand in the coming years.

This paper examines the application of pipe bursting that is used to reconstruct an already aged waste water collection network. And doing so within a trafficked and urban setting.

1.1 An ageing Waste Water collection system

Grand Caymans waste water collection system comprises of collection lines, lift stations with forced mains, and a waste water treatment plant. The waste water generated on Grand Cayman generally flows from the various developments to gravity collection pipelines to lift stations where the waste water is pumped to the downstream gravity collection pipeline. Ultimately the wastewater flows to the main pump station from where it is then pumped to the waste water treatment plant. The majority of the waste water collection system was installed in the late 1980's, it consists of pipe ranging from 4 inches to 18 inches. The total length of pipes in the gravity collection system is approximately 12.5 miles long. The most common type of collection pipe material within the network in 8-inch vitrified clay pipe. Figure one below shows a current map of the network of waste water collection pipes serviced as part of Water Authority Cayman's network.

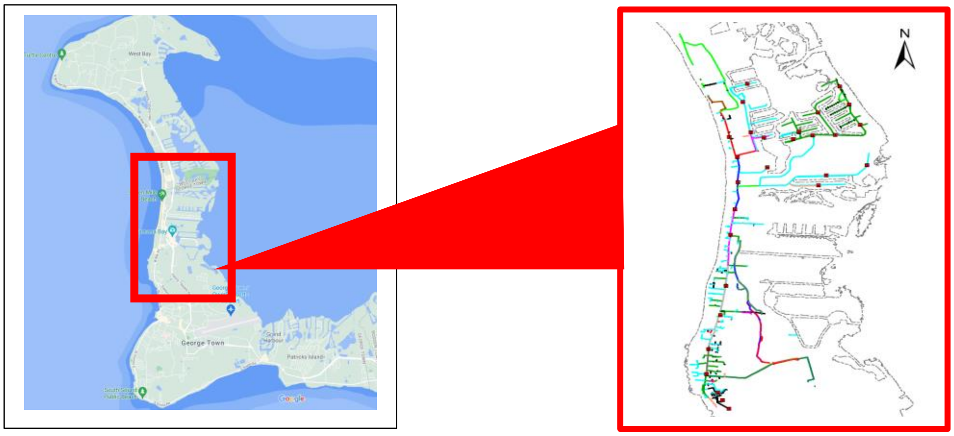

Figure 1 Current map of Caymans Wastewater collection system

1.2 Pipe network Expansion needed due to Population growth

In 2007, a report written by civil servant Dr. Philip Pedley outlined Grand Cayman's growth in a historical context, the report offered a model as to future predictions. Pedley reports that the growth in population is not driven by an increase in birth rate, but that of waves of immigration which fuels the financial services and tourism economy. The results of population increase published by Pedley included that of residents and not an increase in tourists. The prediction model reported by Pedley in 2007 shows an upward trend set to continue post COVID 19, with data analysis predicting a population of 100,000 people by 2031. More people, essentially means more waste produced, and in turn an increase in the waste water generated. (Pedley, 2007)

1.3 Pipe network Expansion needed due to Increase in Developments and Building

With the average human producing 50-70 gallons of waste water per day, a population trending to 100,000 in 10 years from now, a waste water treatment facility with a capacity of 2.5 million gallons per day and currently operating close to capacity, and a building boom, it can be stated that Grand Caymans waste water collection system is due to come under strain. In July 2020 alone 126 new projects applications were filled with the planning department. A recent trend on the island of ten story residential and commercial building construction has been observed and set to become the new method of construction. The seven-mile beach area hosts prime real estate. With this attractive location in mind, existing 3 and 4 story buildings are set to be upgraded and risen to ten story constructions under the same existing footprint. If this becomes a forward trend, it essentially means the sewer collection system will in turn need to deal with over three times the existing sewage being produced

A large part of the rationale behind pipe bursting on Grand Cayman can be mostly, but not fully explained within the areas of population growth and an increase in buildings density, these factors have lent themselves well to the practice of pipe bursting on Grand Cayman. The increase in demand on the network means that the Water Authority Cayman can take an existing network and allow it to be upsized, without the need for conventional excavations. Theoretically, there is no limit on the size of pipe that can be replaced, and successful installation of a larger pipe depends only on cost effectiveness, local ground conditions (e.g., the potential for ground movement), and the ability to provide sufficient energy to break the old pipe and pull new pipe (States, 2006). When upsizing to increase the waste water network collection capacity, two critical dimensions must be calculated: distance to the surface, and distance to existing pipes and structures. First it is necessary to determine the upsize co-efficient.

Upsize co-efficient: OD of expander – OD of the host pipe, Where OD of expander is the largest OD of the new pipe PLUS an overcut clearance of between 10 and 30%.

Example: ID of host pipe 150mm; OD of expander 225mm (new pipe OD 200mm + 25mm overcut). Upsize co-efficient is 225 – 150 = 75mm.

Depth of cover must be not less than 10 x upsize co-efficient.

Distance to existing pipes and structures should be no less than 3 x upsize co-efficient with a minimum of 400mm. In granular soils where the adjacent pipes are brittle and fragile (clay, for example) the minimum distance should be no less than 5 x upsize co-efficient with a minimum of 400mm (PE technical guidance, 2013).

2.0 Dealing with extra demand on our wastewater network due to Inflow and Infiltration

A factor which contributes negatively to Cayman's waste water network is I&I. I&I describes what happens when stormwater (inflow) and groundwater (infiltration) enter a wastewater system. This water, which ideally should drain into the ground or be routed to storm drains, can easily overload wastewater systems. Grand Cayman has an extremely high-water table level. The geology and soil formation were studied by Matley (1926) and Jones (1994) and found the soil formation to be chalky or rubbly coralline limestone with brown sand. The relief and drainage of Grand Cayman is directly related to the type of soil present. Patchy soil cover and the jointing karst is the main formation and allow a high flow of water through the ground. With structurally compromised clay pipes inside this constant zone of water, ground water is the main source of I&I being treated by the plant (N, 1996).

Water Authority Cayman has identified I&I which negatively affects our system by implementing a few simple tests. These tests are both visual and lab testing. Monitoring the influence from I&I begins by visually monitoring the flows through pumps and lift stations. This monitoring from a desktop allows the viewer to narrow possible high I&I contribution to a particular pump station. Once the flow has been narrowed to a pump station, wastewater samples are taken at the manholes which contribute to the upstream of that pump station. The samples are taken and salinity and conductivity tests performed that indicate the concentration of saltwater present in the sample. Higher salinity and conductivity mean a higher infliltration of groundwater to the collection system. Following from this, the severity of the I&I is determined by CCTV monitoring of the existing pipework and associated manholes. Figure 2 below shows an 8 gallon per minute leak in an 18inch pipe. This is not an image from Grand Cayman's network. This leak was calculated to be contributing 4.2 million gallons of ground water per year to the network. Pipe Bursting in Grand Cayman has allowed us to actively deal with I&I. I&I will increase operational expenditure due to increase wear and tear on mechanical equipment as well as cause increased corrosion issues due to increased salinity levels.

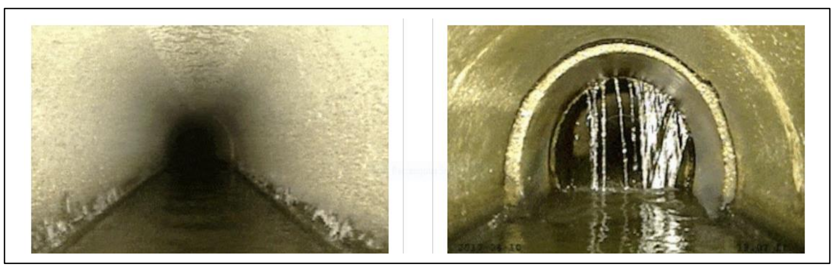

Figure 2 Inflow &Infiltration in a 18inch Waste water pipe

2.1 Existing Wastewater collection system

Clay remained a popular material for city plumbing and drainage systems through the early 1900s, and found its place in Grand Cayman's sewer network in the late 1980s. As a material, and once visually inspected, it is noted that as a material and in Grand Cayman's subterranean environment, it held up extremely well. As clay has its pros and cons, it can be seen that over the course of time, and in Grand Cayman's environment, that the cons have outweighed the pros, hence the reason the system is currently being upgraded using pipe bursting and HDPE pipe. For example, clay pipes are unaffected by acids, but susceptible to root intrusion and leaks and have a low tensile strength. Grand Cayman rests close to the orient fault line and in January 2020 was subjected to a 7.7 magnitude earth quake. From examining pump run times in the days following the earthquake, a spike in pump run times could be seen. Evident that the brittle clay pipes have fractured and allowed I&I (Whittaker, 2020).

2.2 Previous Condition Assessment of Grand Cayman's Wastewater collection system

Previous condition assessments of the waste water collection system were mostly refined to Manhole surveys by the Water Authority Cayman. The vital reporting of these surveys allowed action to be taken on the manholes themselves which contributed largely to I&I. These condition assessments were conducted by means of a Go-Pro camera and by capturing a video of the Manhole in the field and reporting visual results on hardback format in the field. In recent times and moving towards a more technologically advance approach, the Water Authority Cayman has since implemented the use of the Cues SPiDER Camera. The SPiDER is a scanner that can calculate its position in the manhole shaft by using its sensor data to measure its incremental motion. SPiDER collects millions of 3D measurements during each manhole inspection. The raw data is processed to a 3D point cloud that provides engineering and survey quality information on manhole geometry and condition that can be used for structural assessment, pre- and post-rehabilitation analysis (i.e., lining thickness), hydrological surveys, as well as general condition assessment. Figure 3 below shows the SPiDER scanner at work in the field (Technology, 2016).

Figure 3 SPiDER Cam in the field

2.3 Previous Remediation methods of Manholes and Sewer pipes on Grand Cayman

Following a condition assessment of Grand Caymans waste water collection system in the early 90's, it was determined that rehabilitation would start on pump stations and manholes firstly, but in particular the pump stations, as these were areas of the network that obviously had the most turbulent conditions with respect to waste water collection due to the high levels of sulfuric acid attack produced from sewer gases on the concrete that made up the structure of the pump stations and manholes. In sanitary sewers, splashing and turbulence happens where pressurized flow discharges to gravity pipes, releasing hydrogen sulfide (H_2S) into the air. Where hydrogen sulfide exists in sanitary sewers, bacteria feeds on the hydrogen sulfide and excretes sulfuric acid. The sulfuric acid quickly corrodes concrete manholes and also some metals such as the Manhole covers. The product used was Ameron T-Lock which is a PVC liner that is cast in new concrete inside the existing MH and utilizing the old concrete structure as an outside form. Figure 4 below shows the Ameron T-Lock Technology used as part of an existing rehabilitation method, and also shows the PVC liner and its anchoring to the new concrete interface.

Figure 4 Ameron T-Lock Liner

The Water Authority Cayman carried out a thorough investigation of the available manhole rehabilitation methods. The permaform process used in conjunction with Ameron T-Lock liner was chosen as the preferred method as it would provide an economical long-term solution with, minimum disruption to the operation. No alternative rehabilitation technology at the time was considered to offer the same long-term solution. The first manhole rehabilitation project was carried out in 1991/1992 and consisted of the rehabilitation of 38 manholes. In early 1994 the Water Authority Cayman carried out another detailed investigation to determine the condition of its collection system. The permaform process used in conjunction with Ameron T-Lock liner showed no sign of deterioration and excellent performance, however the (bio) chemical corrosion of the non-lined manholes was found to have vigorously continued, and an additional 38 manholes were rehabilitated in 1996 with this method. With the Water Authority’s continued efforts to maintain its system, it now uses AGRU lined precast manholes. These manholes come premanufactured with a PVC liner anchored in the concrete. The work of replacing degraded manholes becomes quicker, easier, and longer lasting using this product. Figure 5 below shows an AGRU lined Manhole.

Figure 5 AGRU Lined Pre-cast concrete Manhole

2.4 Pipe Lining Technology to rehabilitate Grand Caymans Pipe Network

Connecting the manholes as part of Grand Cayman’s wastewater collection system, is nearly 62000 linear feet of gravity sewers, both PVC and vitrified clay pipe ranging in size from 4 inches to 18 inches. In 1992 leaking vitrified clay pipeline sections were found to be negatively impacting Grand Cayman WWTP in the form of increased hydraulic loading and action was taken to remediate the problem of this I&I. The action taken at the time is examined below using FIPP and CIPP Technology.

2.4.1 1992/1993 FIPP Pipe rehabilitation project

In 1992/1993 the first pipeline rehabilitation project was carried out. This rehabilitation method was conducted using formed in place pipe (FIPP) also called U-lining. FIPP is a trenchless method of installing a cured-in-place pipe liner to repair a damaged sewer or drain pipe. With the FIPP method, the liner is already impregnated with a resin and hardener. Once the sleeve is pulled through the damaged section of pipe, hot air or steam is pumped inside the liner causing the liner to expand, harden and take the shape of the damaged pipe section, all while repairing and sealing the cracked or damaged pipe. The total length of pipe that was rehabilitated as part of this project was 5000 feet and consisted of both 6 inch and 8-inch nominal diameter sewer pipe. Figure 6 below shows an example of the U-liner technology used as part of this project.

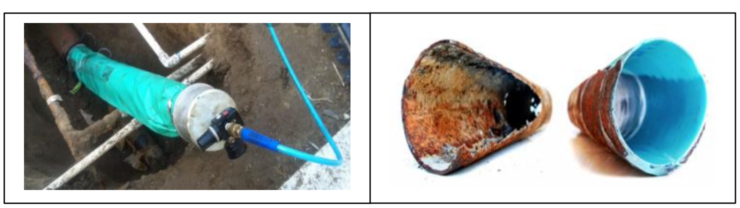

Figure 6 U-Liner. In situ pipe lining Technology

2.4.2 2013 CIPP Pipe rehabilitation Project

Following the 92/93 rehabilitation project, pipeline sections were surveyed between 1993 and 2013. The Water Authority Grand Cayman identified further leaking sections of pipeline comprising approximately of 2100 feet or 6 inch and 3000 linear feet of 8-inch nominal diameter sewer pipelines. Cured in place pipe (CIPP), much like FIPP is a trenchless method of rehabilitating sewer pipes. CIPP lining is a method of trenchless rehabilitation and restoration, used in the repair of existing pipes. CIPP lining uses a textile liner tube and a liquid resin. The process begins with the wet-out stage. During this stage, the textile liner is impregnated with the resin mixture, an epoxy base with a pre-determined hardener. Next, the liner is inverted into the pipe with air pressure. The resin will now be on the outside of the liner against the existing host pipe wall. After inversion, a calibration tube is inverted inside the liner which can then be ambient, hot water, or steam cured. During this period, the curing agent activates the resin causing it to harden, creating a fitted, smooth, and corrosion-resistant new pipe wall. If necessary, a robotic cutting device will be inserted into the newly lined pipe to reinstate any branch line connections. Figure 7 below show the CIPP technology used as part of this project.

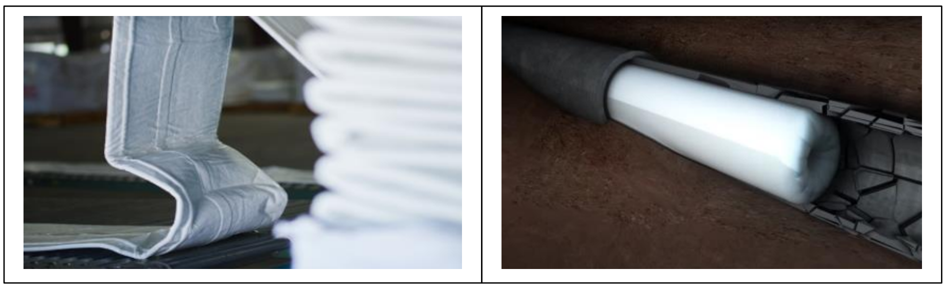

Figure 7 CIPP Technology

The use of both relining technologies of in situ pipes used as part of Water Authority Cayman's efforts to rehabilitate its network, be it FIPP or CIPP has huge benefits over traditional open cut excavation methods. The traditional open cut method is costly, time consuming and intrusive which means traffic closure and general disruption to the existing environment in the vicinity of the network that is under rehabilitation. Emphasis must be put on the benefits of both these products, whereby, **at the time** suited the problems faced by Grand Cayman's waste water network and were chosen as the preferred option.

2.5 Pipe Bursting Technology to rehabilitate Grand Caymans Pipe network

2.5.1 Rationale for Pipe bursting on Grand Cayman

With the rationale behind using the method of pipe bursting on Grand Cayman already examined under the headings 1.1, 1.2, and 1.3, there were some other factors that fully caused the implementation of the pipe bursting method to rehabilitate the system on Grand Cayman. The lining method of FIPP and CIPP was discontinued on Grand Cayman in 2013 due to the chosen contractor practices becoming problematic and general quality issues surrounding the installation of the lining.

The FIPP method of relining pipes had produced just over of a 98% success rate, with only two sections out of 107 sections that reinverted, essentially meaning the pipe lining material had failed and which ultimately led to a collapse in the material and therefore a blockage in the line.

A similar situation in 2013 was observed whereby the CIPP method of relining also failed. Again, causing the liner to collapse and cause a blockage. The remedial methods of repairing these issues, coupled with a conflict between the Water Authority Cayman and the chosen contractor, ultimately led to the WAC having to excavate the areas, and relay new pipe. In essence, the method, which was due to rehabilitate the network, ending up becoming the method causing the problems of blockage in these areas. The observations/conclusions of the Water Authority indicate that the most common vulnerabilities of the epoxy lining system are associated with the planning and quality of the preparation as well as training of the applicator personnel performing the installation. With short of 100% video documentation, there is no way to know with complete certainty, how well the pipes were cleaned and prepared for the epoxy application, which is directly correlated with whether the epoxy will adhere properly to the inside of the pipe, or if an adequate coating was blown into the piping system.

The failure modes and vulnerabilities of epoxy are widely known and highly consistent in their progression. It is also widely recognized that the project planning, surface preparation, and precise measurement and application of the ingredients to the substrate are the most significant variables in determining the probability of a successful epoxy coating assignment. In short, when the pipe is not prepared properly or if the epoxy is not mixed properly, there is a greater chance of failure, and both of these variables fall squarely on the experience and quality of the installer.

2.5.2 Water Authority Caymans first pipe bursting experience

Water Authority Cayman first implemented the use of pipe bursting technology on February 27th 2019. The location was Lawrence Boulevard on West Bay Road. The burst was conducted between Manholes 2401 and 2487A and consisted of replacing 200 feet of 8-inch vitrified clay pipe with 10-inch HDPE butt fused pipe. The clay pipe had collapsed from MH2401 upstream 10 lineal feet towards MH2487A. Due to the collapsed nature of the pipe, the implementation of lining technology was not an option. Figure 8 below which shows the location of Grand Caymans first pipe bursting method

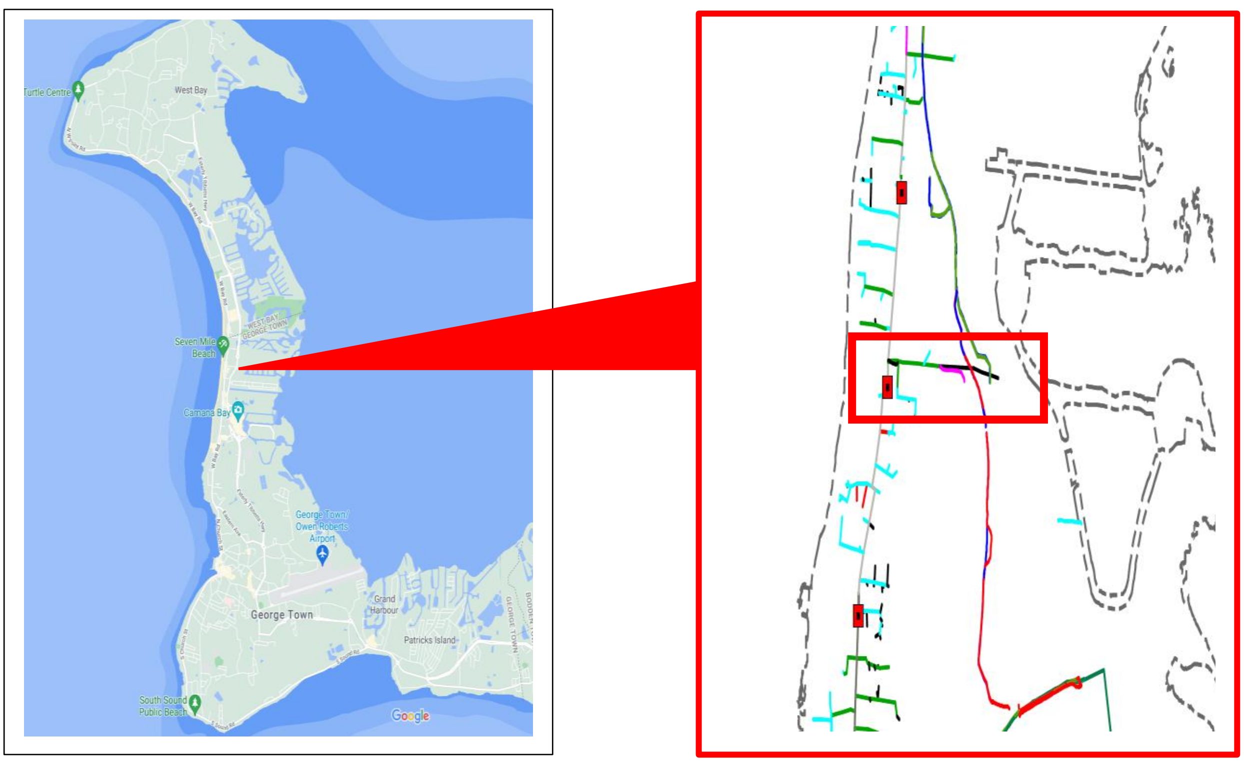

Figure 8 Location of Grand Cayman first pipe bursting project

3.0 Cost Comparatives and Parameters when deciding to use pipe bursting

Options presented for Lawrence Boulevard sewer pipe repair (2013)

3.1 Open Cut repair method and challenge

- Replace clay pipe with PVC SDR 35
- Existing utilities. Cayman Water Company water mains relocation
- Dewatering, at least two 6" pumps hard piped to a drainage well
- Traffic control, turn lane closure and diversion of west bay south bound lane
- Trench safety. Steel sheeting piling system, trench boxes or shoring jack system to be installed and all to be imported
- Restoration and reinstatement of curb, island, sidewalk and asphalt pavement
- Connection and transition to existing clay pipe, PVC gasketed adaptor
- Sand collar at manhole.

Cost concerns

- Importing of trench sheet piling material
- Large hydraulic excavator to achieve sheet pile depth
- Import of hydraulic sheet pile driver to attach to excavator
- Restoration
- Dewatering well, piping and discharge system

3.2 HDPE Liner method

- Pipe lining was a concern based off the past projects of year 1992/93 and 2013. The HDPE would be 7.125-inch SDR 25 fitting inside the existing host clay pipe with no structural integrity of the host pipe near the manhole.

3.3 Pipe bursting method

- Using this method pipe bursting would allow a SDR 18 pipe that would be acceptable as a direct burial
- Dewatering well will be required
- Piping discharge system will be required

Cost concern

- Cost of procuring the equipment
- Cost of shipping the equipment
- The relatively small scope of work would exceed the open cut method
- As a side note, the cost for feasibility would be offset by using pipe bursting for additional pipe repairs and would dilute the initial cost

A decision was made in 2013 to use option 3 on a time and materials basis using specialist contractor SanPik Cayman Ltd. to conduct its pipe bursting operations. At the time of the first pipe bursting operation, there were several other areas of concern that needed urgent attention and for which pipe bursting was the preferred option.

4.0 The pipe bursting method explained

Pipe bursting represents the ideal pipe rehabilitation solution for replacing and upsizing the capacity of existing pipelines while avoiding the economic and social costs of traditional methods outlined in section 3.0. Pipe bursting is the only trenchless process that enables a city or town to revitalize its piping system without extensive excavation and traffic stoppages. In most bursting applications, the old pipe is made of a rigid material such as vitrified clay pipe (VCP), cast iron, plain concrete, asbestos, or some plastics. Reinforced concrete pipe (RCP) can be successfully replaced when it is not heavily reinforced or if it is substantially deteriorated. The diameter of the old pipe can range from 2 inches to 30 inches, although the bursting of larger diameters is increasing. A length of 300 to 400 feet is a typical length for bursting, however, much longer runs can be completed with bursting systems that are more powerful. To start the pipe bursting a conical bursting head is fixed to a replacement pipe line, and fed through an entry hole to the broken sewer line. The pointed bursting head breaks the existing, damaged pipe line as it travels through, this is because the bursting head's cone shape is larger at its base than the existing pipe's diameter. Using a pull rod or hydraulic power, the entire existing pipe is fractured and pushed from its original location. The replacement pipe, attached behind the bursting head, is then seamlessly fed in place, filling the cavity left behind by the bursting head. Figure 9 below shows an example of pipe bursting in the field.

Figure 9 Pipe Bursting Head & Hydraulic Thruster

The new pipe material that has been used to replace the old, vitrified clay pipes on Grand Cayman's system is High Density Polyethylene (HDPE). HDPE is the most-used replacement pipe type for pipe bursting applications. The main advantages of HDPE pipe are its continuity, flexibility, and versatility. The continuity, which is obtained by butt fusing together long segments in the field. The flexibility allows bending the pipe for angled insertion in the field. In addition, it is a versatile material that meets all the other requirements for wastewater lines and sewer pipes. The smoother interior surface (relative to other pipe material) reduces the friction between the flow and the pipe wall, which allow higher flow speed and increased sewer conveyance capacity. The HDPE pipe does not erode, rot, corrode, or rust and it also does not support bacteriological growth. Figure 10 below shows the type of HDPE pipe used as part of rehabilitation in Grand Cayman's wastewater network (Board, 2019).

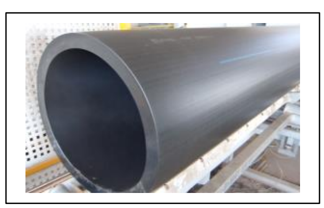

Figure 10 Example of HDPE pipe

4.1 Planning associated with Pipe bursting projects on Grand Cayman

Substantial planning is needed in order to successfully carry out any pipe bursting operation. Even with localized excavation used as part of pipe bursting, there a number of factors that need to be examined before any project can commence. The basis of planning can be examined briefly under the following headings.

4.1.1 Host pipe examination

Meticulous inspection of the existing host pipe and the condition of its joints are carried out by use of CCTV. This is to ensure that the host pipe has not collapsed and will receive the pilot rods which connect to the pipe bursting head. If the pipe is collapsed at any section along the line, further localized excavation may be needed.

4.1.2 Survey of existing pipes and underground structures in the proximity of the host pipe

The Water Authority Cayman carried out this stage by looking at previous as built drawings and carrying out locate requests. In nearly all cases, where a sewer network lies, so too do fiber optics, water lines, or Gas and Electricity. Where the Water Authority cannot identify other services, the service provider is contacted directly, and a utility service locate request lodged. Once the locate request has been approved, the service provider meets with and WAC Engineer on site and marks the areas between localized excavation for the pipe bursting.

4.1.3 A "Serve notice on property owner" notification

In all cases of pipe bursting and manhole replacement on Grand Cayman, managing the ground water is of upmost importance, due to highly permeable soil and high-water table. To mitigate this factor, a drainage well may need to be drilled close to the proximity of the pipe bursting operation. This sometimes happens close to the property of a customer. In these cases, notice is served to a customer and under government law, the Water Authority Cayman reserves the right to gain access to, or close to a property to repair or replace part of its network.

4.1.4 Notification to Customers

The WAC strives to keep its customers notified of any works or disruptions that may be planned. Public service announcements (PSA) are dispatched by the WAC customer service department in the form of social media notifications, property letter drops and radio communication, and help notify the customers in the area where a pipe burst in scheduled to happen. This notification takes place well in advance of the operation and allows for any queries to be answered by customers regarding possible disruptions.

4.1.5 Drilling of Drainage wells

The drilling of drainage wells is a major part of the pipe bursting operation when conducting a pipe bursting operation on Grand Cayman. Due to Grand Cayman's high water table which is at a constant five and sometimes 4 feet (depending on location) below existing ground level, managing water during a pipe bursting operation is key to the success. Each drainage well is drilled to a specific depth, sealed in accordance with Water Authority guidelines and designed to dispose of ground water level under pressure whilst being connected to a large pump. Figure 11 below shows Water Authority specifications on disposal wells

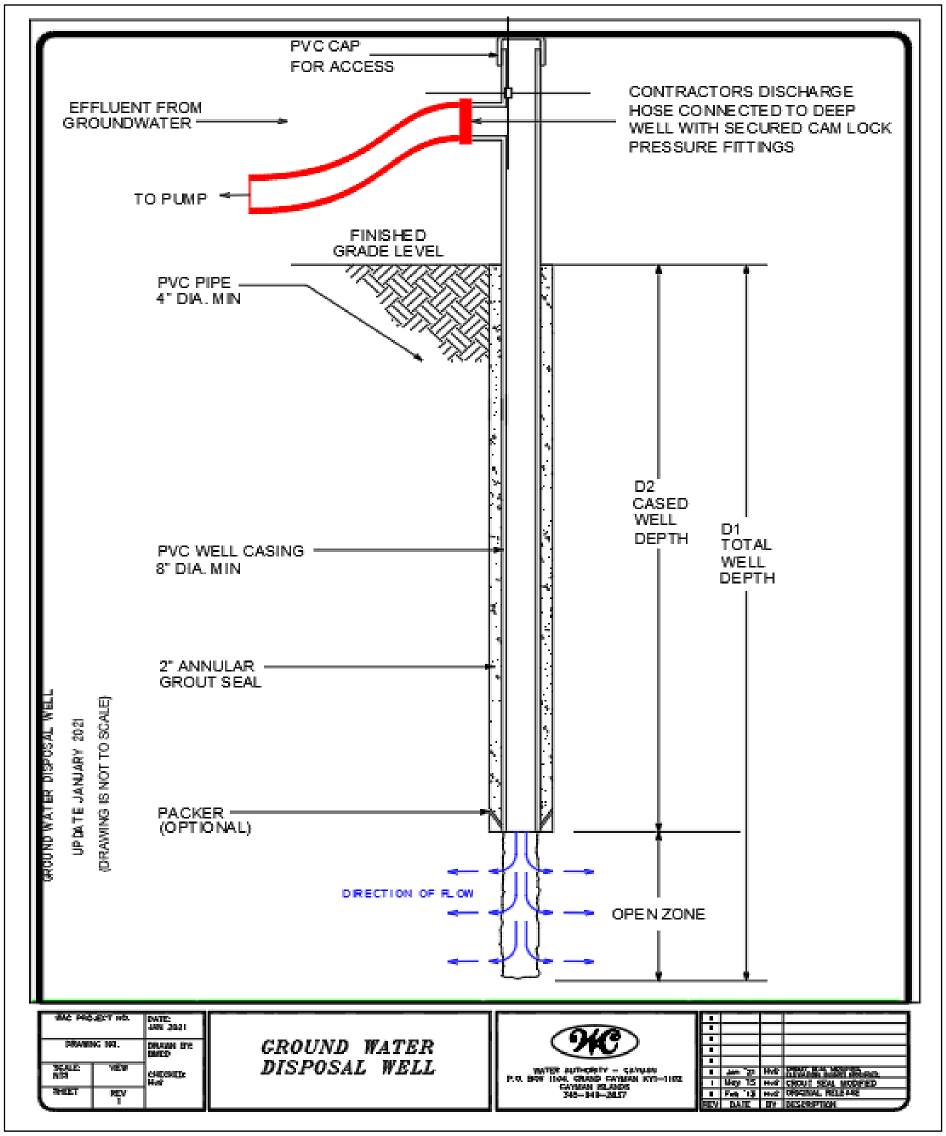

Figure 11 WAC Deep well configuration for ground water management on a pipe bursting project

5.0 Local availability of Contractor

In relation to the availability of a local contractor, outside of general building and structural concrete works, there is no contractor that specializes in pipe bursting or trenchless technology on Grand Cayman. Pipe bursting and trenchless technologies are specialized methods of pipe replacing and contractors who use this method tend to be experts in this area. The current contractor who carries out all pipe bursting projects on Grand Cayman is SanPik Contracting Cayman. SanPik is a privately owned underground utility contractor specializing in complex and environmentally sensitive utility projects for communities and municipalities throughout the state of Florida and the Caribbean. Founded by Daniel Picek, William Picek and Matthew Sands, collectively they have brought many years of experience successfully installing underground utilities to Central Florida when they decided to join forces to incorporate SanPik in the year 2015. SanPik has a reputation for completing projects under budget and on time in challenging terrain and conditions. This is a result of concise planning and preparation, training and utilizing state-of-the-art equipment

5.1 Specialized equipment of Contractor

The benefit of using a specialist contractor for this type of work, outside of their expertise, is the added benefit of the contractor having an inventory of specialist equipment. At the current time, SanPik has in its inventory the following equipment to allow them to fuse pipes of all sizes between 4 and 38 inches and gain the results immediately of whether or not the weld is satisfactory.

- McElroy Trac Star T618
- McElroy Trac Star 412
- McElroy Trac Star T900
- McElroy Data logger systems

Once the HDPE pipe is butt fused and welded together, the results for the fuse and weld bead are logged. The next step of the procedure is the pipe burst and ultimately pull the new pipe into position. This operation is completed using the Pow-R mole PD 8. The Model PD-8 is a thrust boring machine that pushes a solid 2" Chrome alloy steel bar at rates up to 9' per minute, this type of machine top loads meaning it can work in small spaces and therefore excavation is more localized. The machine is designed for up to 12-inch holes or pipe splitters up to 12 inches and exerts a force of 151,000 lbs. of thrust. Figure 12 below shows the pipe fusing and pipe bursting equipment used as part of SanPik’s operations on Cayman.

Figure 12 McElroy T618 Pipe Fusing machine & Pow-R Mole 8

5.1.1 Interpreting the results of the McElroy Data Logger for HDPE Pipe fusing

There are 5 in total, but 3 main components that form part of the pipe fusing procedure, that need to be observed closely during and after a pipe fusing operation is complete. They are, 1). Defacing the pipe, 2). Heating the pipe, 3). The open and close process, 4). The fusion process, and finally, **(in the case of fused gravity sewer HDPE)** 5). De-beading. As procedure 1 and 5 are a process which essentially involves the alignment of pipe interfaces at the joint and a smoothing of the inside of the joint, they are done by the use of a cutter, and therefore cannot provide a graph for interpretation. Figure 13 below shows the processes of 2,3, & 4. The image below shows the graphs of a fused 24-inch HDPE pipe that formed part of the Water Authority’s Project on the new airport connector road. It is worth noting and explaining that once the graphed line falls within the red and blue boxes for the allotted time, the fused is considered a pass.

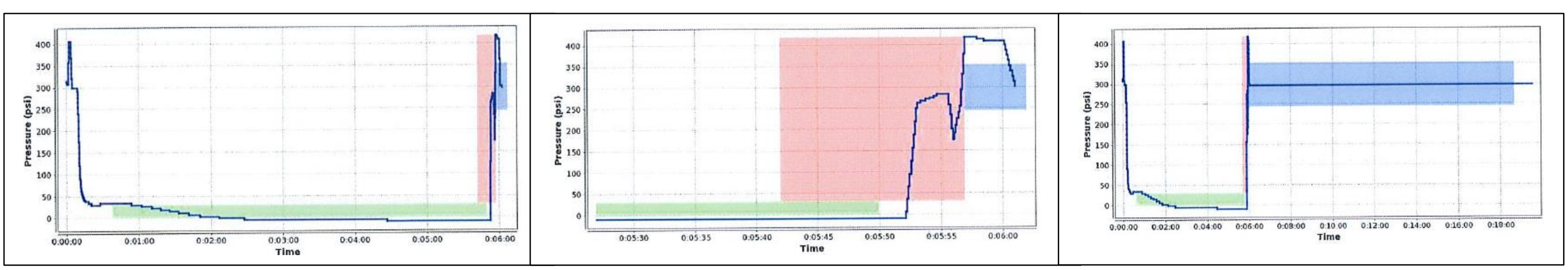

Figure 13 Graphs of Heating, open & close, and fusion of the HDPE pipe

5.1.2 Challenges faced during a pipe bursting project

The main challenges faced during a pipe bursting operation outside of locate requests, health and safety, and traffic management, and which greatly effects the time and efficiency of a project is ground water. Most aspects of a pipe bursting project can be planned for. Ground water however cannot. All pipe bursting projects conducted so far on Grand Cayman and on the Water Authority Cayman network have ran successfully. Successful in a sense that they were completed, but not without the difficulties of fighting the intrusion of ground water during localized excavation. As WAC mains sewer network is mostly located below the water table, coupled with the fact that the region is mostly made of coralline limestone and jointing karst formation, leads to most pipe bursting projects encountering fissures that allow high flow rates of water. The remediation measures for dewatering on Grand Cayman are with the use of deep wells whereby water is disposed of under pressure to a deep well. See figure 11 for specifications on WAC deep wells.

6.0 Conclusions

The need for economical and efficient solutions to replacing, renewing, and up-grading our waste water systems can no longer be problematic to deal with. Local authorities are becoming more aware of what many trenchless contractors have known for years. While pipe bursting is gaining more and more traction on the wastewater and potable water side of our industry, there are many that are still getting their arms around the technology and simply need to be assured before they can take that leap of faith with the technology. Possibly a conversation with an experienced contractor to answer frequently asked questions is just what is needed to allow owners and engineers to pipe burst wastewater and water lines with confidence. The main downside to this method is that it is not always possible to pipe burst based on existing pipe circumstances.

Generally, pipe bursting is the most efficient way of replacing sewer lines on Grand Cayman and elsewhere, especially if minimal disruption is required around the existing pipe area. By using the pipe bursting method local authorities will not have to go through the weeks and months of rehabilitation and reinstatement needed with conventional cut and fill methods. Although the pipe bursting method does tend to cost more, it is important to weigh this factor against the knowledge that you will also save on the costs associated with reinstatement works.

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In-House Water Meter Testing Program Analysis

(PSM20)

The Role of Hands-On Experience with Data Collection to Better Formulate a More Accurate Result

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Abstract

This paper provides an overview of the current results of the In-House Water Meter Testing Program employed at the Water Authority-Cayman. The program was put in place to serve the public interest by ascertaining when would be the best time to replace the customer meters in order to mitigate inaccurate readings due to meter degradation. The first area of investigation was to determine whether the meters in the field should be replaced based on age (years in service) or rather by total flow recorded. In regards to accuracy the initial findings pointed to there being more correlation when viewed by total flow compared to age. Following this finding, the second area of investigation was to determine at what total flow should the meters be replaced, this was found to be at 1800 m^3. Being that additional data leads to more precise results, now that the program currently spans over 10 years, during which 2374 individual meter test results have been collected, a more detailed analysis has been undertaken to compare and contrast with the earlier findings. Meters are tested (AWWA, 2012) at four flow rates and assigned a passing grade if the average overall accuracy lies within the range of 97.5% - 102.5% inclusive of the extents. This paper will walk through the analytical process with the intention of highlighting the importance of personal experience in the data collection. This experience greatly aids to interpret, organize, and formulate the results gathered to create an informed conclusion for the people of the Cayman Islands.

AWWA, 2012. M6 WATER METERS-SELECTION INSTALLATION, TESTING AND MAINTENANCE, FIFTH EDITION, s.l.: American Water Works Association.

Introduction:

The WAC Meter Testing Program in its current iteration began on the 11th of August 2011. From that time until now a total of ~1778 PSM20 meters have been tested for overall accuracy. Following the Water Authority Cayman Standard Operating Procedure (WAC-SOP W2), this test consists of four individual tests at varying volumetric flow rates (5000, 2500, 37.5, and 25 l/h) and specific quantities (400, 200, 20, and 10 liters respectively) after which the average result is calculated and a pass/fail grade is awarded. Pass is defined in our in-house testing as an overall average accuracy grade that spans 97.5 - 102.5%.

This testing is done to instill confidence within the community of the Cayman Islands that the meters in the field are accurate and reliable. Meters are read on a monthly basis within 17 different meter routes. As such the purpose of this exercise is to mitigate the levels of complaints within the Customer Service Department *(*Table 1*)* as many customers at times believe their bill to be inaccurately high on account of the meter.

Table 1 - Previous Annual Customer Complaints

CUSTOMER COMPLAINTS	YEAR
9	2003
18	2004
19	2005
138	2006
54	2007
74	2008
124	2009

As such the meter accuracy as well as the testing procedure have both been analyzed in order to reassure customers that they can have faith in the high standard upheld by the Water Authority-Cayman.

Methods

Section 1

WAC Meter Testing Program Analysis

A batch test was conducted with six randomly selected PSM20 meters and the pilot to study the repeatability and variability within the testing procedure. Six tests were conducted in total from which the variability and standard deviation were calculated for each test's accuracy *(*Table 2*)* and then for each meter's individual accuracy spanning the six tests, at each flow rate. The average accuracy was also obtained at this time for both calculations and recorded in the associated table.

Testing the repeatability of the WAC Meter Testing Program created flow profiles for each meter at all four flow rates and also flow profiles for each test at all flow rates. These results were graphed in order to visualize the impact of variability within the meter testing program and any other under lying trends. Similarly, the variability and averages of all the individual test sessions were calculated and the averages graphed to create an overall sense of the results garnered by the WAC Meter Testing Program over the past 10 years.

Section 2
Meter Testing Analysis

Initially Flow Accuracy Graphs were created for the range of meter in order to identify any overall trends. To create a sharper picture rounding was employed across the range of values to group similar meters. The first step was a 1-Digit Round eliminating the decimals from the readings and grouping the reading by tens. The second was a 2-Digit Round aggregating the data by hundreds for ease of comparison.

The two main variables under investigation as the root cause of meter inaccuracy are age (years of service) and flow (overall customer consumption recorded). As part of the analysis required an age comparison the data was sorted on this basis initially. Age is defined as the year of installation, as obtained from the first two digits of the meter's serial number, minus the date of testing after the meter has been removed from service. Further sorting was carried out by grouping the resulting data into three categories which were previously employed by outside testing adjudicators; Great Southwest Meters. These categories are Over Reading: meters returning average total measurements that were above the pass threshold, Pass Reading: meters returning average total measurements that fall within the WAC specified pass range and Under Reading: meters returning results below the pass threshold. Meters recording less than 10% percent overall flow were categorized as Stuck and while documented were excluded from the overall analysis as the numbers are skewed due to them not being recorded at all if found during initial test bed setup. The count and ratio of the three main categories detailed were graphed over the range of years of service for the meters, 0 to 25 years.

The data was then sorted by volumetric flow by dividing the recorded consumption range from 0 to 10,000 into segments spanning 250 units. Further sorting was done on an Over Reading, Pass Reading, Under Reading basis. Variance, Standard Deviation and Averages based on the age within these segments were also calculated to be later graphed for analysis.

Note that the raw data was normalized to account for human error. This was done based on the overall accuracy. The average of all “Total Accuracies” was calculated and a 95% confidence interval range was established by deleting all data that fell outside of the average plus/minus two standard deviations.

Results

Section 1

WAC Meter Testing Program Analysis Results

Below are the results for the batch test to observe the variability within the WAC-Meter Testing program. Figure 1 shows the flow results for the pilot while Figure 2 shows the results for the associated, randomly selected PSM20 meters (6). The range of the y axis goes from 90% to 115% accuracy.

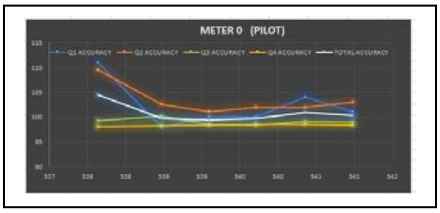


Figure 1 -Pilot Meter Flow Profile

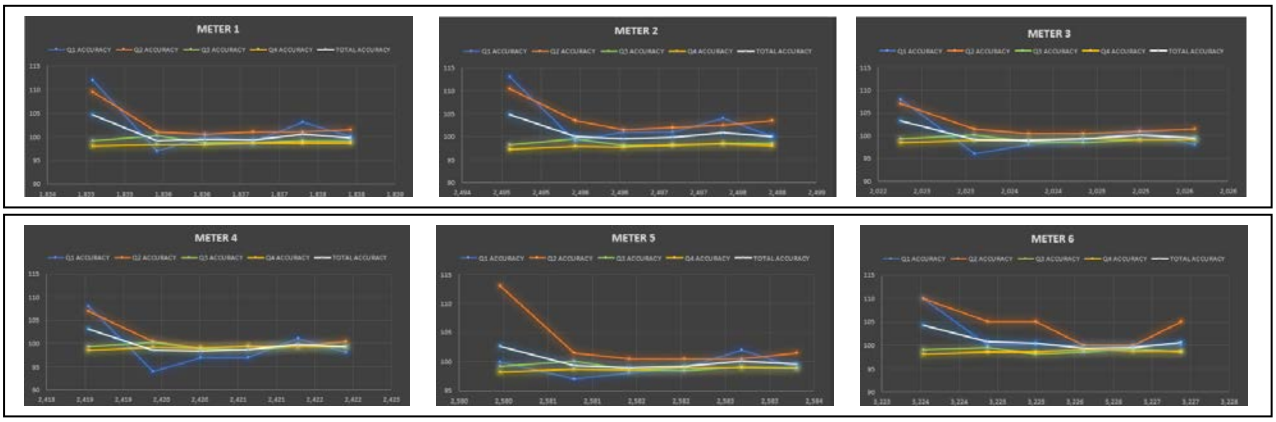


Figure 2 -Flow Profiles for Six Random PSM20 Meters

Table 2 shows the variance, standard deviation and average accuracy for each test of the six meters. Figure 3 are graphs of these tests where the six lines at each flow rate represent the six tests that were conducted. They were graphed individually for easier comparison within the four flow rates and later combined in Figure 4 to get an overview of the situation. A box plot was created as seen in Figure 5 to illustrate the variability within each flow rate via a comparison between the calculated Standard Deivations. It can be seen that most of the variability in the Total Accuracy can be attributed to the Q1 Results which is the most sensitive to error.

TEST #	VARIANCE	STANDARD DEVIATION	AVERAGE ACCURACY
1	7.35425E-05	0.008575692	1.0
2	5.32225E-05	0.007295373	1.0
3	3.69505E-05	0.006078694	1.0
4	1.5383E-05	0.003922122	1.0
5	2.88294E-05	0.005369299	1.0
6	2.32498E-05	0.004821806	1.0
AVERAGE	0.0	0.0	1.0

Table 2 -Batch Test Results for standard Deviation and Average Accuracy

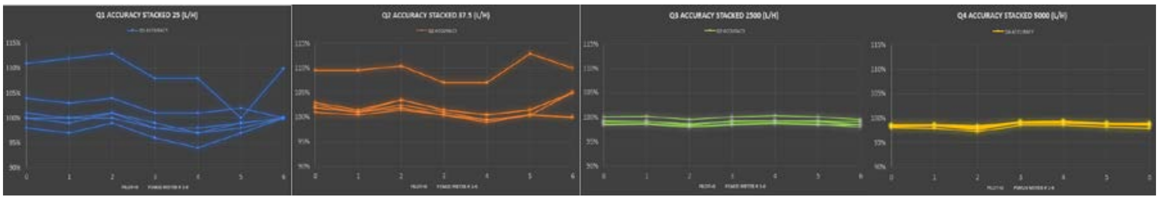


Figure 5 -Difference in Flow Accuracy for Six Meter at All Four Test Flow Rates (6 Tests)

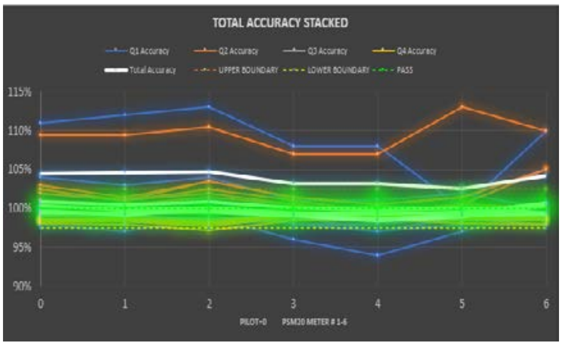


Figure 3-Combination of All Flow Rates

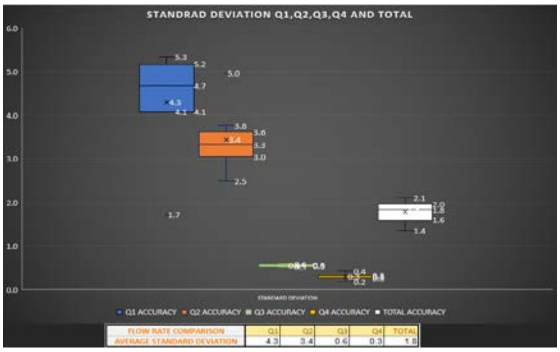


Figure 4 -Differences in Standard Deviation Between Flow Rates

The individual meter results spanned 295 tests over the past 10 years. Figure 6 shows the average results of each test session with values and percetages assiged to session results where the group of meters either passed, fell below or were over above the specified pass range. The following Figure 7 is a graph of these resulting category figures.

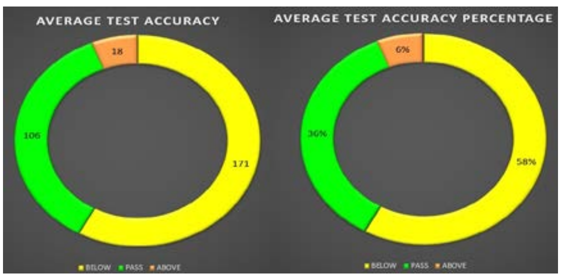


Figure 7 -Test Session Results

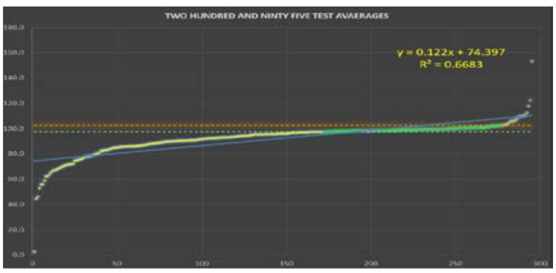


Figure 6 -Graph of 295 Test Series Results

Section 2

Meter Testing Analysis Results

Figure 8 below shows the progression of the initially created flow accuracy graphs. The raw data is shown in blue for the range of total flow from 1750 - 2250m^3 with accuracy ranging from 0 - 105%. The first image shows the raw data in blue, when a one-digit round is applied the green dots appear then when a two-digit round is applied the orange aggregation becomes visible. This leads to Figure 9 which provides a good overall graph to illustrate the total flow accuracy of the meters tested within the program to date sorted by flow. Total Flow ranges from 1750 - 4050m^3 and accuracy is shown from 0 to 150%.

Figure 8 -Average Accuracy Results by Flow: Raw Data->One-Digit Round->Two-Digit Round of Data

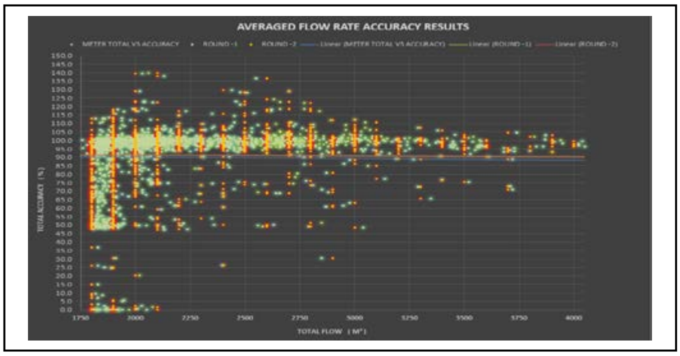


Figure 9 -Average Meter Accuracy Ordered by Total Flow

It was due to the level of outlying data in Figure 9, which causes noise, why it was decided that it would be best to normalize the data before continuing the analysis. A confidence interval of 95% was calculated and after normalization there were 1626-meter test results to compare. The lower boundary was 63.1% and the high was 124.4% Average Total Accuracy respectively. Individual worksheets were created in Excel to study the three categories of results, Under Reading, Pass Reading and Over Reading. Their individual category results were sorted and plotted by age, and then by flow as seen in

Figure 10 & Figure 11. In order to determine the significance of each numerical value at the varying intervals the ratio was calculated and plotted for comparison as seen in Figure 12 & Figure 13.

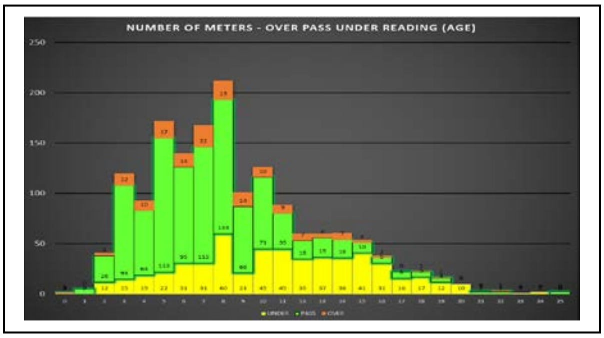


Figure 10 -Accuracy Results Sorted by Age (0-25 Years)

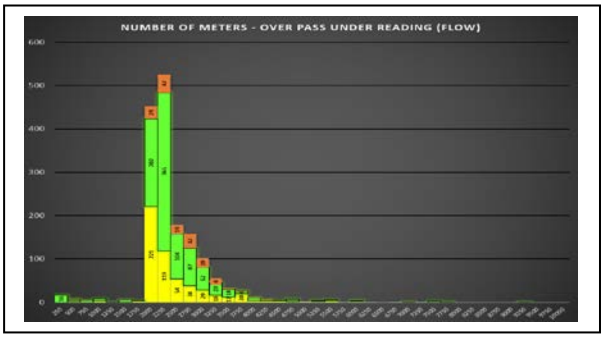


Figure 11 -Accuracy Results Sorted by Total Flow (0-10000 m³)

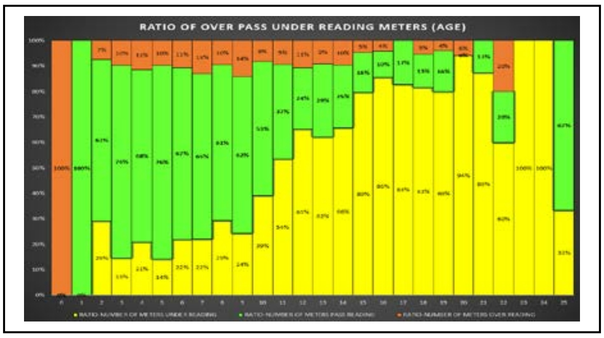


Figure 13 -Ratio of Meters Sorted by Age

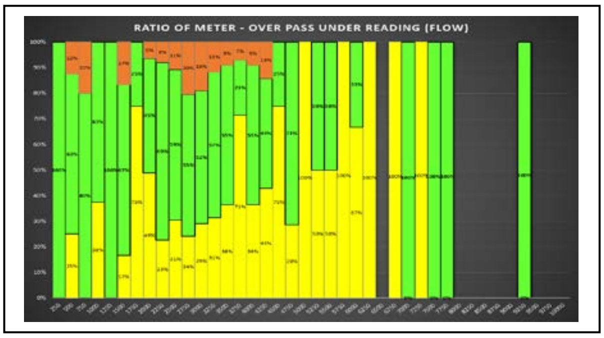


Figure 12 -Ratio of Meters Sorted by Total Flow

These numbers were graphed across the range of data, see Figure 14 & Figure 15. Then they were graphed across the range containing the majority of the data in order to obtain the equation of linear regression from which a degradation formula can be derived for the purpose of cost analysis, Figure 16 & Figure 17.

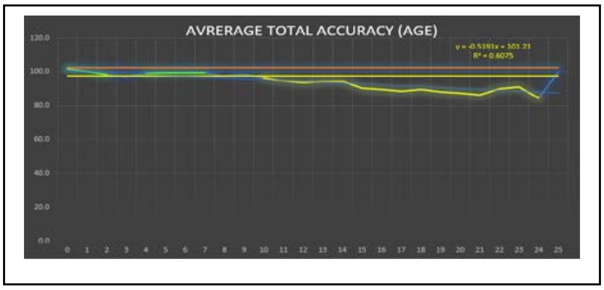


Figure 16 -Graph of Average Total Accuracy Sorted by Age

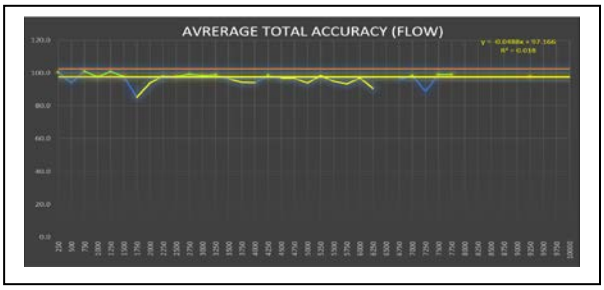


Figure 17 -Graph of Average Total Accuracy Sorted by Flow

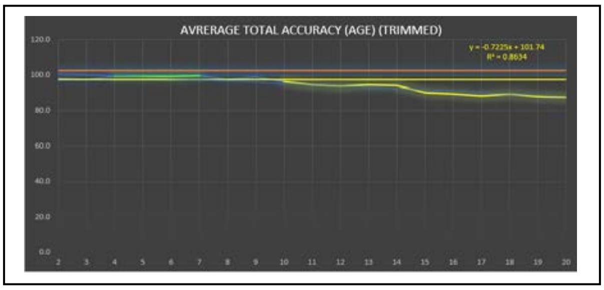


Figure 15 -Graph of 99.14% of Meters by Age

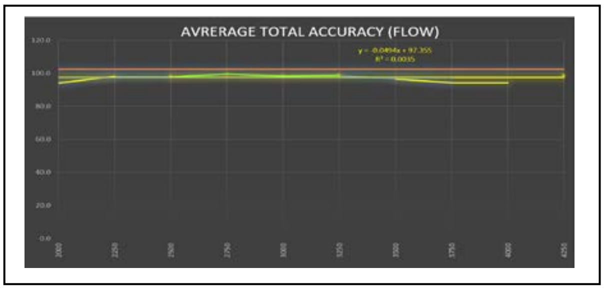


Figure 14 -Graph of 94.83% of Meters by Flow

Discussion

In summary it can be said that the Water Authority-Cayman employs a robust in-house testing procedure on behalf of our customers. Based on the data trends it is safe to say that contradictory to public fears when meters fail, they fail down not up. Or in other words a customer is more likely to be under billed than over billed as the 10% of the total recorded flow that passed through potentially over reading meter is far less than the 34% that passed through the under reading. The meters overall can be said to be accurate as 56% of consumption data passed through meters that were on the money in terms of accuracy. The data is summarized in Figure 18.

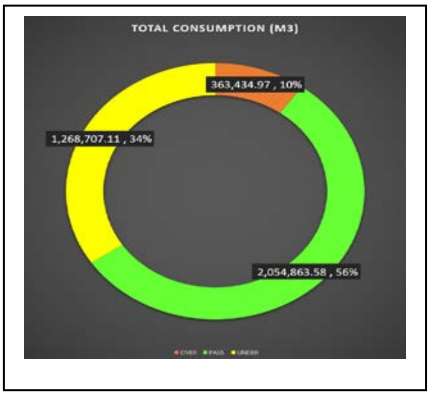


Figure 18 -Distribution of All Recorded Consumption by Tested PSM20 Meters

An interesting observation in the two graphs which illustrate the Average Total Accuracy based on Age and Flow, Figure 14 & Figure 15, is that any over reading is averaged out as the majority of meters pass or are under reading for each graph subdivision. As such the primary area of investigation when it comes to meter accuracy error is in the Under Reading Category. Both graph for these categorized meters can be found below in Figure 19 & Figure 20 below. What these graphs show is surprising as it is contradictory to our starting premise as it appears that the years of service shows greater correlation and is also trending in a direction which follows logic. This contradiction is due to the fact that there was an error in the previous analysis as the age of the meter although properly defined was not properly implemented. Instead, the installation year was being used which produced a different set of results.

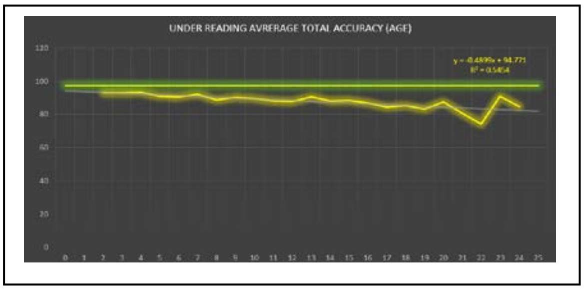


Figure 20 -Under Reading Average Total Accuracy by Age

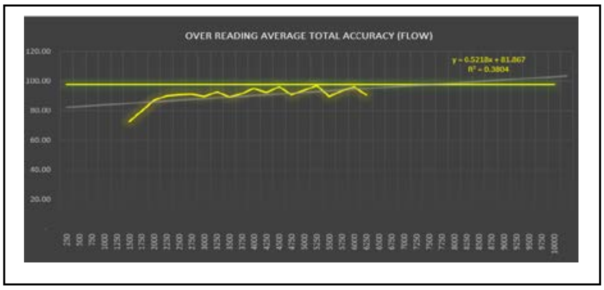


Figure 19 -Under Reading Average Total Accuracy by Flow

The overall level of under reading meters is of some significance as at the time of testing meters were measuring as low as ~ 60% of the total reading. The profile of these losses across the meters tested can be seen in Figure 21.

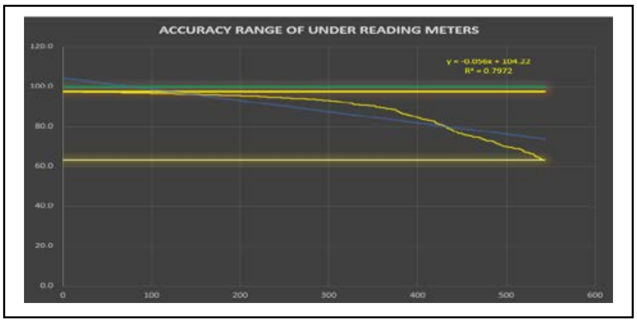
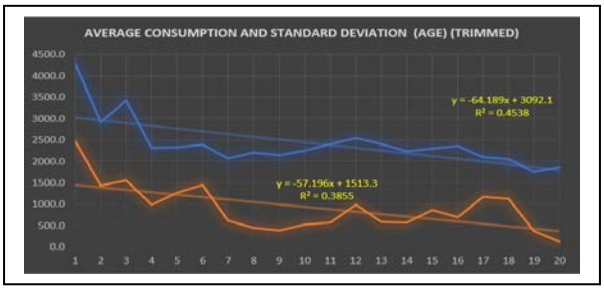


Figure 21 -Accuracy Range of Under Reading Meters

Following the logic of meter under reading increasing with age, it could be assumed that overall consumption would also be elevated. This however is not the case as shown in Figure 22 as the Average Consumption trends towards decreasing with age. Figure 23 lends support to this reasoning as it shows a decrease in average age as flow increases. This would lend one to believe that it is not a high flow that causes degradation but rather under usage, aka stagnation. An example that supports the theory is an outlier that was found on the Pass Reading Excel Spreadsheet. Its total flow was so high that at first it was thought to be a data entry. However, upon inspection the meter turned out to have the Account Number RBGT which meant it was actually a meter that had been recording readings at a Water Authority-Cayman Plant and after 5 years of service still boasted and overall average accuracy of 99.1% with 17,673 m^3 recorded.



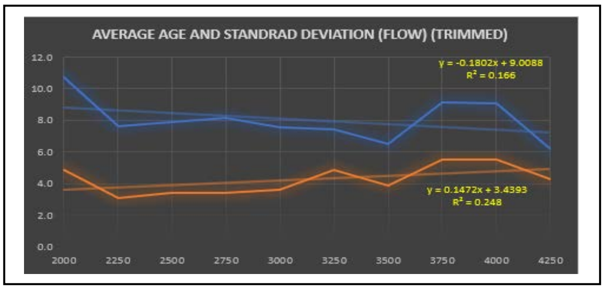


Figure 23 -Average Consumption and Standard Deviation by Age *Figure 22 - Average Age and Standard Deviation by Flow*

Conclusion

The Summary of the paper is as follow:

- The WAC Meter Testing Program is accurate and demonstrates high repeatability
- There is however a Human Error Factor which can be eliminated with the implementation of automation during testing
- New meters could be tested before installation to answer the question if meters typical fail by under reading which would mean that the current over reading results would be mostly attributed to human error during testing and factory faults
- A cost analysis needs to be done to determine when it would be ideal to replace a under registering meter based on the new data
- Age (Years of Service), plays a significant factor in meter degradation while Total Volumetric Flow plays a less defined role
- Overall customer usage pattern is ultimately the deciding factor in degradation which at this point cannot by readily quantified however with AMI may be possible in future
- Extrapolation of Sample Data to create model of WAC-Distribution System for calculation purposes
- An audit of current meters in service needs to be conducted in order to cross-reference the information with accumulated degradation data to more accurately estimate Non-Revenue Water Losses
- Adjustment to meter changeout strategy to be based on age would be recommended with replacement of all meters greater than 8 years in age as a priority

Making Peace with Nature - Using the IWEco Approach to Ecosystems Restoration in St. Kitts and Nevis

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Topic Area: Nature-based solutions for water and land management
Keywords: Integrating Water, Land and Ecosystems Management (IWEco)

Abstract

The themes of both Earth Day and World Environment Day in 2021 were focused on ecosystems restoration and the urgent need for us to make peace with nature. How can we do this? What actions can we take in small island developing states of the Caribbean to BECOME "Generation Restoration". The answer lies in unity, integration, and collaboration. Nature-based solutions (NbS) are critical to making peace with nature.

This paper will highlight NbS in action in St. Kitts and Nevis implemented through the IWEco project. In St. Kitts, about 5 acres of land inside of a major ghaut (i.e. ravine) were restored in order to mitigate against erosion and land degradation through the installation of gabion baskets and planting of deep-rooted vetiver grass. The project has also commissioned the design of a pilot greywater collection, treatment and reuse system utilizing constructed wetlands. In Nevis, restoration activities were activated over 23 acres at three separate sites including an abandoned quarry at Potworks Estate and a coastal wetland at Nelson's Spring.

Introduction

The themes of both Earth Day and World Environment Day in 2021 were focused on ecosystems restoration and the urgent need for us to make peace with nature. How can we do this? What actions can we take in small island developing states of the Caribbean to BECOME "Generation Restoration". The answer lies in unity, integration and collaboration. Nature-based solutions (NbS) are critical to making peace with nature.

Nature-based Solutions (NbS) are defined by the International Union for Conservation of Nature (IUCN) (2016) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."

NbS are at the core of a regional project termed the Integrating Water, Land and Ecosystems Management (IWEco) in Caribbean Small Island Developing States. St. Kitts and Nevis is one of ten participating countries in the multi- focal regional IWEco project with funding from the Global Environment Facility (GEF). The United Nations Environment Programme (UNEP) is the lead Implementing Agency in partnership with The United Nations Development Programme (UNDP). The United Nations Environment Caribbean Regional Coordinating Unit (CAR/RCU) and the Caribbean Public Health Agency (CARPHA) serve as co-Executing Agencies. In St. Kitts and Nevis, the Department of Environment within the Ministry of Environment and Cooperatives is the lead implementing agency.

IWEco's objective is to contribute to the preservation of Caribbean ecosystems and the sustainability of livelihoods through improved fresh and coastal water resources management, sustainable land management and sustainable forest management. IWEco is an integrative approach which focuses on systems, people and values. All project activities consider whole ecosystems (such as watersheds) and focus on relationships and processes within the system. Next, the approach puts people and sustainability at the heart of environmental management and ensures intersectoral cooperation and stakeholder engagement. Finally, this approach recognizes that our environment provides us with important and valuable benefits (also called ecosystems goods and services) which support all life and seeks to enhance the sharing of those benefits.

The overall goal of the sub-project in St. Kitts and Nevis is to reduce and reverse land degradation using the IWEco approach. The project will strengthen the institutional capacity, improve the policy framework and facilitate pilot projects within the College Street Ghaut watershed (St. Kitts), and key quarry sites and nearby wetlands and coral reefs (Nevis). The next section will highlight the main guiding principles of NbS and then several on-the-ground interventions taken by the IWEco SKN project will be highlighted as examples of NbS.

Principles of NbS

In 2016, the IUCN adopted a concrete definition and goal for NbS and outlined key guiding principles of NbS. The goal of NbS is "to support the achievement of society's development goals and safeguard human well-being in ways that reflect cultural and societal values and enhance the resilience of ecosystems, their capacity for renewal and the provision of services". NbS are designed to address major societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development. The following are considered guiding principles in the application of NbS:

1. NbS embrace nature conservation norms (and principles);

2. NbS can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g. technological and engineering solutions);

3. NbS are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge;

4. NbS produce societal benefits in a fair and equitable way in a manner that promotes transparency and broad participation;

5. NbS maintain biological and cultural diversity and the ability of ecosystems to evolve over time;

6. NbS are applied at a landscape scale;

7. NbS recognise and address the tradeoffs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services; and

8. NbS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

Utilizing these principles under the IWEco umbrella, the project embarked on several on-the-ground interventions in St. Kitts and Nevis.

Land Degradation Control Works in College Street Ghaut, St. Kitts

The College Street Ghaut watershed covers 662 hectares. The watershed has a complete range of features from upland natural forest, former sugar cane lands and urban development. Land use changes especially due to urban growth have resulted in more rapid surface water runoff and severe soil erosion following rainfall events. The impacts of this land degradation are far-reaching and include public health risks due to flooding and inappropriate disposal of liquid and solid waste as well as loss of top soil, poor water quality at the outlet of the ghaut and contamination of the near shore environment. Major flood events linked to land degradation and chronic sedimentation have been a frequent occurrence, with the last major event in summer 2013 causing an estimated US$120,000 in damages. Works to reduce and control land degradation inside the ghaut are a critical first step leading to a more proactive way of managing this important environmental zone.

The works began in earnest in February 2020 after a clean-up exercise where excess vegetation and solid waste were removed from a 5-acre area targeted by the project shown in Figure 1.



Figure 1. Target location inside the College Street Ghaut

The main land degradation control measures implemented were gabion baskets, repair of existing weirs and the planting of deep-rooted vetiver grass. A gabion is a galvanized wire cage, cylinder, or box filled with materials like concrete, stones, sand, or soil. When filled with these materials, gabion structures act as building blocks and become a powerful and cost-effective defense against erosion. The baskets are used to maintain stability and to protect streambanks and beds. Historically, gabion baskets have been utilized in the Federation of St. Kitts and Nevis especially in the agricultural sector (notably during the times of sugar manufacturing) as a means of soil stabilization and conservation along the banks of major ghauts.

Over 300 gabion baskets were installed. The works also saw the repair of two weirs (or barrier wall structures) that were installed inside the ghaut over 50 years ago (Figure 2). The weirs act as a barrier for soil and when dredged in a timely manner avoid large volumes of soil from entering the coastal zone. Excess debris and sediments have also been cleared from culverts and drains including at the outlet of the ghaut. Over 500 metric tons of sediment were dredged from the outlet of the ghaut in the year from August 2020 to September 2021.


Figure 2. Gabion baskets installed (left) and weir repair (right)

Deep-rooted vetiver grass is also being planted along the banks of the ghaut (Figure 3). This type of vegetation prevents surface erosion and shallow slides by slowing the speed of rainfall runoff and holding soil particles in place. Deeply rooted vegetation prevents slumps and slides through stabilization from the root systems. In addition, this grass (known locally as couscous or bedgrass) is used for weaving and handicrafts thus providing a livelihood for many persons. Planting will continue into 2022 until the end of the project.


Figure 3. Vetiver grass planted in June 2020 (left) and after one year of growth in May 2021 (right)

To address the greywater disposal issue inside the College Street Ghaut, the IWEco SKN project also commissioned the design of a pilot greywater collection, treatment and reuse systems utilizing constructed wetlands. This work is detailed by Daniel and Paul (2021). It is anticipated that this pilot system will be built with funding from the upcoming GEF-CREW+ project.

The next step now that the works are mostly complete is the development of a management plan for the ghaut to ensure ghaut health is maintained and actions taken to dredge behind the weirs as needed to avoid soil runoff into the nearshore environment. The key stakeholders will be consulted in the formulation of the plan to ensure that the roles and responsibilities are clear, and the necessary course of action triggered based on regular monitoring of the ghaut.

Alongside these land degradation control works, there has been several public awareness activities related to "caring for our ghauts". The main message is that ghauts are environmentally significant areas that require special protection and care to preserve their qualities. The ghauts throughout the island serve as a natural drainage system carrying storm water runoff to the ocean and serve as recharge zones for groundwater aquifers. There are over 150 miles of ghaut throughout St. Kitts and Nevis. Other key messages promoted through public education and outreach activities include:

The ghauts of SKN -

- support health and well-being
- help define the identity of our twin island Federation
- give people a sense of place
- support biodiversity
- provide critical ecosystem services
- offer a chance to learn about nature
- mitigate climate change effects
- have a rich cultural history, including indigenous settlements
- support the local economy through tourism
- help cultivate future champions for nature conservation contain important infrastructure

How can I care for the ghaut?

To maintain a healthy ghaut and prevent erosion:

- practice good management by minimizing disturbance adjacent to and on ghaut slopes and planting large growing native tree species, native shrubs, and forest plants, appropriate to your area
- control invasive plants
- ensure and maintain proper setbacks from the edge of the ghaut
- be a good neighbor – realize that your actions affect the property owners beside you, and below you especially if you live adjacent to a ghaut

Overall, the suite of interventions taken in this section of College Street Ghaut (i.e. a modified ecosystem) are a good example of NbS as the actions taken help significantly reduce the impacts of excessive soil erosion and flooding. The solutions in place now allow for sustainable management of the ghaut. The positive benefits to human well-being include mitigation of flooding risk and improved water quality in receiving waters. Also, biodiversity benefits include the propagation of vetiver grass and other native species which prevent soil erosion but can be used for livelihood generation.

Reforestation and restoration at three sites in Nevis

A robust reforestation and rehabilitation effort is being spearheaded by the Nevis Historical and Conservation Society (NHCS). This sub-project officially began in May 2020 and has a lifetime of 2 years. Building on a successful GEF Small Grant Programme project at Coconut Walk Estate (2017-2019), the IWEco project in St. Kitts and Nevis provided a grant of USD 150,000 to the NHCS to continue its reforestation programme at Coconut Walk (approximately 10 acres), to reforest 5 acres of degraded lands at the abandoned quarry at Potworks Estate and to start a pilot wetland restoration effort at Nelson's Spring (approximately 8 acres).

Coconut Walk Estate
The site at Coconut Walk has seen persistent land degradation over decades due mostly to overgrazing, unsustainable farming practices and upstream quarry operations. The site is characterized by harsh conditions of a wind-swept landscape with constant sea-blast, rocky and arid conditions, degradation of original vegetation, diminished rainfall in recent years and lack of water retention capacity. Despite this challenging environment, the NHCS has adopted several interventions aimed at sustainable reforestation of this site.

The entire site has been fully contoured with berms to restrict erosion, under which swales were developed for water retention and with biomass to support vegetation regrowth. Additionally, sediment traps and small catchment areas were constructed to aid water retention and vegetation regrowth, including cactus gardens, with evidence of teeming life of plants, insects, lizards, and birds, with some of the plants as naturally occurring pioneering species and others propagated (Figure 4). Small scale compositing was developed at the site to promote soil nutrient health. Finally, fencing, and electrical wire were erected as deterrents from ruminants, particularly goats and donkeys that previously roamed and grazed the area.


Figure 4. Soil retention techniques at Coconut Walk – contours (left) and sediment traps (right)

After much experimentation and consistent effort, native sea grape, coconut, almond, and vetiver grass including a variety of forest species and fruit trees have adapted and established under the prevailing harsh conditions of strong winds and sea blast, drought, and otherwise barren soils (Figure 5). These were supplemented by drip irrigation from municipal water sources when available. Although the area is only sporadically serviced by the municipal water supply due to drought conditions. As such, the work crew devised a system to water the newly planted seedlings whereas a recycled 1-gallon plastic water bottle, perforated at the base, is nestled beside the new seedling. The perforated base allowed for slow watering of the root zone (Figure 5). The bottles are refilled manually once a week.


Figure 5. Planted coconut trees (left) and recycled plastic bottle watering system (right)

Overall, there is evidence of progressive vegetation growth and habitation of insects and crabs particularly along the berms and swales. Over 1,300 trees were planted in the last year (May 2020 to August 2021) at Coconut Walk.

Abandoned quarry at Potworks Estate

Quarrying operations ceased at Potworks Estate over 10 years ago. No restoration efforts were undertaken at the end of the operation leaving a denuded exposed hillside prone to severe erosion after heavy rainfall. At the inception of the IWEco SKN project, the site still had abandoned equipment littering the landscape and had become a hotspot for illegal dumping of waste. There was significant evidence of soil erosion and land degradation with a proliferation of invasive plant species.

Despite the ongoing challenges due to the COVID-19 pandemic, a robust effort of solid waste clean-up and land preparation was undertaken by the NHCS in 2021. Similarly to the site at Coconut Walk, the land was contoured, and berms, sediment traps and catchments created to restrict stormwater runoff and promote infiltration. Invasive plant species were also removed. Native forest and fruit species are now being actively planted at the site with over 100 trees planted in the first month (Figure 6).

Figure 6. Abandoned quarry before clean-up (left) and after (right)

Wetland restoration at Nelson's Spring, Nevis

The area known as Nelson's Spring occupies approximately 8 acres on the west coast of Nevis. Within the site is a pond, maintained year-round by the main Nevis west coast aquifer and fed, mainly in the rainy season, by drainage from the slopes of Nevis Peak to the east. There is one drainage channel to the sea, usually closed by a sand berm which may be breached once or more per year after heavy rains.

In recent years, Nelson's Spring has been subject to many negative environmental pressures, neighboring developments have cut off the natural links with other wetlands. There has also been wholesale clearing of vegetation aimed at 'cleaning up', without any attempt at replanting. The result of these disturbances has been the invasion of the whole area with non-native species. Around the drier edges, the most frequent colonising species are Casha *(Acacia macracantha)*, Clammy Cherry *(Cordia obliqua)* and Wild Tamarind *(Leucaena leucocephala)*. This has resulted in dense almost impenetrable scrub suppressing the regeneration of native species including White Mangrove *(Laguncularia racemosa)* and Seagrape *(Coccoloba uvifera)*. The pond itself has been colonized by Southern Cattail *(Typha domingensis)*, these fast-growing vigorous reeds have displaced native reeds and other species, presenting a threat to the natural biodiversity (Figure 7). They have also severely reduced the open water of the pond and changed the open aspect from the road to the sea (NHCS 2021).

The NHCS has teamed up with a local community group - the St. Thomas' Improvement Group (STIG) - to restore the wetland at Nelson's Spring by removing non-native invasive cattail reeds and scrub thus reopening the beautiful vista to the sea. Clearing began in late November 2020 and proceeded rapidly, cattails were cleared from the whole perimeter of the pond, and scrub was cleared in the southern section to around 50ft out from the pond edge. Replanting began in December 2020; some surviving coconuts were relocated, and Red Mangrove (*Rhizophora mangle*) was planted near the mouth of the pond.

Figure 7. Arial view of the wetland at Nelson's Spring – evidence of scrub and cattails throughout the pond

In January 2021, community days were held, species planted were seagrape, coconut, white mangrove, seaside almond (*Terminalia catappa*), swamp fern (*Acrostichum danaeifolium*) and beach morning glory (*Ipomoea pes-caprae*), volunteers also helped remove regrowing cattails. Along with the replanting, there was encouraging regrowth of native species of sedge and spike reed (*Eleocharis mutata*). There had been concern for the native spike reed which had once been widely present in the wetland, but which was no longer in evidence amongst the dense cattails, however this was soon seen regrowing in cleared areas (Figure 8). By April 2021, the water lily (*Nymphaea ampla)*, had re-established and has now spread through the whole pond. Currently, work has centered on slowing down the regrowth of cattails by employing one or more laborers to physically remove plants and cut off flower stalks. A recent purchase of a reed cutter will enable faster clearing (NHCS 2021).

Figure 8. Wetland after initial cleaning and replanting (left), spike reeds (upper right) and sedges (lower right) return to the pond

Water birds have been very visible during all stages of the project. In April 2021, a group of young birders on an ornithology course visited Nelson's Spring on a field trip. The local ornithologists accompanying them identified 33 species of birds in the two-hour visit, more than at any other site they had visited in both St. Kitts and Nevis. Fish are seen jumping in the pond, and crab holes are evident. Also, recently lots of butterflies have been seen in the areas where native plants are re-establishing. In addition, the neighboring beach is a nesting site for Leatherback and Hawksbill turtles.

In mid-2021, the NHCS applied for and received grant funding from the US National Forest Service under their Natural Infrastructure for Caribbean Resilience (NiCAR) programme to continue the restoration effort at Nelson's Spring.

Future actions

To create synergistic and continued positive impacts of the NbS implemented so far under the project, efforts in the last year of the project will be focused on strengthening the main legal instrument in the Federation for environmental management and conservation, the National Conservation and Environment Management Act, which has been in draft form for several years. In addition, a management plan will be developed for the College Street Ghaut. In addition, actions will be taken to strengthen environmental monitoring especially as it relates to potable and recreational water quality monitoring. Finally, knowledge and lessons learnt will be shared and the public engaged through outreach and awareness activities.

Conclusion

Wide ranging Nature-Based Solutions were implemented across the Federation of St. Kitts and Nevis under the IWEco SKN project. We can recall the definition of NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (IUCN 2016)

The actions highlighted in this paper include land degradation controls works in the College Street Ghaut, St. Kitts including the installation of 300 gabion baskets, repair of weirs and planting of vetiver grass and in Nevis, reforestation, and restoration activities across three sites at Coconut Walk, Potworks Estate and Nelson's Spring wetland. In St. Kitts, over 5 acres of ghaut lands were restored thus mitigating excessive soil erosion and flood risk to neighboring homes. It is estimated that these actions will prevent annually up to 500 metric tons of soil from entering the near shore environment thus addressing the serious challenge of land degradation and contamination of the coastal zone. This also positively impacts marine biodiversity along the coastline. Coupled with strengthening legal instruments and management plans, these NbS can continue to provide positive impacts into the future and ensure sustainable use and management of the College Street Ghaut.

In Nevis, over 20 acres of degraded lands have been restored with more than 1,400 trees planted and soil conservation actions such as contours, sediment traps, composting and planting of deep-rooted grasses transforming the landscape at three separate sites. These actions have restored both natural and modified ecosystems and have effectively addressed issues related to land degradation due to overgrazing, quarrying and other unsustainable practices. The biodiversity benefits have been well documented especially at the wetland at Nelson's Spring with many water birds, native wetland plant species, crabs, fish, and butterflies returning to this fragile coastal wetland. These benefits result in overall enhancement of human well-being especially as it related to community stewardship and cohesion and re-establishment of green zones for recreation and cultural activities.

Although NbS can be both labour and time consuming and require sustained financing, the long-term benefits are evident and it is clear these types of solutions are the best way forward as we seek to make peace with nature and truly become "Generation Restoration".

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Drafting Project Specifications for SWRO Facilities: Best Practices and Lessons Learned

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ABSTRACT

Desalination project specifications are essential to the successful design, construction, commissioning, and operation of Seawater Reverse Osmosis (SWRO) facilities. From project delivery methods to desalination technologies, there are many decisions to be made and information to be collected before the project specifications are ready to be released to potential bidders.

Project owners in general, and public utilities in particular, need to strike a balance between over-specifying and under-specifying in order to ensure that they end up with a facility that provides better value for money, low Operation and Maintenance (O&M) costs, and smooth transfer of operations in a Build-Own-Operate-Transfer (BOOT) procurement model.

This paper aims to shed light on the key aspects project owners should keep in mind while drafting their project documents to ensure their needs are met and avoid potential disputes, scope creep, and costly add-ons. The paper draws from the experience of Water Authority – Cayman (WAC) in procuring and operating SWRO facilities for more than 30 years.

Key Words: Desalination, SWRO, plant operations, design-build, public procurement

INTRODUCTION

The Cayman Islands has become highly dependent on seawater desalination due to the absence of fresh surface water bodies and the insufficiency of fresh groundwater resources (Jones et al., 2001). While different desalination technologies have been implemented in the Cayman Islands, Seawater Reverse Osmosis (SWRO) plants, the first of which was installed in 1989, are now the primary source of potable water in the islands (Crowley and Pereira, 2001). Water Authority – Cayman (WAC) owns and operates public water supply systems in Grand Cayman and Cayman Brac, serving more than 18,000 customers. The Authority owns a total of four SWRO plants in Grand Cayman and two SWRO plants in Cayman Brac, which includes a containerized plant. The total installed capacity is

23,760 cubic meters per day (6.28 MGD). All of the Authority's SWRO plants were procured through Build-Own-Operate-Transfer (BOOT) agreements. Three SWRO facilities are currently operated through an operation agreement by Ocean Conversion Cayman, Ltd. (a subsidiary of Consolidated Water Company). In contrast, the other three facilities are self-operated by the Authority.

As Figure (1) shows, demand for potable water in the Cayman Islands has continued to increase during the last 10 years. Although the total installed water production capacity has remained almost constant during the same period, WAC is embarking on a time of significant growth that is expected to bring the total installed water production capacity to approximately 48,000 cubic meters per day (12.68 MGD) by 2030 (Water Authority - Cayman, 2020)

Ensuring that desalination facilities are built to the highest standards to reliably meet the water quality and quantity needs of the public is of utmost importance. Therefore, drafting project specifications that guarantee the successful delivery of SWRO facilities has always been central to the Water Authority's mission.

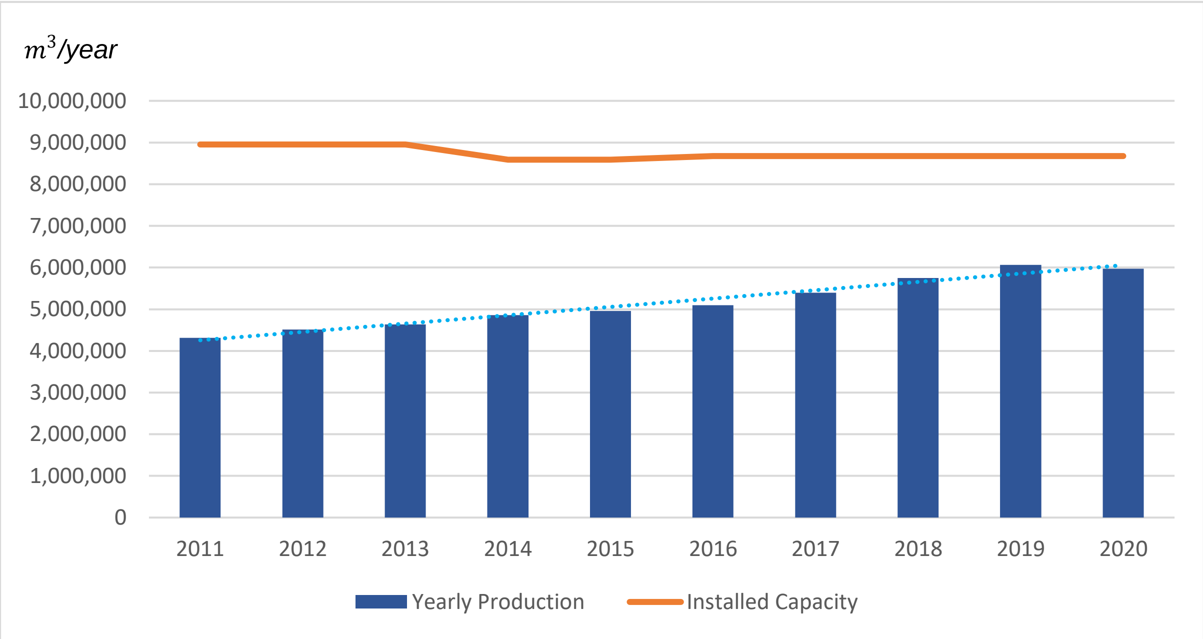

Figure 1. *Yearly Potable Water Production by WAC-Owned SWRO Plants*

(Source: Water Authority – Cayman)

IMPORTANCE OF DRAFTING EFFECTIVE SPECIFICATIONS FOR SWRO PROJECTS

Water utilities hold a great responsibility of ensuring a reliable and safe drinking water supply to the public. Therefore, mitigating and avoiding risks associated with major production and distribution projects is always sought after. Drafting detailed and comprehensive project documents ensures that the utility ends up with a facility that meets all requirements. Additionally, here is a summary of why drafting effective project specifications for BOOT desalination facilities is advantageous:

- **a.** Ensure better value for money
- **b.** Ensure low O&M costs
- **c.** Ensure a smooth transfer of operations
- **d.** Avoid cost and schedule overruns
- **e.** Mitigate/transfer project risks
- **f.** Avoid disputes

SCOPE OF SWRO PROJECTS

Arguably the most critical part of an infrastructure project in general, and an SWRO facility in particular, is the project's scope. A well-defined scope guarantees that the utility receives what they are paying for and safeguards against scope creep, which can be costly and time-consuming.

For an SWRO facility, the project scope may be divided into three categories; product water standards, construction outcomes, and parts and equipment. Product water standards define the type of process and technologies utilized in an SWRO facility. They must include the application the water will be used for, e.g., drinking water, agricultural, industrial, pharmaceutical, etc. Additionally, water quality standards must be clearly defined.

Table (1) shows typical water quality standards for SWRO plants in the Cayman Islands. In this case, all other parameters of the product water not explicitly mentioned in the table are required not to exceed the values published in the latest edition of the WHO Guidelines for Drinking Water Quality.

Parameter	Testing Method	Allowable Value	Maximum Value
		(mg/l, unless stated otherwise)	(mg/l, unless stated otherwise)
pH (units)	Electrometric	6.5 - 7.5	6.0 – 8.0
Boron	Colorimetric	1.2	2.4
Sulphide	Methylene Blue	0.01	0.02
Total Chlorine Residual	Colorimetric	0.00	0.10
Electrical Conductivity (μS/cm)	Electrometric	400	800
Total coliform bacteria (cfu/100ml)	Enzyme Substrate	0	1
E. Coli	Enzyme Substrate	0	1

Table 1. *Typical Product Water Quality Values (Source: Water Authority – Cayman)*

The second category covers construction outcomes, which include civil works, buildings, electrical works, intake and outfall, pre- and post-treatment works, water storage, and distribution infrastructure. A utility must decide which construction outcomes need to be included in the SWRO project's scope.

The third category covers Parts and Equipment. This is everything that enables the plant to produce water at the contracted quantity and quality. Parts and equipment include pumps, membranes, filters, auxiliary systems, instrumentation, emergency generators, and may even include specific tools. Defining what is and is not part of the project scope is imperative to ensure that all stakeholders are on the same page.

SWRO PROJECT INFORMATION AND STUDIES

Providing accurate and comprehensive information in the project specifications ensures a well-designed plant, which leads to reliable operation. Project owners should endeavor to collect as much information as possible about their project before releasing the Request for Proposal (RFP).

Usually, any new desalination facility will start with a feasibility study or a business case highlighting the need for the project. Utilities may commission bathymetric studies for surface water intake or hydrogeological studies for groundwater intake. Additionally, testing source water quality is paramount. Table (2) summarizes feedwater quality values for the Red Gate and North Sound RO plants owned by Water Authority – Cayman.

Parameter	Testing Method	Red Gate RO Plant Feed Wells	North Sound RO Plant Feed Wells
Alkalinity	Titration	180	150
Bicarbonate	Calculation	220	185
Calcium	EDTA Titrimetric	740	470
Chloride	Argentometric	19,900	19,450
Hardness	EDTA Titrimetric	6,400	6,800
Magnesium	Calculation	1,200	1,370
pH (units)	Electrometric	7.1	7.1
Sodium	Na-selective electrode	10,150	n/d
Sulphate	Turbidimetric (barium chloride)	3,100	3,100
Sulphide	Methylene Blue	4.3	4.0
Electrical Conductivity (μS/cm)	Electrometric	52,750	54,000
Total Dissolved Solids	Gravimetric (Dried @ 180°C)	37,100	38,050

Table 2. *Typical Feedwater Analysis (Source: Water Authority – Cayman)*

Moreover, when thinking about procuring an SWRO plant, owners should answer two more questions: is there a need for an Environmental Impact Assessment? And is there a need for a pilot study? The answers to these questions will depend on local laws and regulations for the first and the owners' experience with SWRO plants for the second.

It was also found helpful when information on the relevant laws and regulations is provided to potential bidders. This includes information on trade and business licensing, procurement laws, planning laws, environmental laws, employment, and immigration laws.

PROCESS AND TECHNOLOGY

Process and technology epitomize the core of the technical specifications of any SWRO project. The level of detail provided in this area mainly hinges on the owner's experience with procuring and operating SWRO plants, available in-house expertise, and plant application and capacity.

Project owners who have experience with SWRO plant procurement should leverage their experience while drafting the technical specifications of their next project. This can take the form of specifying a specific pre-treatment process (e.g., MMF or DAF) or energy recovery technology (e.g., pressure exchangers vs. turbochargers). The winning bidder should work around the owner's requirement to provide a viable plant design. Owners may also provide preferred vendors and suppliers, as long as they provide a means for the winning contractor to suggest alternatives that may offer cost or schedule benefits.

On the other hand, owners may run the risk of limiting the contractor's ability to use its expertise to design the most efficient and practical plant if they become too involved with the technical specifications. It may be best to leave design decisions with those most qualified to make them. This particularly applies to desalination plants, where the technologies continue to evolve rapidly. Therefore, owners should strive to reach a middle ground between leveraging their own experience and taking full advantage of the market's expertise.

Finally, plant design is a balancing act between meeting the quality and quantity requirements of water and its cost. A good plant design strikes a balance between both to ensure low O&M costs since it usually is the single most significant expense over the plant's life (Voutchkov, 2014).

STANDARDS AND MATERIALS

SWRO plants must be built in accordance with local or international standards to ensure reliable operation and the safety of plant operators. While it is encouraged that owners defer the majority of the design decisions of SWRO plants to the winning bidder in a BOOT delivery model, standards and materials used should be well-defined in the project documents.

Standards for intake and outfall vary between jurisdictions. In the Cayman Islands, abstraction and disposal wells are used in all SWRO plants and must meet specific standards when it comes to drilling methods, well casings, and annular grout. Additionally, all abstraction and disposal permits must be obtained in advance by the contractor.

Piping standards, including pressure ratings, corrosion and scaling resistance, leaching, UV weatherability, etc., should be included in the project documents. In the case of high-pressure piping, passivated and electropolished 316L SS is adequate under normal operation (Nemeth and Seacord, n.d.). However, higher alloys such as duplex or super-duplex could help against pitting corrosion due to increased chromium percentage (22-25%) (Voutchkov, 2012). Low-pressure piping is usually made of Schedule 80 PVC (Nemeth and Seacord, n.d.).

Membrane Pressure vessels are required to meet the ASME Section X standard on fiber-reinforced plastic pressure vessels. Equipment that comes in contact with potable water should meet the requirements of the NSF/ ANSI Standard 61 to ensure that no harmful chemical compounds are released into the potable water. This standard applies to piping, chemicals, membranes, cartridge filters, etc. (Voutchkov, 2012).

These standards, along with many more not mentioned here, should be kept in mind, and owners should endeavor to include as many of them as possible so that nothing is left for guesswork. This also ensures that all bids are based on the same benchmark, which simplifies the bid evaluation process and reduces the risk of receiving bids that are too low.

INSTRUMENTATION AND CONTROL SYSTEMS

Instrumentation and Control Systems are crucial to a successful desalination facility. Owners should define the type of data required to be collected (e.g., flows, pressures, conductivities, etc.) along with the data acquisition methods and frequency.

Notifications and alarms are also crucial. SWRO plants must have built-in safeguards that protect the public from any water that doesn't meet the quality standards and protect operators and equipment from catastrophic failures.

Another area of consideration is 8-hr vs. 24-hr staffed operation. Some jurisdictions require that municipal water plants are staffed 24/7 (Sommariva, 2010). On the other hand, SWRO plants in the Cayman Islands are only staffed 8 hours, Monday to Friday. Owners should clarify these requirements in the project documents since it may affect the complexity of the control system.

Finally, there is the arena of accessibility, integration, and security. Desalination plants collect a lot of data that usually end up unused in a database on some server. Accessibility is essential to gain insight into your plant operation. How desalination data is integrated with data analytics and even machine learning systems is an exciting new development. Finally, cybersecurity has become a significant concern that needs to be addressed in the project documents.

PROJECT DOCUMENTATION

SWRO plant owners must ensure that their contractor provides clear, complete, and up-to-date project documentation throughout the project's design, planning, construction, commissioning, and operation phases.

Project documentation includes design documents and drawings such as PFDs, P&IDs, design, shop, and as-built. Information on all software, including PLC and SCADA programs, licenses, and other related documentation, is also essential.

Contractors should also supply lists of equipment vendors and IOM manuals along with spare parts lists and inventory. Additionally, detailed Standard Operating Procedures (SOPs) on plant start-up, shut-down, backwash, membrane cleaning, and troubleshooting ensure a smooth knowledge transfer to the plant owners when the operation contract expires and are therefore necessary.

Furthermore, maintenance plans and schedules should be supplied by the contractor. Experienced SWRO plant operators utilize Computerized Maintenance Management Software (CMMS), which contains maintenance schedules and standard maintenance work orders. The CMMS also acts as a database for all historical maintenance tasks, which can be analyzed to gain in-depth insights into the plant's assets, including identifying areas where there is potential for optimization and cost savings (WDR, 2021).

ENERGY CONSUMPTION

Energy consumption represents the highest percentage of the water production cost of SWRO plants. Typically, the energy cost contributes about 50% of a small SWRO plant's OPEX (Avlonitis, 2002). The below figure demonstrates that the energy cost represents an even more significant share in the Cayman Islands, which may be attributed to high energy tariffs and relatively simpler process design, which leads to reduced chemicals, consumables, and maintenance costs.

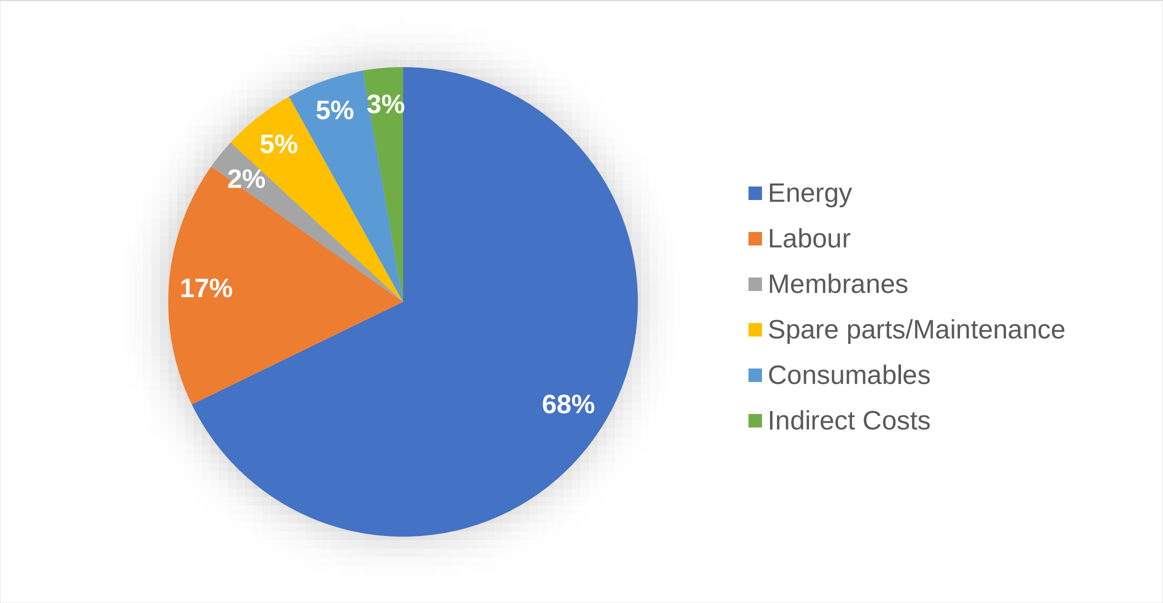

Figure 2. *Breakdown of Operations Costs of the 3,000 m³/day Lower Valley SWRO Plant (Source: Water Authority – Cayman)*

When evaluating bids for SWRO plants, the low cost of water is, of course, a significant factor. However, plant owners may suffer from high energy bills due to inadequate design or operation if the project documents do not include any provisions on the guaranteed specific energy consumption of the facility.

Poor plant start-up sequence, oversized pumps, lack of motor speed control, or inadequate membrane maintenance can contribute to higher specific energy consumption. When the energy cost is passed over to the plant owners, contractors do not have an incentive to save energy unless they are held accountable to a maximum specific energy consumption figure.

The specific energy consumption of desalination plants keeps going down as advances in processes and technologies become available. Recently, the Saline Water Conversion Corporation (SWCC) in Saudi Arabia broke the Guinness World Record for the lowest energy consumption of a desalination plant (2.27 kWh/m3) (IDADesal, 2021). In the Cayman Islands, this figure ranges from approximately 2.5 to 3.5 kWh/m3.

OPERATION AND HANDOVER

When the "Operate" part of the BOOT-delivered desalination project comes to an end, plant owners may either renew the operation contract or decide to take over the plant operations themselves.

A smooth transfer of plant operations is highly dependent on the following areas being kept into consideration when drafting the project documents.

RO membranes are susceptible to fouling and scaling, which leads to reduced permeate production, increased membrane differential pressure, and reduced salt rejection (DuPont, 2021). Therefore, membrane cleaning is essential to a well-maintained SWRO plant. Project owners must include membrane Cleaning-In-Place (CIP) systems as part of the project scope. CIP systems may be hard-piped with valves at the connections to the RO trains. This option has a higher capital cost but leads to lower operation costs and downtime. Another option for CIP systems is having the connections terminated with plugs and connected to the RO trains via hoses or pre-fabricated PVC piping during membrane cleaning. This option is relatively cheaper up-front but tends to be cumbersome and time-consuming depending on the size of the plant and the number of RO trains that need to be cleaned (Nemeth and Seacord, n.d.).

SWRO plants require the use of chemicals, which must be handled, stored, and disposed of in a safe manner and in accordance with local regulations. Owners must ensure that the contractor provides the means to do so. Additionally, Safety Data Sheets (SDS) for all the chemicals used in SWRO facilities should also be provided. The chemicals themselves should be NSF certified for potable water applications, as previously mentioned.

In the Cayman Islands, Sodium-metabisulfite is used in pre-treatment for oxygen scavenging from feedwater in Cayman Brac. In Grand Cayman, Sulfuric acid is used to lower the pH of product water in post-treatment to facilitate hydrogen sulfide removal via degasification. Calcium hypochlorite is used for disinfection, Sodium Hydroxide for pH adjustment, and Zinc Orthophosphate for corrosion inhibition.

During the operation phase of the BOOT contract, reporting becomes a vital area that enables plant owners to gain an insight into their facilities. The owner should require regular reports on the plant operation and maintain up-to-date records. Reporting can be monthly, bi-annual, or annual and include a summary of operation parameters, membrane normalization data, planned and unplanned shut-downs, chemicals and spare parts usage and inventory, and any safety incidents. Owners should also make provisions for regular inspections and performance tests to verify the information provided by the contractor.

Disaster preparedness is another critical area, especially in the Caribbean, and should be given adequate considerations when drafting project specifications. SWRO plants should be designed to withstand natural disasters, such as high winds, flooding, and earthquakes. Plant owners should also require contractors to maintain an up-to-date continuity of operation plan and conduct annual disaster preparation exercises to ensure minimum interruption of water production during natural disasters. Maintaining an inventory of critical spare parts is also vital to a timely re-start of operations after a natural disaster.

Finally, utilities should clearly define their training expectations for when they decide to take over the plant operations. This depends on the availability of experienced operation and maintenance staff and the novelty and complexity of the plant process and technology. The contractor is expected to train the owner's staff on the facility's operations. Still, the exact curriculum and length of the training are usually unclear and may lead to conflicting expectations.

DISCUSSION

As demand for potable water in the Caribbean continues to rise, desalination in general, and seawater reverse osmosis in particular, offers long-term, sustainable means of water supply. In the Cayman Islands, the collaboration between the public and private sectors through BOOT contracts led to the successful delivery of several SWRO projects, which can be emulated in other Caribbean nations.

One of the primary keys to a successful partnership is the development of effective and comprehensive project specifications. In order to achieve that, decision-makers in public utilities should seek feedback from stakeholders, draw from their own local experiences, and utilize the expertise of the market. Successful bidding teams should have the right mix of skills and experience, and the relationship between all parties should be based on collaboration and communication to achieve the project objectives.

SWRO plants should be designed for low O&M costs as they represent a significant share of a plant's life-cycle cost. In addition, mitigating the environmental impact of such plants and bearing in mind sustainability measures should also be prioritized. A great deal of care must be given to project planning and studies as they help determine the optimum plant design, and ultimately the project cost. Finally, contractors must adhere to industry standards and best practices when designing and building SWRO plants to ensure long-term reliable and safe operation.

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Sea Level Rise Wellfield Protection Procedures

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Abstract

Most Caribbean islands are volcanic, with a central core of volcanoes surrounded by carbonate reef and sand shorelines. Historic lava flows flowing down the sides of the volcanoes create dense rock ridges separated by valleys that occur as spokes around a wheel. Between these ridges accumulation of volcanic ejecta and ash fill the valleys. The valley fill is typically comprised of fine sand to boulders and are very permeable. Rainwater percolates rapidly into the valley sediments creating freshwater aquifers in each valley. All of these valleys have a freshwater storage capacity based on the valet basin volume, rainfall recharge, aquifer Storage and Transmissivity (measured by an Aquifer Performance Test). Many of these valleys drain directly to the shoreline and are unconfined aquifers. As each valley has a defined basin (constricted laterally by the ridges) each valley aquifer has a defined volume of stored aquifer water based on rainfall recharge. It is rare that these groundwater basins have been adequately defined to determine the Valleys Safe Sustained Yield. Additionally, it is extremely rare to find a Caribbean Island wellfield that has a salt water intrusion monitoring network installed to control the wellfield pumping schedule or to aid in predicting salt water intrusion locations and rates. Without such a network of monitoring wells and a wellfield operating program for an unconfined aquifer, these wellfields are highly susceptible to salt water intrusion such as occurred in the Basseterre Aquifer in 2015/2016. Mr. Nettles will present examples of how monitoring salt water intrusion has aided wellfields in Florida and how the OET's 2009 Hydrogeologic Basin Evaluation of the Basseterre Valley Aquifer in St. Kitts predicted the intrusion of saline water in 2015/2016. New freshwater resources were located by OET in St Kitts at higher elevations to account for continued salt water intrusion due to sea level rise.

Key words: Sea level rise, fresh/salt water interface, unconfined coastal aquifer hydrogeology, geophysics, monitoring program, hydrologic basin evaluation, safe sustained yield

List of Figures

Sea Level Rise Wellfield Protection Procedures

Sea Level Rise (SLR) is a major concern for Caribbean Islands as it will impact their groundwater resources, increase coastal storm surge, and reduce their overall land mass. The coastal areas of the islands generally exhibit the major population centers, recreational areas, tourist (economic) centers, ports and coastal highways. Encroaching sea level will clearly adversely impact each of these venues. Of primary importance for island communities are the freshwater aquifers that supply the population and commerce water for drinking and product manufacture. Groundwater is often the primary source of most freshwater development on Caribbean islands. Those islands that do not have freshwater aquifers or springs, typically have to develop rainfall capture facilities, desalination methods or import water via ships. As sea level rises, the groundwater reservoirs will be compressed, reducing the volume of the islands naturally stored groundwater.

1. Sea Level Rise Projections

The International Panel on Climate Change (IPCC) 2019 report projected 0.6 to 1.1 meters (1 to 3ft) of global sea level rise (SLR) by 2100 if greenhouse gas emissions remain at high rates. A February, 2021 Special Report on the **Ocean Cryosphere in a Changing Climate (SROCC)** and the **IPCC Fifth Assessment Report (AR5)** stated “Based on global and coastal sea level data from satellite and 177 tide gauges, researchers found that these reports issued projections under 3 different Representative Concentration Pathways (RCP) scenarios “agree well with satellite and tide gauge observations over the common period 2007-2018, within 90% confidence level. However, there remains a potential for larger sea level rises, particularly beyond 2100 for high emission scenarios. **The analysis of the recent SLR data indicate the world is tracking between RCP 4.5 and the worst case scenario of RCP 8.5.”**

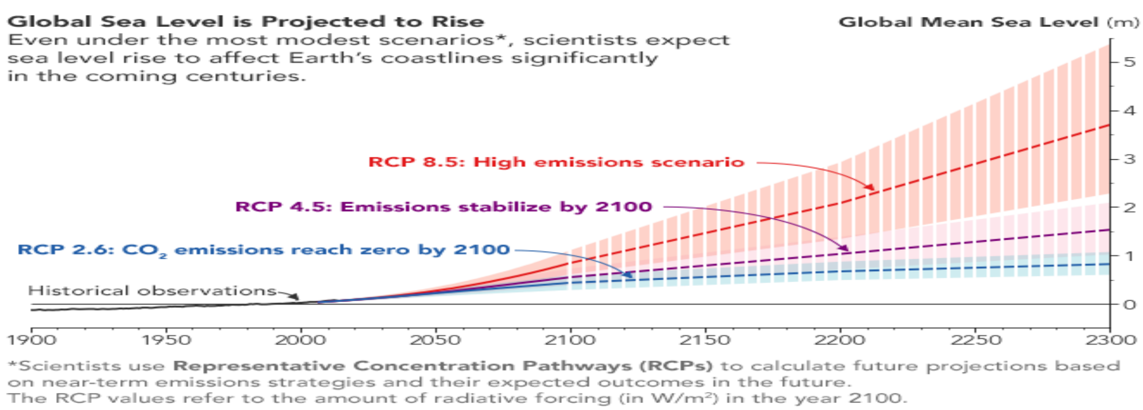

Figure 1- IPCC Projected Global Sea Level Rise

The IPCC SROCC found that global sea level could rise by 30 to 60cm (1 to 2ft) by 2100, and a rise of 110cm (over 3.5ft), was possible but unlikely (Figure 1). The IPCC indicated that sea level rose 15cm (0.5ft) during the 20th century. **The IPCC stated “Even if huge cuts in emissions begin immediately, between 29cm and 59cm of SLR is inevitable because ice caps and glaciers melt slowly.”**

Research by the University of Copenhagen’s Niels Bohr Institute recently found that under worst case scenario using their method that involves including historical (back to 1850’s) temperature and sea level data, the world could see a rise of 135cm (4.4ft) by end of this century. “The scenarios we see before us now regarding SLR are too conservative, the sea looks, using their hindcasts method of analysis, to rise more than what is believed using standard methods. Ice sheets and ocean heat content have multi-century response times and this can lead to model drift if the model (Figure 2) is not perfectly initialized.

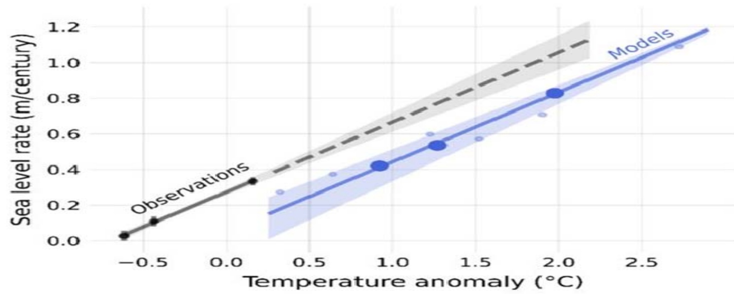

Figure 2- Comparison of measured SLR data to model results

Groundwater

Most Caribbean islands are volcanic, with a central core of volcanoes surrounded by carbonate reef and sand shorelines. Historic lava flows flowing down the sides of the volcanoes create dense rock ridges separated by valleys that occur as spokes around a wheel. Between these ridges accumulation of volcanic ejecta and ash fill the valleys. The valley fill is typically comprised of fine sand to boulders and are very permeable. Rainwater percolates rapidly into the valley sediments creating freshwater aquifers in each valley. All of these valleys have a freshwater storage capacity based on the aerial extent of the valley, the thickness of the coastal aquifer, rainfall recharge, aquifer Storage and Transmissivity (measured by an Aquifer Performance Test). Many of these valleys drain directly to the shoreline and are unconfined aquifers. **It is rare that these groundwater basins have been adequately defined to determine the Valleys Safe Sustained Yield**.

Additionally, **it is extremely rare to find a Caribbean Island wellfield that has a salt water intrusion monitoring network installed to control the wellfield pumping schedule or to aid in predicting salt water intrusion locations and rates**. Without such a network of monitoring wells and a wellfield operating program for an unconfined aquifer, these wellfields are highly susceptible to salt water intrusion such as occurred in the St. Kitts Basseterre Valley Aquifer Wellfield in 2015.

Most island coastal aquifers are water table, unconfined aquifers that are recharged by rainfall. Unconfined aquifer wellfields should not be designed or operated in the same fashion as artesian aquifers. The smaller storage capacity of unconfined aquifers can be easily dewatered (pumping exceeding rainfall recharge), resulting in mining of the water source. Over pumping coastal aquifers will result in salt water intrusion into the wellfield. Controlling salt water intrusion advancement into a wellfield requires an understanding of:

- 3 dimensional hydrogeology of the groundwater basin
- well construction technology
- unconfined aquifer performance testing (72hour pumping test) and determination of the Delayed Yield Effect
- salt water interface monitor well construction technology
- wellfield design and operation for coastal unconfined aquifers
- fresh/salt water interface monitoring methods
- groundwater level elevations
- depth and location of the fresh/salt water interface

The quantity of groundwater that can be sustainably withdrawn is the Safe Sustainable Yield (SSY) and is dependent on several additional factors:

- Delineation of the basin's hydrologic boundary (Areal extent of its water (recharge) basin
- Definition of the underlying geology and aquifer units (Aquifer depth and thickness, presence of dikes or sills, aquitards, stratigraphic lithologies)
- Determination of the groundwater gradient and range of water level fluctuation seasonally and with pumping schedules
- Soils type, distribution and hydrologic characteristics
- Rainfall rate and distribution within the watershed
- Topography and geomorphology
- Evapotranspiration rates and distribution (for water tables less than 5ft below land surface datum (lsd)
- Surface water runoff
- Groundwater recharge rate
- Groundwater withdrawal locations, rates and periodicity.
- Depth to the fresh/salt water interface below the water table
- Slope of the aquifer and water table
- Structural geologic controls affecting groundwater storage and transmission (intrusive dikes, faults)

The Ghyben Herzberg Principle controls the depth of the fresh/salt water interface beneath an island or peninsulas such as the State of Florida.

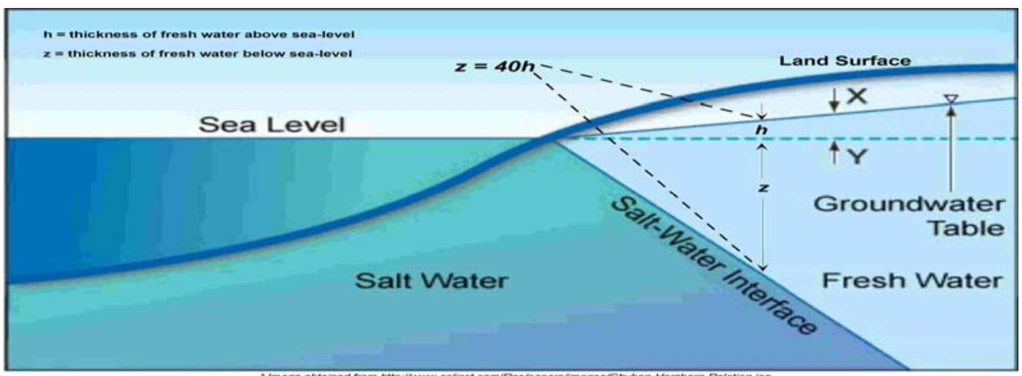

Figure 3 Ghyben-Herzberg Principle

The presence of any fresh water lens stored within an island's sediments or rock is due to the density differential of the fresh water compared to the underlying salt water. Fresh water has a density of 1.00g/cm^3 and seawater has a density of 1.035g/cm^3. The Ghyben-Herzberg principle, based on this density differential states: **For every foot of fresh water (h) present above sea level, there will be 40 feet of fresh water (H) below sea level** (Herzberg, 1901). The equation (Figure 3) has proved accurate and reliable in Island situations.

Coastal Aquifer wellfield examples of salt water intrusion impacts
Example 1 – St. Kitts Basseterre Aquifer Wellfield
In 2009 Ocean/Earth Technologies (OET) was contracted to perform a Hydrogeologic Evaluation of the St. Kitts Basseterre Valley Aquifer Wellfield. The wellfield had been investigated and designed by Dr. Christmas in the 1970's with production wells being drilled in 1988 by Kerr, Priestman & Associates. Williams updated and reworked the Christmas data and confirmed Dr. Christmas's safe sustained yield estimates. OET geophysically mapped the wellfield property using Multi-channel Electrical Resistivity (MER) to provide a more complete and detailed hydrogeologic assessment of the wellfield hydrology and to locate the fresh/salt water interface. OET also investigated the integrity of many of the wellfield production wells and monitor wells.

The most critical data recorded by this 2009 investigation were:

- **The presence of the fresh/salt water interface was recorded to be just below the supply well intake screens across the entire wellfield area (Figure 4).**
- **Salt water intrusion was already encroaching on the wellfield from the SW, SE and NE (Figures 5 and 6).**
- Only five of the SSY parameters are well documented for the entire Basseterre Valley Watershed (boundary, topography/geomorphology, rainfall, soil type/distribution and groundwater withdrawal locations, rates and periodicity).
- Of the five remaining parameters, the geology and aquifer units were defined only within the wellfield area (10 percent of the watershed area) with the 2009 OET MER mapping.
- Ninety percent of the remaining watershed is not accurately defined in terms of the hydrology, geology, and aquifer characteristics.
- The geophysical mapping across the Basseterre Valley Aquifer Wellfield site (the southeastern terminus of the Basseterre Valley) revealed the presence of three distinct resistivity stratigraphic units across the site (from the 2009 OET report):
- The results of the initial mapping emphasize the importance of accurately delineating the fresh-salt water interface across the watershed, and monitoring its location during pumping.
- An extensive monitoring network should be developed to deal with this sensitive interface issue.
- **Additional water supplies needed to be developed immediately**. Construction of new wells should be placed to the north of the airport and in the higher elevations of Sub-basins A and B of the Basseterre Valley Aquifer Watershed.
- **Salt water intrusion into the Basseterre Valley Aquifer water supply wells was predicted by OET to occur in 2014 or 2015 if pumping from the wellfield continued at its 2009 withdrawal rates**.
- **In 2015, the wellfield exhibited a spike in saltwater intrusion and wells had to be shut down and water rationing instituted.**

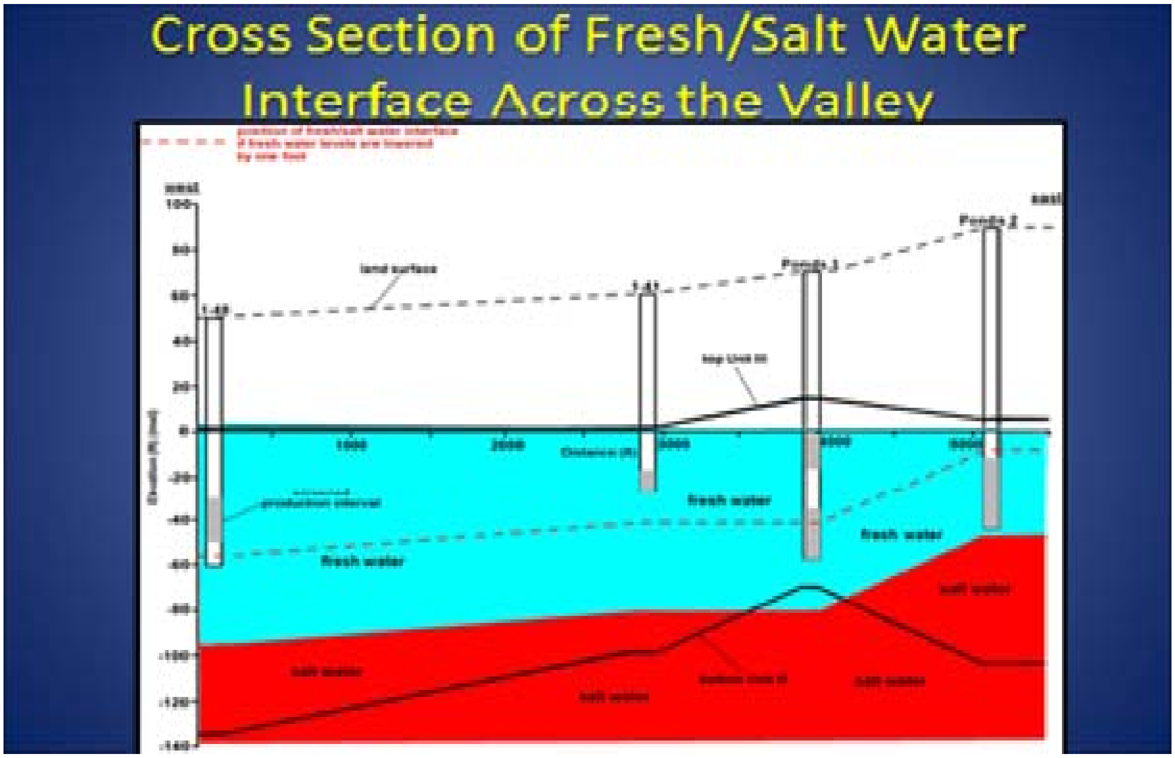

Figure 4

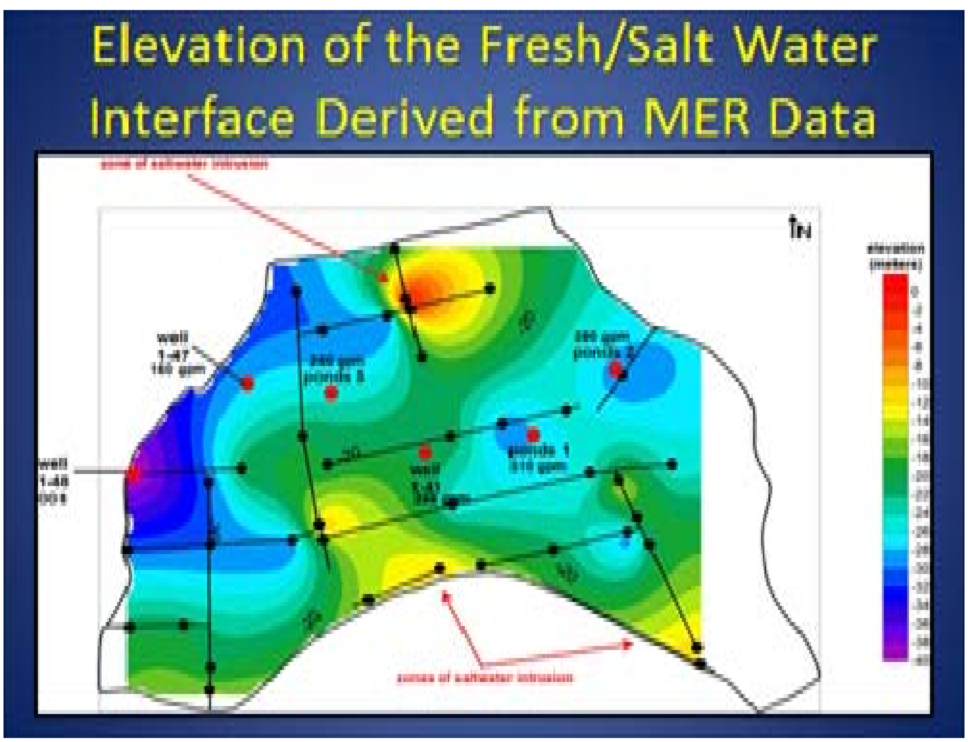

Figure 5

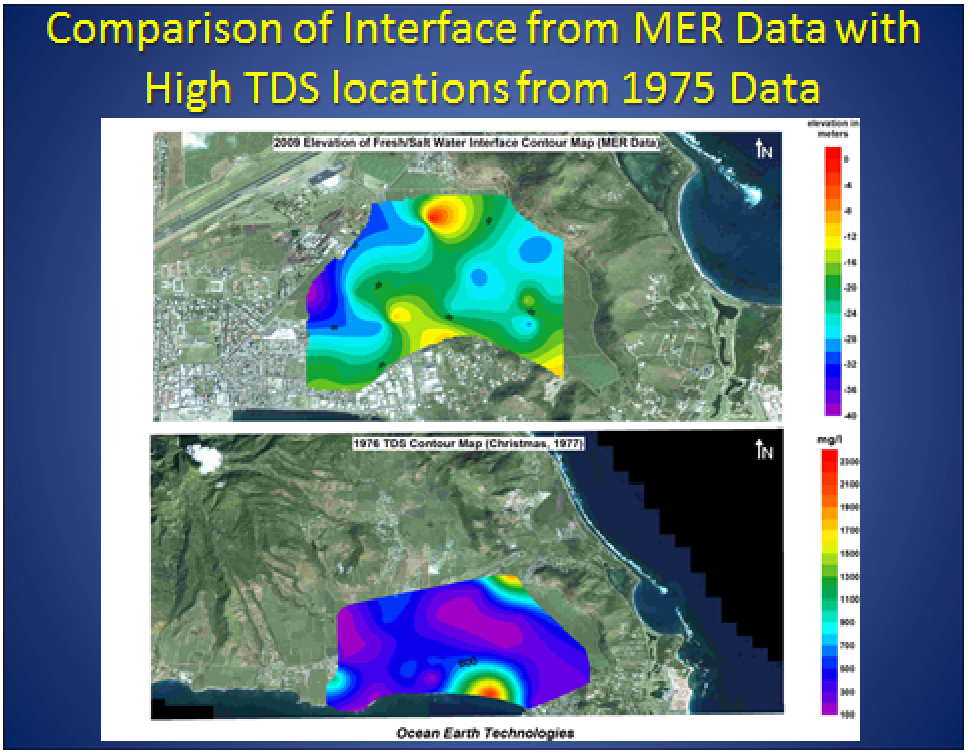

Figure 6

In 2016 OET was contracted to perform an Emergency Water Resource Investigation. MER was recorded in the Upper Basin A watershed of Basseterre Valley as well as in Basin B in the Shadwell and Beacon Heights valleys as shown in Figure 7 below.

MER Transect Location Map

Ocean Earth Technologies
Figure 7

Since our 2009 report, the Government of St. Kitts had entered into a contract with another consultant (2009) to develop deep (greater than 400 feet of elevation) groundwater supplies in the upper Basseterre Valley Watershed. **After 2 years of geophysical mapping the consultant determined that developing groundwater at elevations greater than 400 feet msl was not economically feasible because the valleys aquifers at those elevations were too narrow to store sufficient quantities of fresh water.** As such, OET focused our investigation on locating and developing additional groundwater supplies from less than 400 feet of elevation.

These data support OET's conclusions from 2009 that the highly permeable sediments (units 3 and 5) comprising the Basseterre Valley Aquifer prevent significant mounding of groundwater up-gradient. This results in a limited potential groundwater supply, and this limitation must be built into future hydrologic simulations of the Basseterre Valley Aquifer for Sub-basin A. A relatively flat water table (<5ft msl), as documented within the Basseterre Aquifer Wellfield, appears to extend well north of the airport as shown in MER Transects T-1, T-5 and T-6 recorded in 2016**. This flat water table greatly increases the risk of saltwater intrusion into the existing wellfield from groundwater withdrawals even if new wells are located north of the airport.** By shutting down production of some or all of the existing wells and developing the new wells to the north, moving the water withdrawal points further inland and further from the salt water interface will reduce the rate of seawater encroachment to the new wellfield. The existing supply wells should then be converted to salt water intrusion monitoring wells to track the movement of the saltwater interface and permit the Water Department the ability to more effectively operate and manage water production from the new water supply wells located to the north of the airport. However, the geophysical data presented in this report indicates that there are geologic features (impermeable intrusive dikes) that may limit groundwater storage volume within Sub-basin A.

Sub-basin B water supply development potential

- Sub-basin B includes narrow valley formations that are similar to Sub-basin A but indicate they store groundwater at higher elevations than those in Sub-basin A.
- As the Sub-basin B exhibits the same geologic stratigraphy as Sub-basin A the water production potential for Sub-basin B should be equivalent.
- However, the igneous dikes that hold the groundwater at higher elevation (+19ft msl) and creates a thicker fresh water lens (700ft) in Sub-basin B also limit the aerial distribution of the Sub-basin B aquifers and therefore their Safe Sustained Yield. The higher elevation of the aquifer in Sub-basin B also reduces the potential for saltwater intrusion into wells in this basin.

Results of the Emergency Water Resource Investigation
Site 1- north of the RLB Airport in Sub-basin A

- These data support OET's conclusions from 2009 that the highly permeable sediments (units 3 and 5) comprising the Basseterre Valley Aquifer prevent significant mounding of groundwater up-gradient.
- A relatively flat water table (<5FT msl), as documented within the Basseterre Aquifer Wellfield, appears to extend well north of the airport as shown in MER Transects T-1, T-5 and T-6 recorded in 2016.
- This flat water table (greatly increases the risk of saltwater intrusion into the existing wellfield from groundwater withdrawals even if new wells are located north of the airport.
- Some of the existing supply wells should then be converted to salt water intrusion monitoring wells to track the movement of the saltwater interface and permit the Water Department the ability to more effectively operate and manage water production from the new water supply wells located to the north of the airport.
- Vertically oriented, mid-range resistivity features indicate the porous zones of the Basseterre Aquifer in the central region of the Sub-basin A may be separated by impermeable intrusive dikes

(Unit 6 of Christmas, 1977) or have low permeability zones that may significantly reduce water production capability in these features.

- This suggests that increasing elevation in the Sub-basin A valley does not necessarily increase the water storage capacity of the Basseterre Valley Aquifer or production capacity of this aquifer.
- These vertically oriented features will also have significant impacts on groundwater withdrawals, as they may form lateral no-flow boundaries that will adversely impact long-term groundwater withdrawals and model results in these areas by reducing aquifer groundwater storage volume.
- Very low resistivity values are recorded in the sediments below sea level of the central and eastern parts of T5. The very low resistivity values (<10 Ohm.m) may indicate the presence of slightly elevated chlorides in the groundwater.
- Note that the airport runway was constructed through the topographic break between the Canada and Conaree Hills where resistivity data presented in the OET 2009 report indicated saltwater was intruding from the east into the wellfield.

Site 2 - Beacon Heights – West of Sub-basin B

- A low resistance, potentially water-saturated Unit 5 epiclastic volcanics (light blue to purple hues) stratum extends below the Unit 4 lava rock stratum to the base of the profile at 71 meters (234ft) depth. Elevation range for this potentially water productive Unit 5 is below 50m (164ft) MSL.
- No indicators of saline groundwater were recorded in T1, 2, or 3 within the depths mapped.

Site 3 –Sub-basin B, Shadwell

- **Sub-basin B includes narrow valley formations that are similar to Sub-basin A but indicate they store groundwater at higher elevations than those in Sub-basin A.**
- **The igneous dikes that hold the groundwater at higher elevation (19ftmsl) in Sub-basin B** also limit the aerial distribution of the Sub-basin B aquifer and therefore its Safe Sustained Yield. **The higher elevation of the aquifer in Sub-basin B also reduces the potential for saltwater intrusion into wells in this basin as the freshwater lens is 760ft thick and produces 700gpm.**

Recommendations for Monitoring the Fresh/Salt Water Interface to Protect Your Coastal Aquifer Wellfields.

- Monitoring the fresh/salt water interface is a 3 dimensional program. The interface can move both vertically and horizontally through the aquifer depending on recharge activity, pumping and tidal flux.
- Interface monitor well distribution should consist of transects oriented perpendicular to the shoreline with each transect having 3 to 4monitor wells set at 100 to 200ft spacings from the shoreline to the wellfield boundary or nearest supply well. Narrower spacings may be warranted.
- An additional deep interface well should be constructed 20ft from each water supply well to monitor for vertical up-coning of saline groundwater.
- All interface monitoring wells should be fully screened from 5ft below land surface to 30ft below the initially recorded interface depth as determined by Resistivity mapping.
- Production wells should be run for no more than 24 hours at a time with a 24 hour recovery time to permit recovery of the local water table elevation.
- Continuous pumping (24/7) of unconfined aquifers results in a Delayed Yield Effect (removes water from storage) and drastically increases drawdown at the well head. This increased drawdown of the water table elevation induces up-coning of salt water at the well.
- Salinity surveys should be recorded in all interface monitor wells on a weekly basis during dry seasons and monthly during wet seasons.
- Interface vertical and horizontal fluctuation should be mapped with each monitoring episode and compared to previous data to track encroachment so that modifications to the supply well pumping regime can be made to stop the saline encroachment from entering the wellfield.

- Supply well distribution should never be established as 2 parallel lines of wells oriented perpendicular to the shoreline

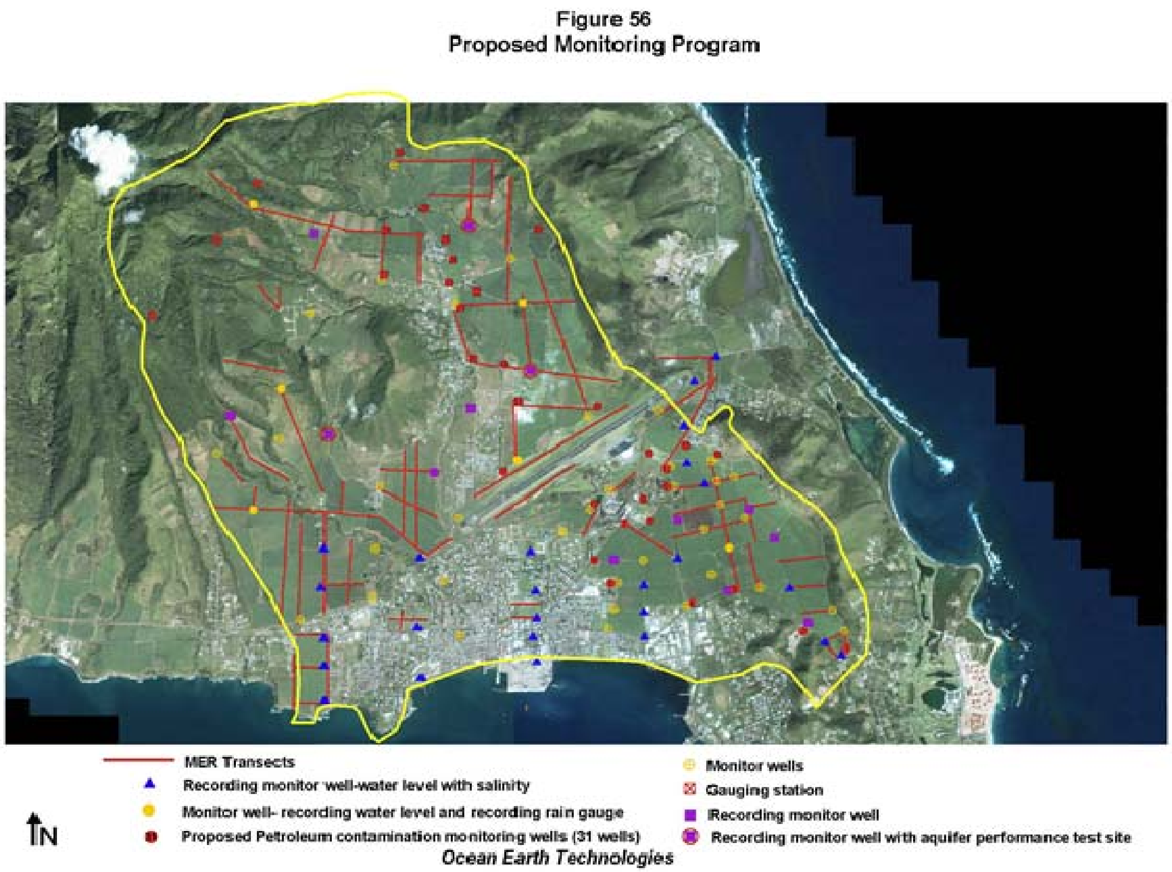

Figure 8 - Recommended Water Resource
Fresh/Salt Water Interface Monitoring program

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Case Study

Public Private Partnership (PPP) Project for Integrated Solid Waste Management in Cayman Islands

Abstract

The Cayman Islands consist of three islands located in the Caribbean Sea, approximately 200 miles west of Jamaica. The largest and most populous is Grand Cayman with a land area of about 100 sq miles and a population of about 66,000. The two smaller islands; Cayman Brac and Little Cayman, are located about 90 miles east of Grand Cayman and have populations of about 1,800 and 300 respectively.

Cayman relies heavily on income from tourism and the financial sector.

The current waste management system includes government owned and operated landfills on each island to dispose of the approximate 120,000 short tons of waste generated annually. These sites, especially on Grand Cayman, are resulting in unacceptable environmental impacts, and are generally unsustainable.

In 2014 the Government brought consultants on-board to assist in developing policies, strategies, and a business case towards a sustainable waste management system. The studies suggested that an integrated waste management system that relies on the 4Rs including a waste to energy component, was the most favorable solution. Furthermore, the best way to procure this solution was through a Public-Private-Partnership.

A Request for Proposals was issued by the Government late in 2016 and in 2017 Dart was selected the preferred bidder to finance-build-own-operate the integrated facilities for 25 years. After the contract period the facilities will revert to Government with an expected additional life of 15 years.

Besides the development of a system to manage waste into the future, it was necessary to develop remediation measures for the existing landfills to minimize environmental impacts resulting from many years of unsustainable waste management practices.

The integrated solution includes waste reduction and recycling, household waste recovery center, yard waste mulching and composting, construction and demolition waste recycling, scrap metal and end of life vehicle recycling, Energy Recovery Facility, bottom ash recycling, and a residual waste landfill for disposal of residual wastes and stabilized air pollution control residue. In all, the integrated system will reduce reliance on landfill by up to 95%. The new waste management system is expected to be fully commissioned in early 2025.

Keywords: integrated waste management; waste to energy; George Town Landfill.

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Introduction

The Integrated Solid Waste Management System (ISWMS) project aims to provide a sustainable long-term waste management solution for the Cayman Islands, developing new recycling and composting infrastructure on each of the Cayman Islands in support of a central new Energy Recovery Facility (ERF) in Grand Cayman.

The project is being procured by the Cayman Islands Government (CIG) under a Public Private Partnership (PPP) arrangement, with the goal of appointing a private contractor to design, build, finance, operate and maintain the new ISWMS facilities for a contract term of 25 years. The recycling and composting infrastructure on Little Cayman and Cayman Brac will be constructed and operated by CIG.

Dart was appointed as Preferred Bidder (PB) for the project in 2017 and is currently working to reach financial close with CIG in 2021, with operations scheduled to commence in 2025.

Cayman Islands Setting

The Cayman Islands are located in the Caribbean Sea south of Cuba and approximately 200 miles west of Jamaica. The three islands comprise land areas as follows:

- Grand Cayman: 76.0 sq. miles including 6.6 sq. miles of inland waters
- Cayman Brac: 15.0 sq. miles including 0.1 sq. miles of inland waters
- Little Cayman: 11.0 sq. miles including 2.3 sq. miles of inland waters

Historically the Cayman Islands were first mentioned by Christopher Columbus who on 10th of May 1503, during his final voyage to the Caribbean, recorded a sighting of Cayman Brac and Little Cayman.

Under British control since 1670 and separating from Jamaica in 1962, the Cayman Islands remain a self-governing overseas territory of the United Kingdom.

Population and GDP

The 2010 census determined a total population of 52,740 for Grand Cayman and 2,296 for the two Sister Islands. The 2020 census has been delayed through the COVID-19 pandemic. However, it is estimated that the current Grand Cayman population is approaching 70,000. From 1999 to 2010 the Cayman Islands experienced an annual average growth in population of 3.2 per cent.

The average GDP (based on current basic prices) from 2015 to 2019 is approximately USD 78,000. Waste volumes per capita generally follow the GDP which explains the relatively high waste generation rate of approximately 1.9 short tons per capita per annum, in the Cayman Islands.

Geology, Topography and Hydrogeology

The Cayman Islands sit above an uplifted fault block commonly referred to as the Cayman Ridge. Sitting on top of this ridge is a sequence of carbonate deposits that rise a few feet above sea level. As such, Grand Cayman and Little Cayman are generally flat and near sea level in height. The bluff on Cayman Brac, however, raises gently from south-west to north-east up to a maximum elevation of 141 feet above sea level at the eastern extent of that island.

The coasts are largely surrounded by reefs with some areas of mangroves that extend into inland swamps. There are no rivers on any of the islands.

Ground water level is high and is generally saline or brackish. The island is dependent on fresh water generated by several treatment plants located throughout the island utilizing reverse osmosis to create potable water from brackish ground water.

Waste Volumes and Types

Waste disposal to landfill has been identified and weighed since the 1990s but, since no tipping fee has been applied, the record keeping of total volumes received at the site over time is incomplete. However, since the beginning of the programme to improve waste management practices, CIG's Department of Environmental Health (DEH) has been keeping a more complete record of waste disposed at site. This information is critical to planning and designing the new waste infrastructure. Figures 2 and 3 demonstrate the total waste tonnage and waste type breakdown respectively.

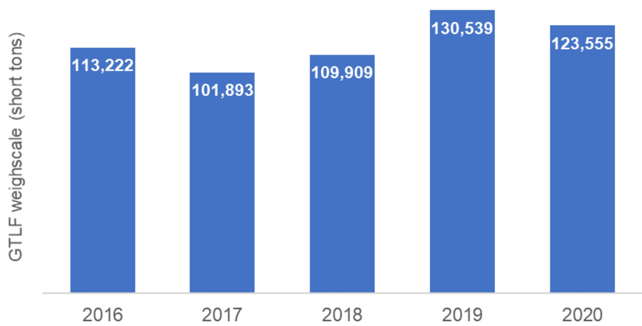

Figure 1 Annual Waste Tonnage (2016 – 2020)

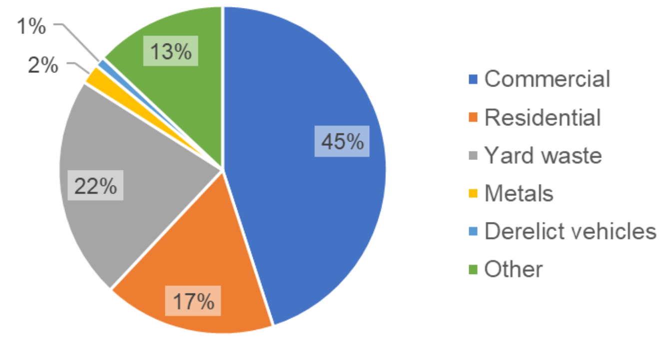

Figure 2 Typical Waste Composition

Note that "Commercial Waste" in Figure 2 includes waste from multi-unit residential properties.

Current Waste Management Arrangements

Waste management activities in the Cayman Islands are largely based on collection and disposal to landfill, supported by various small-scale recycling programmes. The DEH provides most waste management services supported by a few small private sector operators.

The largest of the three landfills is the George Town Landfill (GTLF) in Grand Cayman. This was formed by tipping over an area of former mangrove swamp that was partially excavated to recover the underlying marls (calcareous soils), with the excavated materials being employed to cover the waste on a semi regular basis until this source was consumed.

Tipping operations commenced in the mid-1960s, with the waste volume being reduced by burning until 1985. Thereafter, the mode of tipping switched to placing and compacting waste with heavy equipment, which approach continues to this day. The site has no engineering containment (basal lining and/or capping system) and operates on an uncontrolled dilute and disperse basis. Waste inputs comprise a combination of residential and commercial waste, with small *ad hoc* quantities of other materials. Previously infilled areas have been covered with a thin layer of soil and allowed to naturally revegetate.

Other waste management activities undertaken at the GTLF site are summarized as follows:

- Processing, packaging of dry mixed recyclable materials, batteries, and e-waste
- Bulking up of waste machine oils and cooking oils from public and commercial sources
- Depollution and baling of End-of-Life Vehicles (ELVs) and scrap metal (including white goods)
- Shredding or mulching of vegetation and yard waste
- Incineration of medical and special wastes

Dry recyclables, batteries, e-waste, waste oils, ELVs and scrap metals are packaged and shipped to facilities in the United States for recycling. The crushed glass and shredded vegetation are retained for use on island.

All current GTLF activities will cease when the new ISWMS facilities become operational in 2025. In preparation for this, non-operational areas of the GTLF are currently being remediated by Dart and DEH, with a phased programme of capping and restoration scheduled between now and the final closure of the GTLF. The aftercare management of the closed landfill will continue over the life of the ISWMS project under the joint management of Dart and DEH. Other waste management operations at the GTLF site will be decommissioned and transitioned to the ISWMS project in 2025.

The CIG currently plans to cease waste disposal operations on Cayman Brac and Little Cayman when Dart's new ISWMS facilities come online. The reconfiguration of the current facilities and closure and restoration of the (likewise unlined and uncapped) landfill sites will be undertaken by CIG and, as such, is not covered in this paper.

ISWMS Project Background

Site Setting

The ISWMS project is centered on and around the GTLF site in Grand Cayman, which is owned by CIG and operated by the DEH. This site supports most of the current waste management and recycling operations. The GTLF site covers a total area of approximately 73 acres, with the landfill itself covering an area of approximately 36 acres.

Additionally, Dart has purchased an additional 17 acres of land immediately south east of the GTLF site. Together, approximately 30 acres will accommodate all the new ISWMS facilities.

An annotated plan of the site and the neighboring water treatment facility is provided in Figure 3 below.

Figure 3 GTLF and Surrounding Site Layout

Policy Background

Strategic Outline Case (Ministry of Health & Culture, 2015)

On 6th December 2013, CIG issued a policy directive for the development of a Comprehensive Solid Waste Disposal Management System covering all three of the Cayman Islands.

Subsequently an Integrated Solid Waste Management Steering Committee was formed in January 2014, along with an ISWMS Technical Sub-Committee. The policy directive was used to drive the strategic outline case for the project.

The project main objectives were identified as follows:

- Develop a solid waste strategy for the Cayman Islands for the next 50 years which:
    - Include provision for changing waste quantities due to natural disasters and other unforeseen circumstances
    - Minimize environmental and public health risks e.g., groundwater pollution, air pollution, odors, noise, fires, pests dust and other pollutants and amenity issues
    - Develop a local regulatory framework which meets internationally recognized environmental standards and guidelines
    - Identifies characterizes and address the environmental risks and impacts resulting from current solid waste management practices
- Identify and implement an ISWMS that is based on the nationally agreed strategy

National Solid Waste Management Strategy for the Cayman Islands (Amec Foster Wheeler;KPMG, 2016)

This report prepared for the CIG by AMEC Foster Wheeler sets out the key policies and objectives for future management of solid waste and the delivery of an integrated solid waste management system within the Cayman Islands.

An options analysis performed as part of this report facilitated the development of a reference project that demonstrated that the goals of the National Solid Waste Management Policy and waste management objectives could be obtained and allowed for the estimation of the costs associated with the delivery of each of the project elements.

The waste management hierarchy (Figure 4) was fundamental in developing the ISWMS for the Cayman Islands. The strategy is to as far as practical to move waste treatment from landfill up into more favorable waste management options.

Figure 4 The Waste Hierarchy

Consultation Draft Outline Business Case (Amec Foster Wheeler;KPMG, 2016)

The Outline Business Case (OBC) prepared by AMEC Foster Wheeler and KPMG LLP sets out the means through which the NSWMS for the Cayman Islands can be implemented. The OBC presents comparative fully costed ISWMS solutions between traditional Public Sector Project delivery and a Design-Build-Finance-Operate-Maintain (DBFOM) PPP delivery model. The resulting value for money analysis, based on net present value (NPV) analysis, determined that the DBFOM model presented significant advantage over the traditional public sector project delivery.

Procurement Process

Based on the findings of the ISWMS OBC, CIG went to market seeking expressions of interest in the project from private contractors; prequalifying three companies/consortia to engage in a PPP procurement process in November 2016. This number was reduced to two following the Invitation to Submit Outline Solutions (ISOS) stage in February 2017, with Dart being selected as Preferred Bidder for the project following the Invitation to Submit Final Tender (ISFT) stage in June 2017.

Since then, CIG and Dart have dialogued extensively regarding the exact scope and configuration of the project, signing Pre-Construction Agreements for the project in October 2020 and Project Agreement in March 2021, ahead of an expected financial close in Q4 2021.

ISWMS Solution

The ISWMS solution proposed by Dart employs a combination of technologies to optimize the beneficial use of waste arisings, utilizing source segregation and on-island treatment where possible; with the remaining fractions being transported to Dart's ISWMS site on Grand Cayman for further treatment and/or energy recovery as shown on Figure 5. The estimated capital cost for the new facilities is USD 244 M.

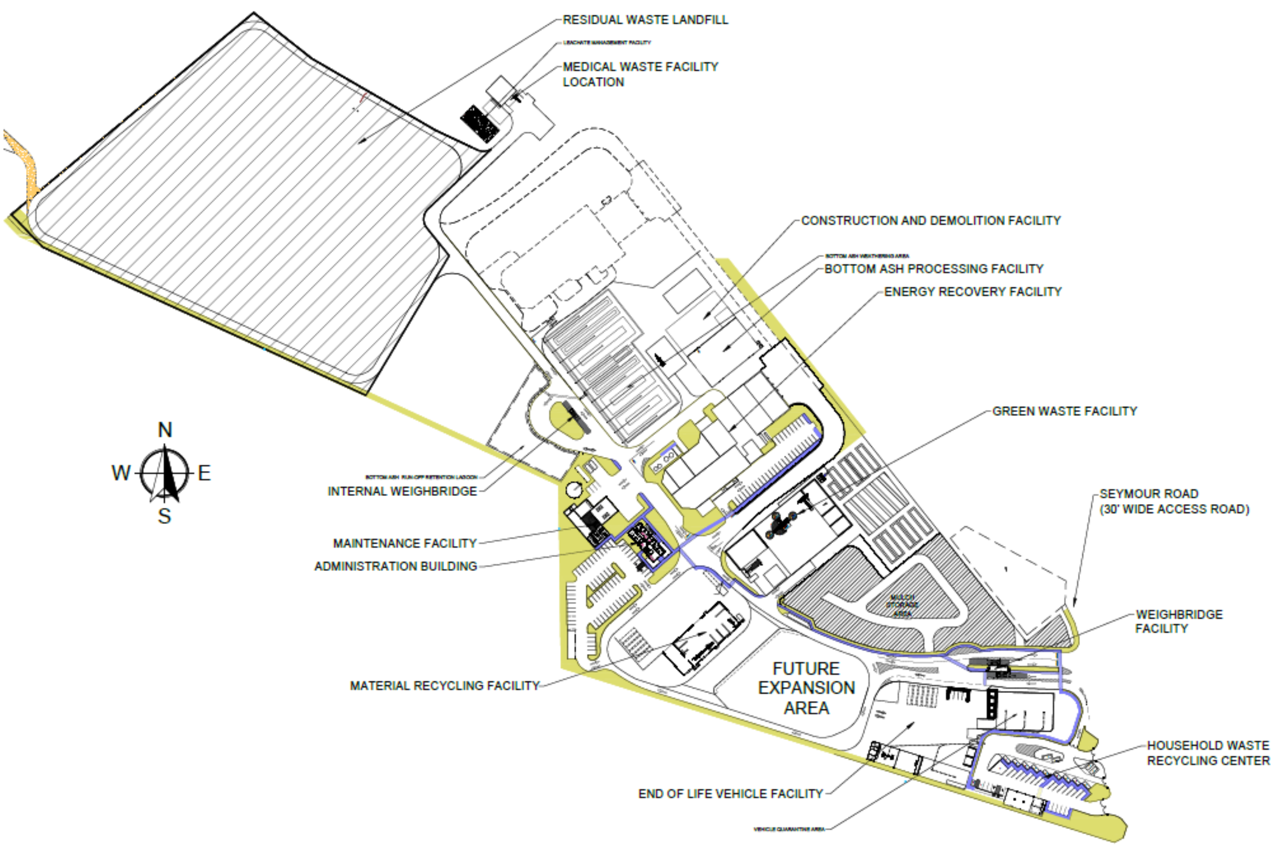

Figure 5 ISWMS Site Layout

The integrated facilities to be provided at the ISWMS site are further summarized below.

Energy Recovery Facility (ERF)

The ERF forms the mainstay of Dart's ISWMS solution, with the capacity to treat approximately 110,000 short tons of Contract Waste per annum. The ERF will utilize combustion process technology to convert primary energy sources from a number of waste streams into heat energy, with recovery of the heat energy taking place in a steam raising boiler. The steam will be used to drive a steam turbine coupled to an alternator which will generate electrical power at 13kV for export to the Cayman electricity grid, as well as powering the non-ERF ISWMS facilities.

The design point parameters for the proposed ERF plant are as follows:

- Thermal capacity 35.5 MW_{th}
- Net electrical output 9.3 MW_e
- Design fuel average heat value 10.2 MJ/kg
- Design point waste flow rate 12.5 tph

The ERF will be designed to meet the European Union (EU) Industrial Emissions Directive (IED) standards, including exhaust gas treatment using Stabilized Non-Catalytic Reduction (SNCR) and a bag house filter system.

Bottom Ash (BA) Processing Facility

BA generated by the ERF will amount to approximately 25 per cent of the ERF input tonnage. This BA contains ferrous and valuable non-ferrous metals that will be recovered through the BA processing facility, with the remaining BA aggregate being weathered and processed to generate secondary aggregates for use in road construction or as general fill.

Construction and Demolition (C&D) Waste Processing Facility

The C&D Processing Facility will take in bulky waste generated through demolition and construction works and process these materials through grinding and separation equipment to produce reusable waste streams such as aggregate from concrete debris, scrap metal to add to the metals recycling function and lighter materials such as wood debris that can be reused or recovered through the ERF.

Material Recovery Facility (MRF)

The MRF will manage the source separated dry recyclables waste streams currently collected through the existing recycling depot system. These materials, including paper and cardboard, tin and aluminum cans, plastic #1 and #2, and glass containers, will be sorted and baled at the MRF for shipment to overseas markets. The glass containers will be crushed and employed locally as aggregate for various uses such as in paver stone manufacturing.

Green Waste Processing Facility

The Green Waste Processing Facility will treat source segregated yard waste generated by the many horticultural contractors on the island, being processed to produce mulch and/or compost for sale into the local Cayman market. In the early years of ERF operation, the scale of the green waste processing operations will be balanced against the ERF feedstock requirements, using yard waste as a supplementary fuel in the ERF operation for optimum energy production.

End of Life Vehicle and Scrap Metal Processing (ELV) Facility

The ELV Processing Facility will recycle, recover, and divert vehicles that have been abandoned or surpassed their useful life. These vehicles will be depolluted and baled for shipment overseas to scrap metal markets. The ELV processing facility will also receive scrap metal from Dart's C&D and BA processing operations, as well as various white goods and other large metal objects received direct to site and/or via the HWRC. Incoming scrap metal will be processed and separated into ferrous and non-ferrous material streams for sale into overseas recycling markets. Where necessary, larger items will be reduced in size using the hydraulic shear. All other materials will be removed to the appropriate storage area awaiting onward processing or sent to the ERF or other ISWMS facility as applicable.

Medical/Infectious Waste

Medical and infectious waste is currently managed through high temperature incineration employing a starved air primary combustion chamber with a secondary chamber to combust the syngas produced by the primary chamber at high temperature. This system has proven robust and effective and so the proposed ISWMS medical waste treatment component will consist of a new similar unit with upgraded operational components and control systems.

Household Waste Recycling Center (HWRC)

Commonly referred to as a public drop off facility, the HWRC will be a split-level facility where the public will have access to containers for discharging the various recyclable materials, general waste, green waste, and special wastes such as oils, batteries, and e-waste. The HWRC will also include a re-use center, where unwanted but serviceable or reparable products can re-used or re-purposed and made available to other members of the public or third sector organizations.

Air Pollution Control Residue (APCR) Treatment Facility

APCR arising from the ERF operations, amounting to approximately 3% of the ERF input tonnage, will be dosed with cement adjacent to the APCR silo to produce a stabilized, non-hazardous material suitable for disposal to the RWL.

Residual Waste Landfill (RWL)

Regardless of the efficiency of Dart's ISWMS operations, there will always be certain wastes that cannot be managed economically in any other manner except landfill disposal. In the case of the ISWMS project, this includes APCR from the ERF. Accordingly, Dart's ISWMS solution includes for the provision of a fully engineered RWL, designed to Florida Administrative Code standards, including leachate collection and treatment. It will be located next to the existing GTLF, providing capacity for all projected residual waste arisings over the life of the ISWMS contract.

GTLF Remediation

As part of the ISWMS, CIG is committed to closing and restoring the existing GTLF in line with the commencement of operation of its new ISWMS facilities. The background to the choice of closure and restoration system is set out below.

Landfill Site Environmental Review

In March 2016, AMEC Foster Wheeler published a Landfill Site Environmental Review (Amec Foster Wheeler, 2016) commissioned by the CIG that identified the key contamination and amenity risks associated with the GTLF as well as the smaller landfills on the Sister Islands.

The risks identified for the GTLF from this report are shown in Table 2.

Based on the above, Dart in 2020 commissioned GHD to prepare a Remediation Options Report (GHD, 2021) and Environmental Risk Based Assessment (GHD, 2021) for the GTLF. The purpose of these reports was to present the conceptual, risk-based approach to the remediation (technical closure) and maintenance (post closure) of the GTLF, leading up to and following the commissioning and commencement of operation of Dart's ISWMS facilities in 2025.

Table 2 GTLF Environmental Risks and Receptors

Receptor	Risk
Site users and visitors	Arsenic in soils as well as hydrogen sulphide generation on and off the landfill, and methane generation on the landfill
Adjacent residents	Nuisance from odour and risks from combustion products in tyre/landfill fires
Adjacent commercial/industrial site users	Hydrogen sulphide from sediments contaminated by various sources including the landfill, as well as nuisance from odour and landfill fires
Groundwater	Hydrocarbons from spills and overtopping of bunds, elevated ammonia contribution to surface water contamination via baseflow
Surface water	Hydrocarbons from spills and overtopping of bunds, ammonia and orthophosphates from groundwater
North Sound	Ammonia and metals from canal water impacting on water quality and ecology, and eutrophication and blanketing of vegetation adjacent to the canal outfall

Remediation Options Report (GHD, 2020)

The ROR considers the spectrum of closure and remediation options for the GTLF from: ‘do nothing’ (the *status quo*), to ‘removal of source’ (wholesale excavation), to ‘landfill mining’ (recovering potentially recyclable and recoverable materials) to ‘technical closure’ (capping) with a variety of after use options.

Of these closure and remediation options, ‘do nothing’ was ruled out as an option for active areas of the site based on this running contrary to recognized international standards and good landfill practice. Moreover, a ’do nothing’ approach ignores the existing risks to receptors in the area.

Thereafter, ‘wholesale excavation’ and/or ‘landfill mining’ was also ruled out on the basis of technical difficulty, safety, environmental and amenity concerns, and affordability. All of these conclusions are in line with those reached previously by CIG in its Outline Business Case Consultation Draft (Amec Foster Wheeler;KPMG, 2016).

‘Technical closure’ of the site was therefore concluded to present the most workable and safely deliverable form of remediation for the GTLF. In the case of the newer, more active North Mound, this includes for the provision of a low permeability vegetated cap, landfill gas collection system, storm water management and long-term monitoring and maintenance. In the case of the older, less active South Mound, monitoring results and risk-based modelling assessments showed the site is no longer having an unacceptable impact on the surrounding environment and, as such, does not warrant a low permeability cap or landfill gas management system; but does still require storm water management and long-term monitoring and maintenance.

Risk Based Assessment (GHD, 2020)

Concomitant with the ROR, Dart commissioned GHD to produce evaluate the environmental risks posed by the GTLF to sensitive receptors surrounding the site, comparing the impacts under status quo conditions against those once an engineered cap has been installed at the site.

The two main sources of contaminants at the site identified in the RBA are the deposited wastes within the landfill and an adjacent waste oil storage area. Previous assessments also identified metals, hydrocarbons, ammonia, and orthophosphate as contaminants of concern at the site. The contaminants are present in the soils and/or the groundwater at the site. Landfill gases and waste fires were also considered as sources due to their asphyxiant, explosive, flammable, and odorous properties. Various potential pathways were considered for these contaminant sources, including but not limited to ingestion, inhalation, direct contact, leaching, vertical and lateral migration, fire, and explosion.

The RBA demonstrates that the provision of a landfill cap provides a physical barrier that disrupts the pollutant linkages in the source-pathway-receptor model and removes or significantly reduces the potential for contaminant exposure to sensitive receptors. Similarly, the provision of a landfill gas management system enables the better control, collection, and management of landfill gas (and odors) from the GTLF. Accordingly, the RBA proves that the provision of a landfill cap and landfill gas management system breaks most of the pollutant linkages, leaving only the risk to marine surface water from groundwater contaminants requiring more detailed, quantitative risk assessment.

Detailed quantitative risk assessment modelling then confirms that an engineered landfill cap reduces the migration of contaminants to the North Canal (and subsequently the North Sound), with contaminant concentrations generally falling within acceptable limits at the receptor thereafter. The only exception to this is ammonia, which continues to exceed the stringent criterion for un-ionized ammonia but falls well below the total ammonia limit for river water (the most applicable criterion for the ISWMS project).

Overall, the RBA concludes that providing an engineered cap results in an overall 85% reduction in contaminant concentrations compared to the *status quo*, rendering the site suitable for use as public open space (subject to on-going practical restrictions, such as access to critical infrastructure) in future.

Conclusion

The ISWMS project will provide a long-term waste management solution for the Cayman Islands and bring about the end of the current dilute and disperse landfilling activities; but has highlighted the complexities of realizing a sustainable alternative to landfilling in an island setting.

Finding a technical solution that reasonably balances deliverability, cost, and risk over a 25-year contract period has required cooperation and open-mindedness in both sides; and taken a significant amount of time to achieve. The reward, however, will be the delivery of a resilient and regenerative solution with lasting benefit to the population and environment of the Cayman Islands.

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An Integrated Water Resource Management Framework to Support Implementation of the Cartagena Convention

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Abstract

20 years after the adoption of the Cartagena Convention (CC) by 28 countries of the Wider Caribbean Region (WCR) and ten years after the entry into force of its Land Based Sources of Marine Pollution (LBS) Protocol, pollution prevention and control from wastewater and agricultural runoff remains a major challenge. The WCR is highly vulnerable to extreme events that impact coastal areas where most of the population resides, which is further exacerbated by climate change. This negatively impacts on economic sectors, ocean-based economies, and the prosperity and welfare of people. The CC Secretariat has developed an outline for a Regional Integrated Water Resources Management Conceptual Framework (IWRM-CF) to address existing challenges and opportunities in sector integration. The IWRM-CF proposes an approach based on common principles for both IWRM and coastal and marine resources management including ecosystem-based management, Source to Sea, sustainable consumption, natural capital, science-policy interface, resilience building, one health for all and public participation. Several IWRM actions that facilitate and promote integration and accelerated IWRM adoption and implementation are proposed. Water should be the connector for meeting Global Commitments such as the SDGs, Paris Agreement, and Sendai Framework. This IWRM-CF enables: i) CC Secretariat to support other sectors and processes such as Disaster Risk Management and Integrated Coastal Zone Management; ii) Consensus building based on common principles, goals and priorities such as the restoration/conservation of the marine ecosystems; iii) IWRM to be the central process for ensuring water security for all; iv) Recognition of the importance of water governance, supported by the Escazu Agreement; v) The development of a three-level governance model to leverage collaborative action at local, national, regional and global levels; vi) Development of climate smart and resilient ocean-based economies for the region; vii) A strong economic case to be made for more integrated and coordinated action for all sectors involved and/or impacted by water resources management.

Key words: integrated water resource management, disaster risk management, integrated coastal zone management

The Cartagena Convention

The “Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region”, referred to as the Cartagena Convention (CC), entered into force in 1986. It´s the only regional legal framework for the protection and development of the Wider Caribbean Region (WCR) and include three protocols concerning land-based sources of pollution (LBS), oil spills and specially protected areas and wildlife (SPAW). The LBS Protocol adopted by the Convention in 1999 and entered into force in 2010 recognizes that the WCR’s marine and coastal resources have ecological, economic, aesthetic, scientific and cultural values and along with human health are seriously threated by pollution from land-based sources and activities.

After almost 20 years of adoption of the CC and ten of the adoption of the LBS Protocol, pollution prevention and control from wastewater and agricultural runoff is still a challenge for the region. It represents a severe impact to the marine ecosystems mainly due to high nutrient loads. In addition, the WCR presents high vulnerability to extreme events that is exacerbated by climate change; it mainly affects coastal areas where 41 million people live. This situation is having a high negative impact to the regional ocean-based economy that represents 18.4% of the GDP of the region, and therefore to the prosperity and welfare of WCR people (Patil et al., 2016).

As a response to this scenario, during the last meeting of the Conference of Parties to the Cartagena Convention (Kingston, Jamaica, July 2021), the importance of Integrated Water Resources Management (IWRM) was recognized, and a decision was taken to have a dedicated technical group to discuss this as an issue moving forward based on a regional IWRM conceptual framework to address existing challenges and opportunities

IWRM

IWRM is a process which promotes the coordinated development and management of water, land, and related resources to maximize the resulting economic and social welfare in an equitable and sustainable manner (UN Environment, 2018). It is a guiding process for the water community and the way to connect with other communities and natural resource management processes. Besides IWRM, other water resource management approaches have been proposed in recent years. The water security approach establishes a desirable condition any society is expecting from water: peacefully, having water for human well-being and development, avoiding water related health problems and disasters, and preserving biodiversity. The Food Water Energy Nexus supports an integrated planning approach among those main water users, and is the best way to formulate effective and efficient solutions.

Under current global challenges of climate change and biodiversity loss and with the need forresilience building and sustainable development, IWRM should play a leading role and can accelerate the achievement of the Sustainable Development Goals (SDGs). Water is identified as the number one priority for adaptation actions in most of the intended nationally determined contributions (INDCs) and is directly or indirectly related to all other priority areas (UNESCO, UN Water 2020). IWRM could become a powerful tool for biodiversity conservation if the role of hydrological regimes is understood as the key driver for many biological processes and as a provider of ecosystem services.

The 2030 Agenda for Sustainable Development, the most important development agreement ever, integrates 17 Sustainable Development Goals (SDGs) and for the first time an SDG 6 about water, which goal is to ensure availability and sustainable management of water and sanitation for all, that is sufficiency, sustainability, health, and inclusiveness. It comprises six targets and eleven indicators that represent a comprehensive global water resource management agenda for the years to come. As part of the SDG *Integrated Monitoring Initiative*, a baseline for indicator *6.5.1 Degree of IWRM implementation* was presented in 2018. The WCR average final score was 34, that indicates a medium-low level. The report concludes that at this level countries are unlikely to meet the global target unless progress significantly accelerates (UN Environment, 2018).

Based on previous experiences and future challenges, the WCR needs an accelerated approach to adopt IWRM. As a part of this approach, it is essential to develop a clear understanding of the benefits and potential synergies with other natural resource management and social processes to support sustainable development. Nowadays, more than ever, IWRM must be developed as an ecosystem-based process to maximize benefits for all, respecting economic and social constraints, and integrating solutions for climate change, human health, and development. Such a process should avoid being dominated by an economic sector or by emerging conflicts, it must be a governance process able to give voice to all and to build water security for the region.

Key IWRM actions to promote integration

The key elements that an IWRM process must develop are those related with water governance, water for the environment (ecological flows) and water budget and allocation, planning, financial mechanisms, data, and information knowledge. These actions should be developed at the appropriate water management system scale, i.e., river basins, sub-basins, micro-basins, aquifers, deltas, and their relationship with the political system at country level (states or municipalities) including transboundary systems. Whatever the scale, it is essential to ensure coordination at the broader scale, that could be a national level or at the main hydrological basins.

Figure 1 presents these key actions as a management cycle to denote the adaptive approach needed to develop an IWRM process. Water governance at the top, then water budget and allocation based on agreeing upon water for the environment to set the water balance for the system up and the limits for water extraction. A Disaster Risk Reduction (DRR) analysis is proposed as a part of this process to ensure adoption of risk management needs. Based on these initial activities, planning of integrated solutions, such as integrated wastewater management or water source recovery, should be better supported. Two final activities refer to financial mechanisms and information and knowledge management, both offer good potential for integration with other programs. There are other activities that could be considered as a part of the IWRM cycle depending on specific needs or scales.

Common principles and key elements

An IWRM framework for the region should focus on having common regional principles, proposing key IWRM instruments to start or to consolidate the process and open opportunities for integration among different agendas. Common principles are those proposed by the Regional Strategy for the Protection and Development of the Marine Environment of the Wider Caribbean Region (UNEP CEP, 2021) and other related with global agendas. They are ecosystem-based management, source-to-sea, sustainable consumption and production, natural capital approach, science-policy interface, resilience building, one health for all, and public participation. Each of these principles have specific implications for different sectors but under a common understanding.

IWRM Conceptual Framework (IWRM-CF)

A Conceptual Framework for IWRM integration into the CC is proposed based on those strategic approaches/issues that would foster synergies for the protection of the marine environment and trigger integrated processes for joint investments and integrated governance. This will inform more programmatic and less project focused approaches in the WCR including through the work of the CC Secretariat.

This framework intends to show why and how IWRM is part of the solutions, keeping in mind that it is not necessarily a sequential process from laws and institutions to instruments, but rather the result of the willingness to advanced good water management practices under existing legal and institutional systems (UN Environment, 2018).

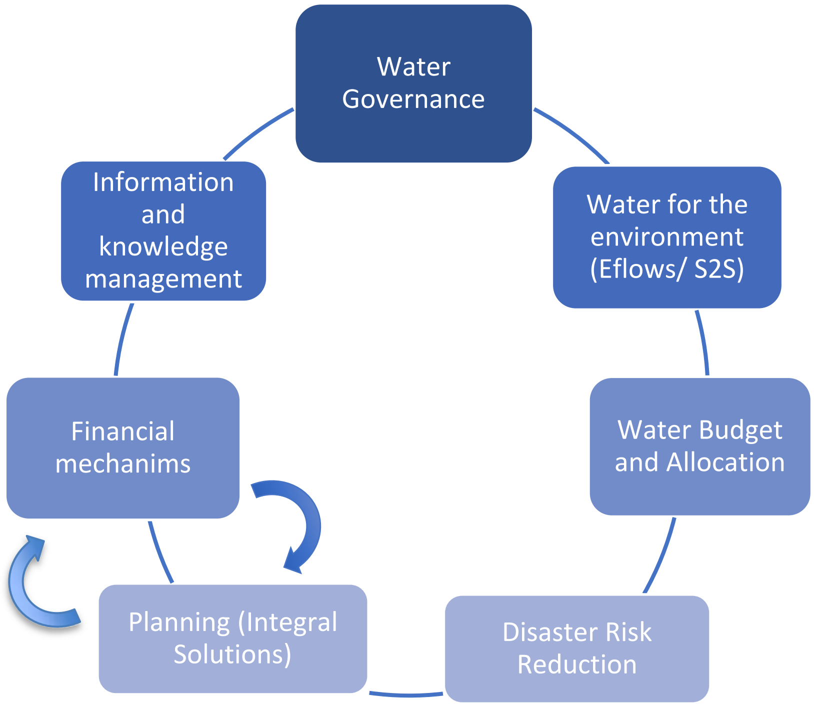

Figure 1 Key IWRM actions to support integration (Barrios, 2021)

Because of the direct implications that water has with the environmental and development agendas, lately it has been proposed to recognize water not as a community but as a connector. Focusing on implementation, water can be located at the intersection of the 2030 Sustainable Development Agenda through the 17 SDGs and their monitoring framework, the Paris Agreement NDCs, and the Sendai Framework on DRR. Under this understanding, water resource management should integrate implementation, connect different strategies, and reduce fragmentation; however, strong political will and leadership are needed to highlight and mainstream water´s value in implementing the global agreements (UNESCO, UN Water, 2020).

The IWRM-CF presents, at global level, water as a connector that integrates implementation of the 2030 SDG, Paris Agreement and the Sendai Framework. At local level, there are three processes that must guide integration of water and marine programs under a resilient goal: IWRM, Disaster Risk Management (DRM) and Integrated Coastal Zone Management (ICZM). At regional level, the CC would play a brokering role to promote a management cycle in which the global agenda feed the local projects and local projects meet global commitments, through a regional institutional structure (Barrios, 2021).

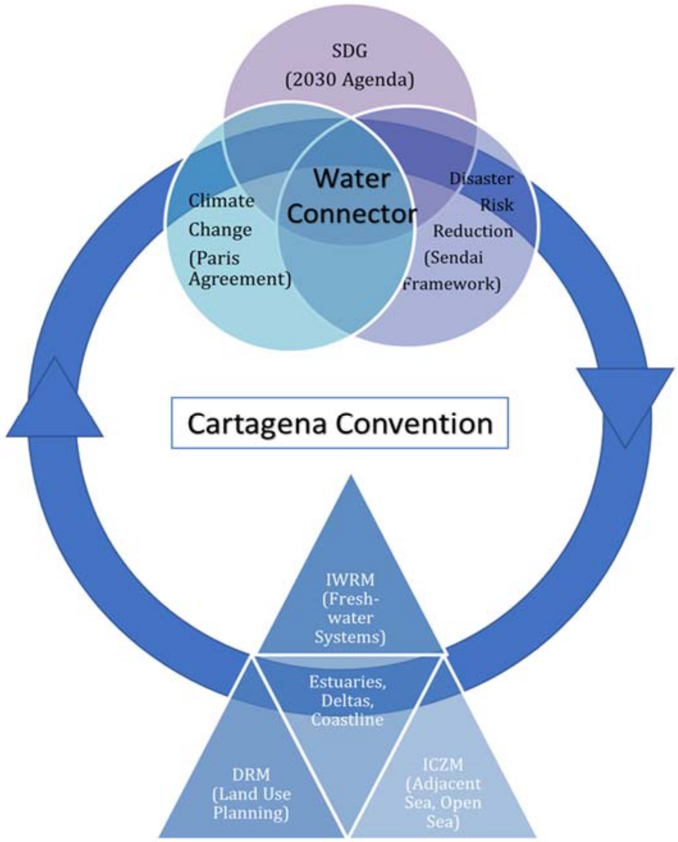

Figure 2 Conceptual Framework for IWRM integration to the Cartagena Convention (Barrios, 2021)

Thus, coastal ecosystems would facilitate the adoption of common goals for the three main management processes -IWRM, ICZM, DRM- under common principles. Upstream, IWRM would cover the hydrological river basin (including groundwater) and DRM would be the link between water and land management, fully integrated at the river basin scale down to the coastal zone (Figure 2): water quantity and quality as a flow regime either from rivers or aquifers would be the goal for an IWRM process upstream that includes land management implications as a goal for DRM. Mangrove ecosystem shows a wide distribution in the region as presented in Figure 3 (Ward D.R., 2016), thus, mangroves could become a conservation goal for the WCR in which water, land, and marine ecosystems are managed under IWRM, DRM, and ICZM to protect marine biodiversity, coastal resilience and therefore a regional ocean-based economy.

Table 1 shows some examples of activities to integrate a hypothetical IWRM-ICZM-DRM agenda based on common principles as explained above.

This IWRM Conceptual Framework enables: i) CC Secretariat to support integration of sectors and processes such as DRM and ICZM; ii) Consensus building based on common principles, goals and priorities such as the climate adaptation of the marine ecosystems; iii) IWRM to be a central process for ensuring water security for all; iv) Recognition of the importance of water/environmental governance, supported by the Escazu Agreement; v) The development of a three-level governance model to leverage collaborative action at local, national, regional and global levels; vi) Development of climate smart and resilient ocean-based economies for the region; vii) A strong economic case to be made for more integrated and coordinated action for all sectors involved and/or impacted by water resources management.

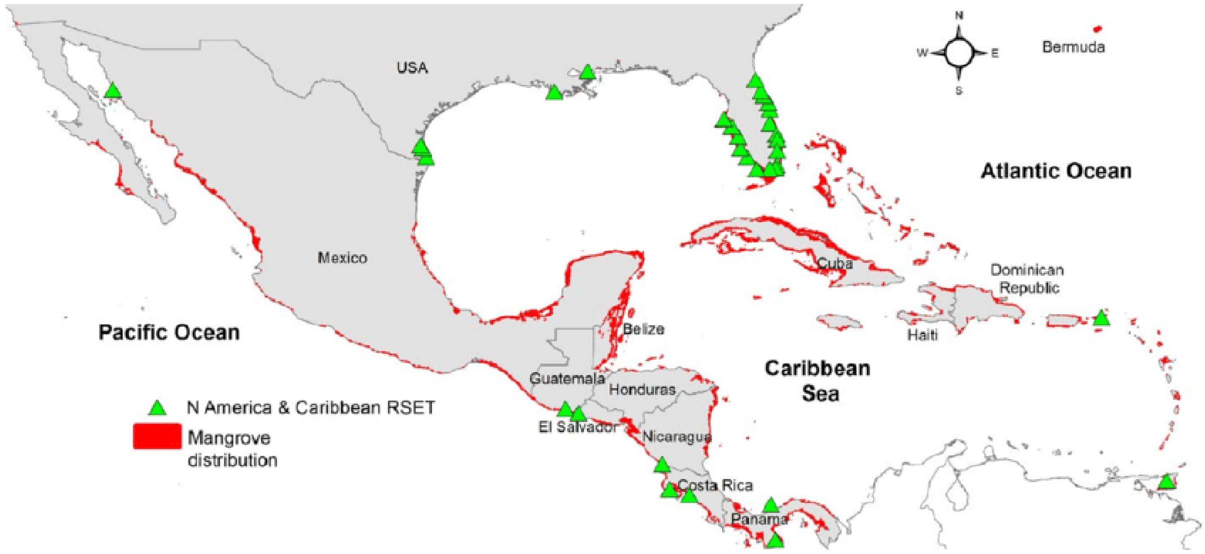

Figure 3 Mangrove distribution in Central America and the Caribbean (Ward D.R., 2016)

IWRM-CF Implementation

An implementation outline with some specific actions organized following the four dimensions of the indicator SDG 6.5.1 (enabling environment, institutions and participation, management instruments, and financing) at local, national, regional, and global levels are presented in Barrios (2021). Some recommendations are presented in this paper:

- SDGs are the most important and useful framework to identify opportunities for integration, common targets and to monitor progress.
- Although each country has different needs and approaches, having a water authority body able to lead a national process and coordinate legal and institutional reforms, plans and actions within the water sector and across other sectors should be one of the first actions to be taken.
- Water resource management is normally based on hydrological units considering both surface and groundwater and the functional divide with the coastal zone. A clear definition of the limits between the freshwater and coastal ecosystem is a key issue to avoid legal gaps and confusing overlap. IWRM must cover the coastal area where water management actions should be implemented. In addition, hydrological units should be coordinated with political boundaries, at international, national and subnational levels.
- At local/national level the priority should be to define if under current policy and legal framework, the possibility exists to institutionalize a water governance model with a water authority body as explained above, and able to guarantee stakeholder participation, with minimal or any changes to formalize water policies and plans.
- Water utilities are key players for IWRM implementation; however, it must be clear that their main role is to provide water and sanitation services in the most efficient and equitable manner. Managing water resources for all is a different task that water utilities should not be responsible for. If this would be the case, it is important to design a governance model which includes a steering committee with participation of authorities from the environmental, risk management, health, and other relevant ministries to avoid conflicts of interest.

Table 1 A common IWRM-ICZM-DDM agenda

Principle	IWRM	ICZM	DRM
Ecosystem-based management	• Ecological flows based on hydrological regime/hydroperiod of coastal ecosystem including water quality (pollution, sediments, nutrients) • Water allocation for coastal ecosystems as a goal for IWRM • Land use plans for coastal ecosystems risk reduction • River basin green infrastructure for DRM		
S2S	• Protect water catchment, storage and distribution • Regulate water uses • Ensure connectivity	• Set limits to sediment and nutrient loads • Define ecological process for migratory species	• Define river hydraulic capacity for protection (floodplains, riparian corridors) • Avoid invasion of flood prone areas
Sustainable consumption	• Water use efficiency • Wastewater resource recovery	• Fisheries • Deltas and estuaries protection (mangrove)	• Specific risk reduction plans for economic sectors
Natural Capital	Integrated value of coastal ecosystem services (e.g., Mangrove Management)		
Resilience building	River basin resilience (water resilience + coastal resilience)		
Science-Policy	Integrative knowledge socio-ecological systems		
One health	• Safe drinking water and sanitation • Aquifer pollution control	• Healthy coastal ecosystems	• Ensure resilient infrastructure
Social participation	• River basin councils	• Coastal communities, port authorities and tourism sector	• Disaster Risk Governance

- In designing/reviewing the institutional framework, the participation of different actors and stakeholders is an opportunity for innovation. Participation of private sector to build solutions beyond business development and traditional social responsibility programs. The participation of civil society is also an opportunity to strength the governance model under the Escazu Agreement. It is important that any participation space be supported by a communication process and public access to information.
- At country level, there are two key actions to fully adopt an ecosystem and risk management based IWRM. The first one is to define water for ecosystems as the core goal of the IWRM process based on the best available water balances and ecological knowledge. A second key action is to integrate water and land management based on a DRR plan, in which ecosystems, as Nature Based Solutions (NBS) would play a key role for a climate risk management and water security. This action will require the need to harmonize legal and regulatory frameworks to ensure there are no gaps.
- Full adoption of the ecosystem-based management principle is one way to really provoke integration. In this sense, building capacity on ecosystem-based management would be an important component of the implementation process.
- Strengthening regional information systems is always an opportunity. Regional hydrometeorological centers such as CIMH or the Comité Regional de Recursos Hidráulicos under SICA in Central America are good examples. Increased collaboration at the regional level with USA and Mexico could further support this process.

- With the WCR being one of the most vulnerable regions in the world to cyclones and therefore to climate change, and the extraordinary costs that this situation represents, a regional and country specific economic analysis should support the investment on IWRM-DRR-ICZM integration as proposed in the Conceptual Framework. Making the economic case should include social and private costs and benefits including ecosystem services and health, and then propose a cost recovery strategy. For instance, the WHO estimates that each dollar invested in water supply and sanitation generates between USD 4-12 in health benefits alone, depending on the type of water and sanitation service (WHO, 2008).

Currently, there are several projects and initiatives in the region that could be part of the implementation process, based on their own goals and experiences but adopting common principles to facilitate integration, synergies and to deliver expected results together.

- It involves a three-level governance model to leverage action from local to global and promote regional collaboration.
- It is oriented to build a climate smart and resilient ocean-based economy for the region.
- It proposes to make the economic case to support the value of integration, synergies and coordinated action for all.

Conclusions and recommendations

Current low IWRM implementation in the WCR offers the opportunity to agree upon a different approach to overcome the current situation, and even to go beyond. In this regard, these are the main issues that could make the IWRM-CF a different approach from previous experiences:

- It opens the process to other sectors such as environment and health, and other processes such as DRM and the ICZM.
- It is based on common principles, particularly an ecosystem-based management principle to promote integration and to build long-term solutions.
- It is geographically focused on the coastal zone and oriented to the climate adaptive restoration/conservation of the marine ecosystem as a common goal.
- It clarifies that although full water and sanitation coverage is urgently needed, it cannot be the only goal for the water sector in the region. IWRM must guide a broader process to build water security for all.
- It observes the importance of having a water governance structure in place, supported by the Escazu Agreement, as a unique binding agreement for Latin America and the Caribbean.

Note: This paper has been prepared based on the UNEP-GEF-CREW+ Information Document An Integrated Water Resource Management Framework to Support Implementation of the Cartagena Convention (Barrios, 2021).

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Title:
Nature-Based Solutions for Wastewater: Opportunities and Barriers in the Caribbean

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Abstract:
In coordination with United Nations Environment Programme Cartagena Convention Secretariat and support from the Swedish Ministry of Environment,The Nature Conservancy (TNC) is assessing wastewater management in four island nations—the Dominican Republic, Haiti, Jamaica, and Grenada—to understand the barriers and opportunities for addressing this issue. The assessment focuses on scientific/technological approaches; policy, legal, and institutional frameworks; the role nature-based solutions (NBS) are playing or can play; and stakeholder engagement, including public opinion research. This assessment is helping guide TNC's engagement on the issue in the region, in order to better support the prevention and reduction of pollution from untreated or inadequately treated wastewater discharges in order to sustain the region's remarkable biodiversity and to ensure human well-being.

The research in this report complements the Marine Biodiversity (SPAW) and Marine Pollution (LBS) Protocols of the Cartagena Convention by focusing on the aforementioned countries and includes an analysis of existing research and interviews with subject-matter experts.

Overall, we have found that the need for wastewater treatment is profound in the region, but there are common threads that hinder both traditional built infrastructure solutions and NBS from being implemented successfully to address wastewater treatment needs. Without the proper planning and design, stakeholder involvement, government policies and regulatory structures, operations and maintenance, and adequate public financing, the biodiversity and human health of the region will remain at risk no matter what types of wastewater solutions are promoted.

NBS for wastewater management represent an opportunity to take a holistic "Source to Sea" approach to conservation programs that can have the added co-benefit of providing climate adaptation. As CWWA leadership is critical to managing water for both biodiversity and human health, we hope an interactive discussion among governments, the private sector, and NGOs will lead to new thinking about NBS and shared solutions.

Key Words:
Nature-based solutions, wastewater management

The Nature Conservancy (TNC) has conducted an analysis of wastewater management in four island nations—the Dominican Republic, Haiti, Jamaica, and Grenada—to understand the barriers and opportunities for addressing this issue using nature-based solutions (NBS). The assessment focuses on scientific/technological approaches; policy, legal, and institutional frameworks; and stakeholder engagement. Additionally, public opinion research in three of the four nations was conducted to determine awareness of the issue and to gauge public support for different options to address wastewater management.

As a point of reference, the Land-Based Sources of Marine Pollution and Specially Protected Areas and Wildlife (LBS and SPAW) Protocols of the Cartagena Convention provide a regional legal framework for addressing the issue of wastewater management in an integrated manner including through the use of NBS. The research in this report complements the LBS and SPAW protocols by focusing on the aforementioned countries and includes an analysis of existing research and interviews with subject-matter experts in the region.

The need for wastewater treatment is profound in the region, yet the use of NBS to treat wastewater is limited. Common threads hinder both traditional built infrastructure solutions and NBS from being implemented successfully to address wastewater treatment needs. Without the proper planning and design, stakeholder involvement, government policies and regulatory structures, operations and maintenance, and adequate public financing, the biodiversity and human health of the region will remain at risk no matter what types of wastewater solutions are promoted.

NBS solutions to wastewater management represent an opportunity to take a holistic "Source to Sea" approach to conservation programs. The way water is managed and used on the land, and especially as it is intercepted and used in cities and towns, affects the health of rivers, estuaries, bays, reefs, and fisheries. Thus it is critically important to manage against changes in both quantity and, especially, the quality of water that flows through the landscape to protect both biodiversity and human health.

The Dominican Republic

In the Dominican Republic, most of potable water supply and sewer collection and disposal services (26 provinces out of 32) fall under the responsibility of the National Institute of Potable Water Supply and Sewerage Service (INAPA) while in the larger cities, it is managed by autonomous parastatal corporations known as *Corporaciones de Acueducto y Alcantarillado* (CORAAs). However, these institutions focus more on the supply than to sewage and sanitation to the point that only 53 percent of the water treatment plants and 26 percent of the wastewater plants are operating adequately[1] and only two water utilities (CAASD and CORAASAN, from Santo Domingo and Santiago, respectively) have plans to enhance and increase their wastewater treatment capacity.

The Dominican Republic has developed NBS wastewater projects in the course of establishing formal water funds[2] in the city of Santiago. In contrast, the approach in areas surrounding Santo Domingo, the capital city, is more focused on agroforestry and riparian restoration. These inland and rural projects are usually associated with biodiversity conservation, climate change

NBS SNAPSHOT

Location: Yaque del Norte River basin of the City of Santiago

Type of NBS: Constructed wetlands that treat 250,000 m^3/year

Costs: Average cost per unit area is USD \$150/m^2

Driving Factors for NBS: As only 20 percent of the wastewater of Santiago is handled by the city's sanitation system, the Yaque del Norte Water Fund was established with water sanitation as a strategic objective, particularly through the construction of artificial wetlands.

[1] World Bank (2020) Realizing SDGs for Water and Sanitation in Dominican Republic, https://www.worldbank.org/en/results/2020/05/06/realizing-sustainable-development-goals-for-water-and-sanitation-in-the-dominican-republic

[2] Water funds are organizations that protect the quality and amount of water by using funds from downstream users to pay for investments that protect water quality upstream.

adaptation and mitigation strategies, and the sustainable use of natural resources. However, all projects have wastewater implications and co-benefits since they help to restore the functionality of watersheds, thus diminishing the amount of pollution flowing into coastal ecosystems.

Since 2014, TNC has been implementing replenishment projects in key watersheds of the country by applying NBS approaches such as promoting agroforestry, reforesting riparian forests, and conserving remaining forest to reduce superficial runoff. These efforts have helped prevent soil erosion and reduced the amount of nutrients washing into waterways.

The use of NBS for wastewater treatment was seldom considered until constructed wetlands arose as a feasible and cost-effective way to provide sanitation services to small communities in rural and suburban areas that were not connected to a sanitary sewer system. Today, these constructed wetlands represent the main technique used in the Dominican Republic for wastewater treatment.

In 2015, the U.S.-based Charles River Watershed Association (CRWA) requested TNC's assistance locating a community to set up the Twinning River partnership program that provides peer-to-peer knowledge exchange and capacity building for sustainable river management. As part of this endeavor, CRWA hired the company Tetra Tech to provide technical capacity development to community partners that were working to improve water quality in Jarabacoa, a small municipality in the upper watershed of the Yaque del Norte River that serves the city of Santiago.

Tetra Tech recommended a series of approaches tailored to the watershed's local context. Among them were:

- *Gravity-flow constructed wetland systems*. These systems consist of a pond covered by an impermeable membrane and filled with gravel containing aquatic macrophyte plants. They reproduce the natural method of water purification by eliminating pollutants through physicochemical and bacteriological processes such as sedimentation, microbial degradation, absorption, and volatilization. Because the systems use gravity, they can only be sited in areas where houses are located at a higher elevation than the treatment site.

- *Riparian wetland side-stream systems*. These systems shunt water from a natural stream into a wetland created in the riparian zone, where the water undergoes enhanced treatment before reconnecting with the stream. These systems are designed to treat baseflows and the most polluted first-flush stormwater flows.

- *Vegetated sand filter wastewater treatment systems*. These are highly effective single-pass sand or gravel filters planted with functional and/or aesthetic vegetation. They consist of a gravity collection sewer to convey sewage from houses that would otherwise directly discharge into the river by using a septic tank, pumping system, and vegetated filters. The wastewater travels through these filters, then infiltrates into the natural soil and is discharged back into the river.

- *In-stream boulder filter systems*. These adaptable systems can be easily implemented in existing flowing conveyances, particularly those with armored banks. They primarily treat baseflows, which likely include a significant amount of wastewater.

- *In-stream mycofiltration* systems. These very adaptable systems use mushroom mycelium mats as biological filters. They are more appropriate for a conveyance with intermittent flow and are targeted for constructed drainage channels within the planning area.

Of these practices, gravity-flow constructed wetlands are most commonly used in the Dominican Republic because they are very scalable and provide effective treatment with practically no maintenance. Sand filters are commonly used in some rural aqueducts as part of the water intake treatment.

Professional capacity limitations and the limited availability of specialized academic training in the Dominican Republic hinders the development and uptake of water quality and sanitation projects. Universities within the Dominican Republic offer degrees in civil engineering, chemical engineering, bioanalysis, microbiology, chemistry, and food technology, all of which have relevance and application engage with water quality management and sanitation. However, not all universities offer graduate level and post-graduate training in fields such as environmental engineering and integrated water management, and the programs of study that do exist are relatively recent additions to academic curricula.

There is little information about the costs of various NBS versus grey wastewater systems. Nevertheless, the initial investment in NBS is generally lower and they tend to be more cost-effective in the long-term compared with conventional grey infrastructure, which often requires electricity, continuous maintenance, and chemical supplies in order to function properly.

Haiti

Until recently, Haiti was one of the few countries in the world without a central sewage system in any of its larger cities. A new central system that collects and treats sludge and wastewater near the capital city of Port-au-Prince has just been launched. Except for a few systems in select towns or communities that were installed by the government or NGOs, there are no sewers connecting sinks, showers, and toilets to large wastewater treatment plants.

Most of Haitians use outhouses, and much of that waste ends up in canals, ditches, and other unsanitary dumping grounds, where it can contaminate drinking water and spread disease. During heavy rains, this wastewater carries household wastes and sewage from pit latrines and is a major polluter of the country's natural waters, such as the Bay of Port-au-Prince.[3] The impact of urban wastewater on aquatic ecosystems is not widely reported in the literature yet, but we know that it is a real threat, especially around large cities like Port-au-Prince and Cap-Haitien.

> NBS SNAPSHOT
>
> **Location:** 243-hectare Parc Industriel de Caracol, along the Rivière Trou du Nord, just above Caracol Bay
>
> **Type of NBS:** Constructed wetland ponds
>
> **Costs:** Not available
>
> **Driving Factors for NBS:** Avoiding soil and water contamination from dyes used in treating clothes at garment factory

One key study carried out in 2009 by Quisqueya University[4] focused on urban effluent in the Bay of Port-au-Prince. The purpose of the study was to: (i) implement an environmental hazard assessment framework for untreated urban wastewater; and (ii) apply the framework on urban wastewater coming from an open channel of the combined sewer system of Port-au-Prince. The study characterized the environmental hazards of wastewater on the Port-au-Prince bay ecosystem by comparing the results with threshold values on effluent discharge. Key findings included:

- Untreated wastewater from rain, residential areas, industries, and manufacturing plants flows directly into the Bay of Port-au-Prince;
- The presence of contaminants in untreated urban wastewater significantly threatens the biological equilibrium of the bay ecosystem and its aquatic organisms; and
- The maximum concentration of dissolved oxygen (CDO: 4.54 mg/L) was lower than the concentration required (5 mg/L) to protect aquatic organisms against the wastewater effects.

[3] Emmanuel, E., Perrodin, Y., Théléys, K., Mompoint, M., and Blanchard, J.M.B. 2004. Environmental hazard assessment of untreated urban wastewater on the ecosystem of Port-au-Prince Bay.
[4] Emmanuel, E., Lacou, J., Balthazard-Accon, K., and Joseph, O. 2009. Ecological hazard assessment of the effects of heavy metals and nutrients contained in urban effluents on the bay ecosystems of Port-au-Prince, Haiti. *Revista Aqua-LAC* 1(1).

The practice of discharging waste in Haiti's waterways poses a significant concern to water quality and to the health of aquatic organisms. Not only are there various types of pollutants that impact these systems, but there are many ways pollutants can harm aquatic organisms.[5]

Pollution in Haiti has increased gradually during the past decade, due to a significant increase in the number of poorly maintained used cars that leak enormous amount of oil all around the cities, uncontrolled urbanization, and other factors. The mismanagement of wastewater in Haiti has a profound negative impact on the quality of life, for people and ecosystems both inland and in the ocean.

Haiti's investment in NBS for multiple outcomes, including for wastewater management, is growing. Yet with limited wastewater infrastructure overall, NBS gains are modest compared with the overall need.

Jamaica

Wastewater management in Jamaica is the responsibility of several government ministries and agencies, with accompanying legal instruments used to govern and define roles and responsibilities. Jamaica's existing legislation is considered fragmented,[6] as government agencies appear to lack an integrated approach to wastewater management issues. Wastewater management is primarily governed by four instruments: the National Resources Conservation Authority (NRCA) Act, the Public Health Act, the National Water Commission Act, and the Water Resource Act. The NRCA (Permits and Licenses) Regulations implements a system of permits for waste disposal. The Public Health Act sets national standards for the collection and disposal of waste material and assigns the responsibility for monitoring and enforcing these standards to the Ministry of Health and Wellness. In addition, the Office of Utilities Regulation sets and enforces quality of service standards for sewerage networks. The National Environment and Planning Agency monitors the health of the environment.

NBS SNAPSHOT

Locations: Dunns River Falls and Hellshire

Type of NBS: Constructed wetlands (reed beds) and stabilization ponds

Costs: Inexpensive, compared with grey infrastructure

Driving Factors for NBS*:* Available land and costs

Effluent from sewage treatment plants, other types of sanitation facilities, and industrial discharge are known to pollute the environment and endanger ecosystem and human health. In Jamaica, 75 percent of sewage waste disposal systems are soak-away systems, which collect wastewater in underground chambers and disperse the water slowly through surrounding soils. These have been shown to contaminate groundwater sources, particularly in densely populated areas (e.g., Liguanea Plains).[7] While the construction of new soak-away systems is no longer permitted, these systems are still prevalent in older construction.

About 83 percent of all Jamaicans have access to improved sanitation facilities[8] (meaning flush or pour-flush to a piped sewer system, septic tank, or pit latrine; ventilated improved pit latrine; pit latrine with slab; or a composting toilet).[9] Sewage volume reaching various sewage treatment plants commonly exceeds the plant's design capacity, and the noncompliance rate for sewage effluent quality standards is known to be high.

This lack of compliance is mainly due to issues such as improper plant designs, old technology, overloading, lack of maintenance, and improper operations.[10] Decision makers and the public generally place a low priority on wastewater management compared with other issues. There is also a lack of public

[5] Adams, S.M. and M.S. Greeley. 2000. Ecotoxicological indicators of water quality: Using multi-response indicators to assess the health of aquatic ecosystems. Journal of Water, Air, and Soil Pollution 123:103-115.
[6] GEF CReW (2010) Situational Analysis – Regional Sectoral Overview of Wastewater Management in the Wider Caribbean Region.
[7] MEGJC (2019) National Water Sector Policy and Implementation Plan 2019, pp. 75-76
[8] MEGJC (2019) National Water Sector Policy and Implementation Plan 2019, pp. 75
[9] https://www.indexmundi.com/jamaica/sanitation_facility_access.html
[10] GEF CReW+ Project, Appendix 23 National Package for Jamaica

awareness of wastewater issues and their effects on the environment and a general “out of sight, out of mind” attitude.

The use of traditional mechanical treatment plants is widespread and typically more common in Jamaica than in other Caribbean countries. The use of NBS for wastewater management over the last few years has increased. The most commonly used NBS for wastewater management in Jamaica are:

- Constructed wetlands, mostly reed beds;
- Waste stabilization ponds;
- Anaerobic digesters/reactors;
- Natural wetlands (e.g., mangroves); and
- Reuse of treated effluent for irrigation.

The use of these types of systems seems to be driven by the cost of construction, but not necessarily the cost of maintenance. Typically, if the NBS is more expensive to construct and the costs of maintenance is not a primary concern of the operators, then there is a high probability that grey solutions will be used. Typically, the costs of maintaining the natural system are less expensive compared to the mechanical treatment plants, meaning potential savings could be accrued over the short- and long-term in a natural system.

The NBS most commonly used in Jamaica (such as constructed wetlands and stabilization ponds) often require substantially more land than mechanical plants, and if land prices are high or land is unavailable, the systems are considered too expensive and impractical. Mechanical systems while requiring less land area, often require a higher energy input, more frequent maintenance, and more skilled personnel. In some cases, engineers may suggest hybrids of natural and mechanical solutions to overcome the disadvantages of each.

There are no ardent policy mandates that drive or encourage the use of NBS in any significant way for wastewater management, so the use of NBS seems to be driven more by the client’s specific situation and the design recommended by the specific engineer, based on their own experience and competence.

In some cases, permit requirements have led to the use of NBS. For example, improved building codes, industrial effluent, and development permitting requirements dictate that wastewater treatment systems exist or are improved to operate legally. There are also positive spinoffs that can occur when wastewater management has to be improved due to legislative directives to meet effluent standards. In some cases, implementation of new NBS systems has required water-intensive industries to find ways to reduce their overall water consumption and water-use requirements so that they can take advantage of more affordable NBS approaches.

Grenada

In Grenada, sewage management touches on the mandate of several ministries and government agencies. The principal institution is the National Water and Sewerage Authority (NAWASA) where it is coupled with water resources management and distribution. With respect to sewage, NAWASA has oversight for operation, maintenance, and monitoring the performance of the sewage systems and advises the Housing Association of Grenada on sanitation solutions for their developments. Other key agencies include the Environmental Health Department and the Fisheries Division, both of which share mandates related to the control of water pollution, namely monitoring water quality and sanitation and water quality relating to marine life, respectively. The Physical Planning Unit also contributes to sewage management through its regulatory functions on development activities.

In this regard, cross-sectoral coordination is critical for creating coherence and synergies among these key entities – including other actors and stakeholders – to ensure effective management. Experts agree that this cross-sector coordination of water, land, coastal areas and public health issues is a critical and urgent need in Grenada. The likely contributors to this “silo approach” are: (i) no formal coordination arrangements or institutional agreements to support cross agency or intragovernmental collaboration; (ii) inadequacies in management and leadership; (iii) resistance to information sharing (particularly for water quality data); and (iv) limited human and financial resources and technical capacity.

NBS SNAPSHOT

Locations: Grenville Bay and Telescope

Types of NBS: Coral reef restoration, mangrove restoration, beach restoration, natural retention ponds, and seamoss farms

Costs: Varied among different projects

Driving Factors for NBS*:* Climate resilience, community involvement, and costs

The growing tourism industry, increase in urbanization, and increasing city populations (of residents and tourists) are increasing the pressure on Grenada's critically important marine and coastal environments. One major threat to its marine assets has been large amounts of wastewater—particularly sewage, the inadequate disposal of which not only pollutes and damages the critical assets on which the tourism sector and national economy so heavily depend, but also poses serious public health risks to tourists and citizens alike. Interventions to support the proper management of sewage are therefore crucial to Grenada's sustainable economic, social, and environmental development.

The current disjointed sewage disposal system is considered inadequate and an urgent problem of national importance, so much so that an interviewee described it as a "ticking time bomb." This is largely due to substantial sewage leakages and pollution entering Grenada's water courses, ocean, and groundwater supply, causing significant contamination and sanitation issues, health risks, and severe threats to marine life and habitats.

A variety of disposal methods are in use in Grenada: septic tanks, self-contained treatment systems, pit latrines, and disposal of sullage (used kitchen and bath water that does not contain human waste) into surface drains. According to national census data from 2011, approximately 62 percent of Grenadian households have indoor toilets, including 58 percent linked to septic tanks and four percent connected to sewer systems. A significant 30 percent of the population still use pit latrines, and the Pan-American Health Organization estimates that 67 percent of the island's low-income families use pit latrines.[11] Meanwhile, five percent of Grenadians do not have access to any excreta disposal facility. Several Grenadian interviewees indicated that open defecation into rivers and drains is still practiced in several rural communities, and a World Health Organization/UNICEF study[12] places this figure at 3.5 percent of the population. One hotel is reported to have its own treatment facility that is not functioning properly.[13]

During periods of heavy rainfall and flooding, a significant amount of wastewater from home systems (pit latrines and septic tanks) overflows and is discharged into the ocean through runoff from the upper watersheds. This problem is exacerbated by pollution from poorly constructed pit latrines and malfunctioning septic tanks. Unplanned development over the years has resulted in the unregulated expansion of communities bordering the capital city of St. George's, including several informal or slum-like areas.

There are also numerous cases around the island of dense housing developments that discharge wastewater into rivers and tributaries, from which it eventually finds its way into the sea. Sewage leakages and run-off not only affect the river and coastal waters in Grenada, but also can affect freshwater supply. In several cases, sewage has seeped into and contaminated the groundwater, particularly in areas below sea level or with higher water tables such as Grenville. By and large, the topography and geology of Grenada allows for the safe application of septic and soakaway options. Further, the Environmental Health Department has standard designs for septic tanks and soakaways, the specifications of which are based on the number of persons in the household. The challenge is the poor design, construction, and/or placement of septic tanks and pit latrines, due to the limited monitoring and enforcement of the Physical Development Department.

[11] Pan American Health Organization. 2012. Health in The Americas, Grenada Country Report.
[12] WHO / UNICEF Joint Monitoring Program. JMP (2015. www.wssinfo.org.
[13] OECS Grenada Wastewater Management Project Final Report. 1999. Howard Humphreys and Partners, Ltd.

Public Opinion Research

Through three online focus groups conducted in March 2021, we found that many participants are vaguely aware of sewage and wastewater pollution in the ocean but are not familiar with the details, though awareness was much higher among Dominican participants than among those from Jamaica or Grenada. All participants recognize that this type of pollution is a serious threat to bodies of water, coral reefs, fish, and other sea life, as well as humans. Most felt that both individuals and the government bear responsibility for finding solutions, and many of these participants were open to NBS such as reed beds.

Relationship with the Sea and Awareness of Water Problems

- Residents of these three countries said that the sea was an integral part of their lives.
- When asked whether the sea is in good condition or bad condition, participants responded that it depended on the location.
- Participants reported a wide variety of pollution sources flowing into the sea.
- While some felt that businesses, ships, and resorts were responsible for most threats to marine environments, most agreed that individuals need to behave more responsibly as well.
- Most participants recognized climate change as a serious concern, especially with regard to rising sea levels.

Focus Group Participants' Feelings About Sewage

- Participants from all three islands were aware that sewage ends up in the sea, and many had thought about the issue before.
- There was little awareness of laws regarding sewage dumping across all three islands; if they exist, participants agreed that they are not being enforced.
- Participants agreed that government, individuals, and businesses, particularly resorts, share the responsibility for sewage pollution, but each person applied a different amount of blame to each group.
- All agreed that sewage pollution has a wide range of negative effects.

Reasons to Act

Top Concerns	
Fish/seafood contamination	**12**
People getting sick from swimming in polluted water	**7**
Destruction of coral reefs*	**6**
Eventual impact on tourism and the economy	**6**
Seaweed on beaches and in the sea	**0**

- When participants were given a list of potential impacts, they ranked fish and seafood contamination as the top concerns, followed by public health concerns for swimmers.
- Destruction of coral reefs and the impact of sewage pollution on tourism and the economy were also seen as serious problems.
- Seaweed washing ashore was not a top concern for these participants.
- Notably, many participants said it was hard to choose just one or two concerns, and saw these problems as intertwined.

Most Convincing Reason to Act

- Participants were divided on the most compelling argument to take action, but felt that when talking about coral reefs, a science-based argument worked better than an economic one.
- The top argument overall directly addressed the dangers to fish and sea life; however, its popularity was entirely driven by the Dominican Republic group, which almost unanimously agreed that it was their top choice. The scientific argument about protecting coral reefs and the argument about algal blooms and human health had more widespread support.

Exploring Solutions

- The consensus among participants in all three groups was that education of the public is the key to finding a resolution, but that the government has an important role to play, too. Participants from the three different islands had slightly different ideas of which entity should have a larger role.
- Overall, participants agreed that both the public and the government have to work together for any solution to be effective.
- Participants generally did not think that anything was being done to help resolve this problem.
- There was tentative support for NBS such as reed beds. Participants did not feel they had enough information to gauge how well they would work but thought it was a good idea to try them.
- In addition to not fully understanding how reed beds can filter sewage and wastewater, participants had other concerns.
- While participants were open to having reed beds in their community, they had mixed reactions about whether they would be willing to pay for them, and how much.

Most Convincing Argument	
It's not just people who get sick from sewage. Fish, shellfish, and the birds and wildlife that rely on them for food can suffer due to toxins that flow into water. In addition, sewage can lead to algae and seaweed that can kill sea turtles, sea birds and other animals.	**7**
Sewage pollution hurts coral reefs, as it spurs the build-up of algae and seaweed, which smother and kill reefs. Scientists estimate that living coral cover in the Caribbean has decreased by 60% in the past 30 years alone. That is a problem, because reefs help protect our communities against flooding and hurricanes.	**5**
Sewage dumping leads to toxic algal blooms that are deadly to people, as well as outbreaks of cholera, hepatitis, infectious viruses, and gastroenteritis.	**5**
The fishing and tourism industries cannot survive without flourishing coral reefs, as many of the fish we eat need the reefs in order to survive. One study revealed that tourism from people coming to see fish and the reefs generates over $7.9 billion for Caribbean economies annually.	**2**
Our traditions, customs, and livelihoods often revolve around the sea, and food from the sea, and we need to ensure that our children and grandchildren enjoy them like we do.	**2**

In Summary

The main idea participants took from the discussion was that it is vitally important to care for the health of the sea and to help their friends and family understand the damage that sewage and wastewater pollution can cause. Some participants mentioned ideas for larger education campaigns, suggesting that social media and celebrity endorsers could be used to explain the dangers of sewage pollution to the public and create awareness of what can be done to help.

The Caribbean residents who participated in these focus groups and interviews were clearly concerned about the health of the waters that are an integral part of their communities and way of life. They understood how sewage pollution affects life at every level, sickening humans, fish, and other sea life and destroying reefs. In turn, they were concerned that those problems would also hurt the tourism and fishing industries that have a large role in their economy. These participants were willing to support NBS such as reed beds, but they could be a tough sell depending on whether and how much residents are asked to help finance them.

Conclusion

As Caribbean countries continue to grapple with the serious implications for biodiversity and human health of untreated and poorly treated wastewater, it is clear that NBS can and will play an important role. Pilot projects are proving successful, and local and global research on different NBS for wastewater management show that these types of projects are viable in the Caribbean.

Some consistent realities about NBS were clear across all countries studied:

- NBS can be applied across a range of sectors and scales – hotels, rural communities, urban areas, private sector businesses, and more;

- Public/private/civil society partnerships play an important role to make NBS viable and there is an opportunity for organizations like TNC and UNEP to work more closely together to address this issue;

- Global and regional legal frameworks and commitments have a role to play in catalyzing national policy and legislative reforms and harmonized regional approaches (e.g. United Nations Environment Assembly (UNEA) Decisions, LAC Ministers, CARICOM Ministers and OECS Ministers of Environment, Agenda 2030 and SDG Commitments especially on SDG 6 on Water and Sanitation and SDG 14 on Oceans). UNEP Global Programme of Action and their Global Partnership on Wastewater and the LBS Protocol within the UNEP Cartagena Convention which forms the framework for all of projects and activities on wastewater management has an important role to play, as well;

- As the understanding of the issue of wastewater management grows in the region, the more NBS projects include wastewater management "co-benefits," the more the ocean-based economy/blue economy of small island developing states (SIDS) will be protected. Efforts such as SPAW and LBS are promoting integration of NBS for wastewater management as part of an overall strategy to enhance SIDS ocean-based economies; and

- The more we maximize the use of donor grant funding and existing projects available for focusing on NBS, the more we can leverage public and private dollars to address wastewater management. Approaching this work from a combined pollution control, biodiversity conservation, climate change adaptation, water security and livelihood generation provides a holistic, "Source to Sea" solution set for many related issues in the Caribbean.

While many of these efforts show great promise, barriers remain to Caribbean wastewater management solutions, including NBS and grey infrastructure. Many countries lack the legal, regulatory, and financial means to implement widespread wastewater management. And without public awareness and political leadership on the issue, wastewater solutions—green or grey—will not be scaled enough in a timely fashion to have a significant impact on biological and human health.

To truly position NBS in a more prominent role for wastewater management, the underlying barriers must be addressed in a systemic and inclusive fashion. Increasing education and awareness, improving planning and design, investing more resources in scientific analysis and monitoring, enhancing legal and regulatory functions, and developing dedicated funding for water health will all be necessary for NBS projects to succeed. Until we make these investments, we will never know the true capabilities of NBS to finally address the long-standing need for wastewater management in the Caribbean.

30th Annual Caribbean Water and Wastewater Association Conference and Exhibition: Cayman Islands

Technical Sessions Paper

Title: Water Reuse and Resiliency: From Florida to the Caribbean?

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Organization: Broward County (Florida, USA) Water and Wastewater Services

Keywords: Water Reuse, Wastewater, Drought, Resiliency

Abstract

Water reuse conserves traditional drinking water sources and strengthens water sector resilience, especially during droughts. Drought resiliency and improved wastewater management are two important broad goals within the Regional Strategic Action Plan for the Water Sector in the Caribbean (RSAP). The United Nations Environment Programme's and Inter-American Development Banks' Caribbean Regional Fund for Wastewater Management (GEF CReW+) is one important initiative working towards wastewater solutions. An optimal time to integrate water reuse systems into a utility's strategy is when new wastewater systems are being planned. As programs such as GEF CReW+ continue to grow, the potential for Caribbean water reuse to supplement traditional drinking water sources, desalination, and conservation appears good. Water reuse can diversify regional water supplies and provide more drought resilience to the Caribbean water sector. However, water reuse development requires scientifically sound regulations, public education, and political support. The state of Florida's water sector utilities are national leaders in United States' water reuse production. The state set its first water reuse rules over 30 years ago and state, as well as local, political leadership, including financial support, was critical for large scale implementation. Important public education programs also contributed to water reuse growth in the state. With high population growth, Florida is now implementing potable reuse to strengthen its water supply resilience. The author will tell the 'Florida Water Reuse Story' and then discuss strategies to transfer knowledge and 'lessons learned' for a future 'Caribbean Water Reuse Story'. With a similar climate, including droughts, and close geographic proximity, the Florida water sector could be optimal water reuse collaborators with its neighboring water sector. An opportunity to start the conversation now should provide water reuse opportunities sooner as the RSAP and programs such as GEF CReW+ and a new World Bank one continue to implement their important strategies.

Water Reuse Introduction

Water Reuse is a resilient water supply tool for several countries around the world and its application goes back decades (United States Environmental Protection Agency 2020). The water reuse types and strategies are dependent on regional and local needs. In Florida (USA) a common phrase is “right reuse, right time, right place” (Potable Reuse Commission 2020). Importantly this technology builds drought resilience by providing an alternative water supply when traditional water sources become stressed or nonexistent. Arid countries or region of countries traditionally lead the way in water reuse production through necessity. For example, Israel produces water reuse from 90% of its wastewater volume primarily for agriculture irrigation (WaterWorld 2016). However, Singapore, with a wet tropical climate, produces up to 40% of its drinking water needs with potable reuse and plans to expand to 55% by 2060 (PUB, Singapore's National Water Agency 2021). From 1980 until 2020, the state of Florida’s population growth increased from over 10 million people to over 20 million people (Florida Office of Economic and Demographic Research 2021). Even though the state of Florida averages around 60 inches of rainfall a year, its water utilities are national leaders in United States’ water reuse production to meet this high population demand, as well as one of the world’s largest tourist industries. Florida’s water reuse production grew from nearly 500 million gallon per day in 1998 to nearly 900 mgd in 2020 (Figure 1). Due in part to a large population, neighborhoods, parks, and golf course irrigation (public access areas) is the number one application (Figure 2).

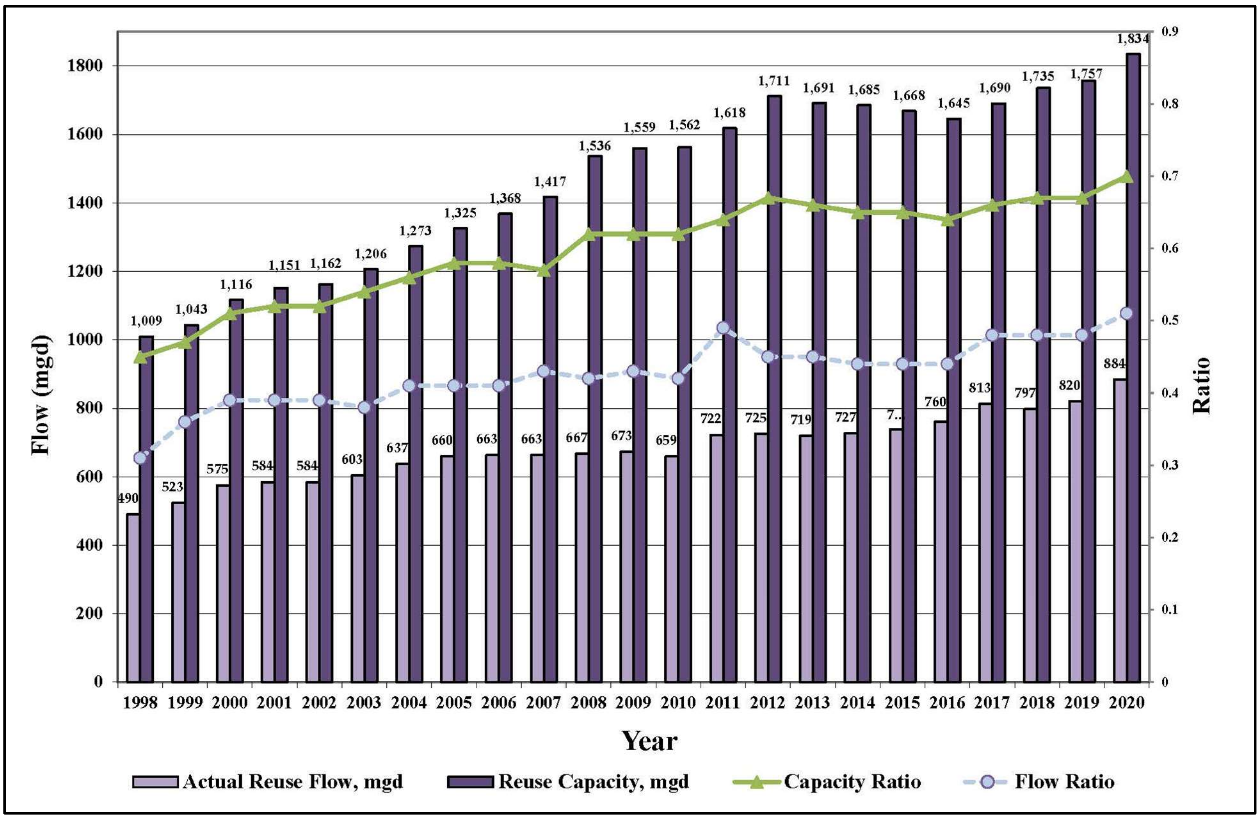

Figure 1. Florida's water reuse capacity and production from 1998 through 2020. Source: Florida Department of Environmental Protection 2021a.

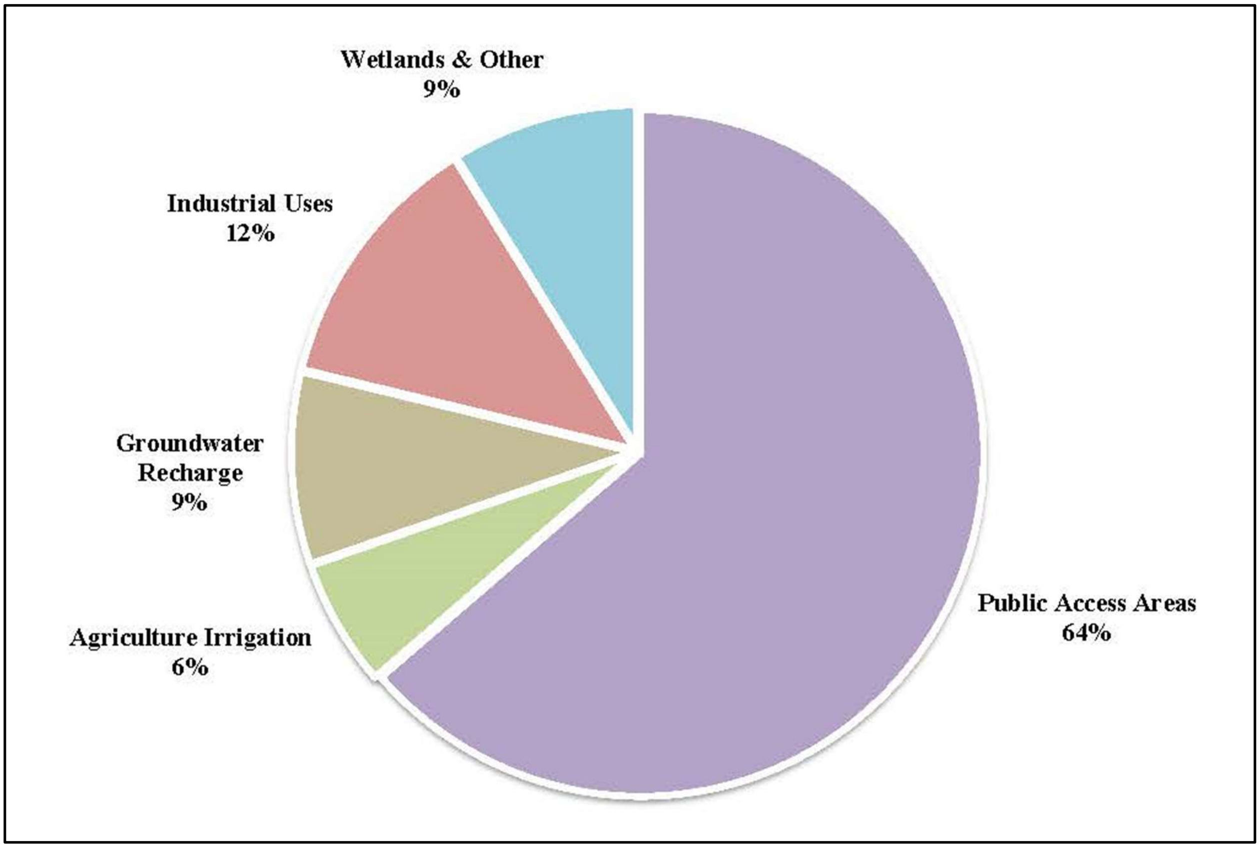

Figure 2. Florida's 2020 water reuse utilization based on percent of overall flows (884 million gallons per day, see Figure 1) Source: Florida Department of Environmental Protection 2021a.

Caribbean Drought Resiliency and Wastewater Management Needs

The Food and Agriculture Organization (FAO) of the United Nations' Regional Office for Latin America and the Caribbean (FAO 2016) listed seven Caribbean countries in the world's top 36 water-stressed countries with Barbados being in the top ten. Thus, drought management is critical in the Caribbean basin as climate is expected to become even drier into the next century. Climate change is a key driver for future, longer drought periods and the agricultural sector and food security will be at particular risk (FAO 2016). Water security also is greatly impacted by droughts among several other key factors in the Caribbean, for example under Cashman's (2013) "Water Security four As -Adequacy, Accessibility, Assurance, and Affordability."

Wastewater management is a steep challenge in the Caribbean with the United Nations Environment Programme's (UNEP) Caribbean Environment Programme (CEP) estimating approximately 80% of wastewater discharged to the environment is untreated (UNEP 2021a). However, programs such as the Caribbean Regional Fund for Wastewater Management (GEF CReW+) funded by the Global Environment Facility and co-implemented by UNEP and the Inter-American Development Bank (IDB) (UNEP 2021a) are working towards new infrastructure in 18 countries (Figure 3). Importantly, the GEF CReW+ also seeks to increase water reuse in the region (UNEP 2021a). The opportunity to augment new wastewater infrastructure with water reuse development would also promote drought resiliency. Drought resiliency and improved wastewater management are two important goals within the Regional Strategic Action Plan for the Water Sector in the Caribbean (RSAP, Caribbean Water and Wastewater Association, CWWA 2019a) and coupling their implementation integrates water sector solutions at regional and local scales.

The Caribbean and Florida water sectors are closely connected through geographic, family, social, cultural, economic, and climatic characteristics among other close ties (Carter, K. 2019). With the state of Florida's long history in water reuse production, current and future Caribbean water reuse producers could gain important information and 'lessons learned' from their neighboring Florida water and wastewater utilities. This paper will first tell the "Florida Water Reuse Story" to describe key milestones leading to Florida's successful programs. Mechanisms to use over 50 years of water reuse history towards the Caribbean water sector's benefit with wastewater management, water reuse development, and drought resiliency will be described in closing recommendations.

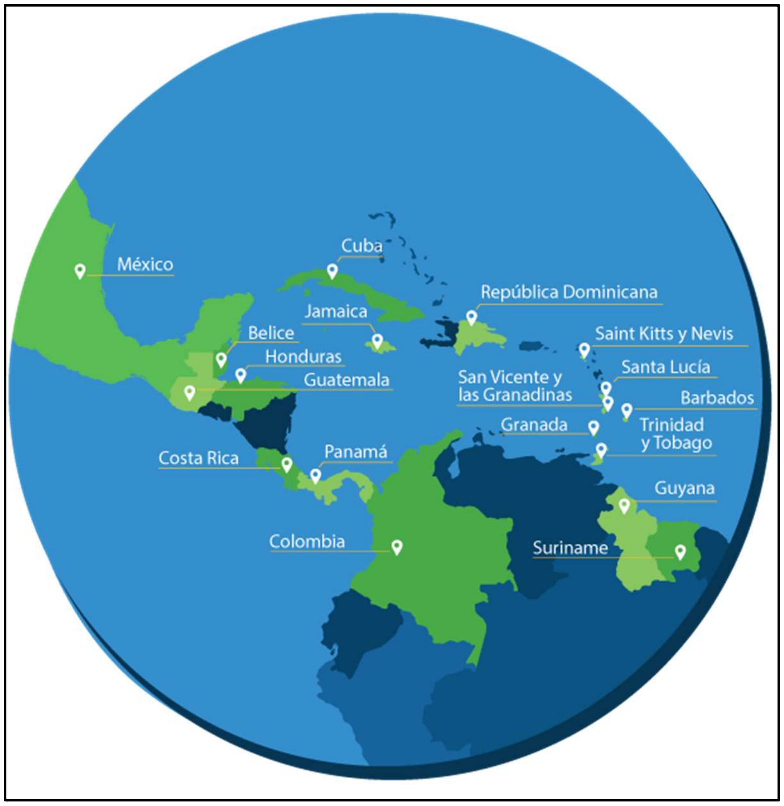

Figure 3. 18 Countries Working with the Caribbean Regional Fund for Wastewater Management (GEF CReW+) funded by the Global Environment Facility and co- implemented by United Nations Environment Programme (UNEP) and the Inter-American Development Bank. Source UNEP 2021b.

<u>'Florida's Water Reuse Story': The Beginning Decades</u>

'Florida's Water Reuse Story' began in the late 1960's and early 1970s with the groundbreaking work of the City of Tallahassee (see Table 1). They investigated mechanisms to reduce or cease wastewater discharges into a local lake. Through this planning, an innovative process was developed to use wastewater effluent on agricultural lands. Another important early milestone was the City of St. Petersburg implementing one of the nation's first urban water reuse programs in 1977 (Table 1). In 1986, two large urban utilities – Orange County and City of Orlando - partnered with their adjacent agriculture community for a Central Florida project named Water Conserv II that became "the largest reuse project of its kind in the world" (Water Conserv II 2021). Importantly, Water Conserv II was the first water reuse project permitted by the Florida Department of Environmental Protection (FDEP) to irrigate crops produced for human consumption (Water Conserv II 2021). All three of these early projects shared a common goal to reduce or eliminate wastewater discharges to surface waters by implementing water reuse projects.

Table 1. Milestones in Florida's Water Reuse History

1967	City of Tallahassee implements one of the first agricultural water reuse pilot projects and expands it to over 120 acres in 1976. The United States Environmental Protection Agency and the University of Florida Institute of Food and Agricultural Science performed important initial research to understand a crop's agronomic needs to water reuse irrigation practice.
1977	City of St. Petersburg implements one of the first urban water reuse projects in country.
1986	In Central Florida, Water Conserv II became "the largest reuse project of its kind in the world" (Water Conserv II 2021). Florida's overall water reuse production tops 200 million gallons per day (York and Wadsworth 1998).
1987*	Florida Department of Environmental Regulation (FDER, now Florida Department of Environmental Protection, FDEP) initiates reuse program.
1988*	FDER adds reuse provisions (includes mandatory reuse in Water Resource Caution Areas) in Chapter 17-40 Florida Administrative Code (F.A.C).
1989*	FDER creates reuse rules in Chapter 17-410 F.A.C. and establishes 17-400 F.A.C. for domestic wastewater facilities that refines high-level disinfection requirements.
1989*	State of Florida** (1989) declares water reuse a state objective and reuse feasibility study requirements are added to law (Laws of Florida 89-324).
1990*	FDER adds permitting requirements to 17-410 F.A.C.; State of Florida (1990) passes the Indian River Lagoon System and Basin Act of 1990 (Laws of Florida Chapter 90-262) to encourage reuse in Florida's central east coast through feasibility studies.
1991*	FDER publishes guidelines for preparation of reuse feasibility studies. Water management districts' (WMD) designate Water Resource Caution Areas.
1993*	FDER (along with Florida Department of Natural Resources) becomes FDEP and initiates 2-phased rulemaking to redefine and expand reuse rules (now in Chapter 62-610, F.A.C. FDEP 2021b). The recently established (1992) Reuse Coordinating Committee published Reuse Conventions. Florida's overall water reuse production tops 300 million gallons per day (York and Wadsworth 1998).
1994*	State of Florida (1994a) enacts the APRICOT Act (Laws of Florida Chapter 94-153) that permits backup discharges for reuse systems when the utility provides advanced wastewater treatment and high-level disinfection. It also allowed high-quality reclaimed water to be injected into certain potable ground waters.
1994*	State of Florida (1994b) enacts additional reuse legislation - Laws of Florida Chapter 94-243 – that adds reuse objectives to Chapter 373.250 (WMDs). The act also refines reuse feasibility study requirements and links FDEP and WMD permitting closer.
1995*	State of Florida (1995) creates WMDs' reuse funding programs (Laws of Florida Chapter 95-323).
1996*	FDEP adopts Phase I revisions to Chapter 62-610, F.A.C. - created parts dealing with industrial uses and groundwater recharge/indirect potable reuse. Florida's overall water reuse production tops 400 million gallons per day (York and Wadsworth 1998).
1997	Almost 39 million gallons per day water reuse produced in counties within area of the Indian River Lagoon System and Basin Act of 1990.
1999	FDEP adopts additional revisions to Chapter 62-610, F.A.C supported by a risk impact statement. They added an Aquifer Storage and Recovery rule as well as expanded ground water recharge and indirect potable reuse rules (FDEP 2003). Monitoring for protozoan pathogens is also now required (see York and Burg 1998). Florida's overall water reuse production tops 500 million gallons per day (Fig. 1).
2003	DEP Water Reuse for Florida Strategies for Effective Use of Reclaimed Water report published by the Reuse Coordinating Committee, a Water Reuse Work Group, and Water Conservation Initiative. Document recommends major steps and vision for water reuse growth for next 20 years. Florida's overall water reuse production tops 600 million gallons per day (Fig. 1).
2005	State of Florida (2005) passes Laws of Florida 2005-291 commonly known as Senate Bill 444 that creates the Water Protection and Sustainability Program to increase water reuse funding through the WMDs.

2008	State of Florida (2008) enacts the "Ocean Outfall Law" (Laws of Florida 2008-232) that bans any new wastewater ocean outfalls and requires 6 wastewater plants along Florida's southeast coast to cease their ocean discharges by 2025. Although peak flow events are allowed with restrictions under a subsequent amendment (see State of Florida 2013).The 6 facilities must also convert 60% of baseline wastewater discharge flow to water reuse.
2009	FDEP releases informal "Connecting Reuse and Water Use: A Report of the Reuse Stakeholders Meetings" that includes specific recommendations for the use and expansion of reclaimed water, conservation and consistency. A Reclaimed Water Workgroup consisting of FDEP, WMDs, and FWEAUC begin meetings that will last for almost four years.
2011	Florida's overall water reuse production tops 700 million gallons per day (Fig. 1).
2012	Reclaimed Water Workgroup issues final paper called the "Purple Paper." State of Florida (2012) clarifies FDEP and the WMDs can't regulate water reuse through consumptive use permitting (Laws of Florida 2012-150, also known as House Bill 639). Regulatory incentives for water reuse expansion are also included in new law.
2014	State of Florida (2014) passes "Senate Bill 536" (Laws of Florida 2014-79) requiring FDEP to perform a comprehensive study and submit a report on how to best expand water reuse for reclaimed wastewater, stormwater, and excess surface water.
2015	FDEP (2015) publishes the "Senate Bill 536" report after receiving stakeholder input for over a year including via public meetings.
2016	State of Florida (2016, Laws of Florida 2016-1) enacts a comprehensive environmental and water resources bill (Senate Bill 552) that includes new alternative water supply project funding enhancements and processes. FDEP forms an informal reclaimed water working group to build off the "Senate Bill 536" Report and hosts 5 public meetings to promote water reuse dialogue.
2017	Florida's overall water reuse production tops 800 million gallons per day (Fig. 1).
2018	International Water Association ranks City of Altamonte Springs' (2021) potable reuse project, pureALTA, top three in the world and awards it a Silver Winner Trophy in Tokyo, Japan.
2020	Potable Reuse Commission (2020) publishes its findings in January to recommend new or revised regulations and laws to facilitate potable reuse expansion in the state. State of Florida (2020) enacts another comprehensive environmental and water resources bill ("Clean Waterways Act", Senate Bill 712) directing FDEP to begin potable reuse rulemaking by the end of the year which they do.
2021	State of Florida (2021) passes law essentially banning remaining wastewater surface water discharges by 2032 unless utilities are already under similar programs (e.g., Ocean Outfall Law, see State of Florida. 2008, 2013) or meet other requirements to promote more beneficial water reuse in state. The law also contains additional water reuse rulemaking directives for FDEP which is still developing potable reuse rules.

* Information adapted from Young and York (1996)

** State of Florida refers to the combined actions of the State Legislature and Governor. Note many of the laws have been amended since their original passage. For historical purposes, the original law is provided here and References.

In 1989, the state of Florida declared water reuse a state objective which was an important step showing policy makers' support for the relatively new technology (Table 1). The Florida Department of Environmental Regulation (FDER) promulgated its first water reuse rules in 1989. In the 1990s, FDER, which became the FDEP during this period, spent most of the decade building upon its initial rules (Table 1) with important feedback from a working group (Reuse Coordinating Committee and stakeholders). The Florida Legislature continued its support for water reuse expansion with four new laws between 1990 and 1995 (Table 1). The legislative and regulatory actions along with a growing population led to the state's water reuse production doubling from 200 million gallons a day (mgd) to 400 million gallons a day between 1986 to 1996 (York and Wadsworth 1998).

'Florida's Water Reuse Story': The 21st Century - Policy and Funding Milestones

As Florida entered the 21st century, water reuse continued to climb in production to 575 mgd (Figure 1) and FDEP formed another working group (FDEP 2003) to lay out the industry's vision for the next twenty years (Table 1). Part of the vision included increased funding opportunities and fortunately, the State of Florida (2005) passed Senate Bill 444 that stimulated water reuse construction projects. Florida Water Environment

Association Utility Council (FWEAUC) estimates nearly $1 billion of state funds were allocated between fiscal years 2005-2009 on water reuse projects (22% of overall project costs, author a FWEAUC member).

Another workgroup formed in 2009 and met for four years to advance water reuse regulations and policy (Table 1). Importantly in 2012, the State of Florida (2012) passed legislation that ensured water reuse produced by utilities could not be regulated under state consumptive use laws like traditional sources. 4 additional laws (State of Florida 2014, 2016, 2020, and 2021) were enacted with provisions to promote water reuse including potable reuse (Table 1. State of Florida 2020 and 2021). Over ten utilities in the state implemented direct and indirect potable reuse pilot projects during this decade, including the City of Altamonte Springs who won a 2018 International Water Association award (Table 1, City of Altamonte Springs 2021). However, specific potable reuse rules do not exist in the state. FDEP is currently developing these rules primarily based on recommendations from a Potable Reuse Commission (2020) as required by Florida Clean Waterways Act (State of Florida 2020, see Table 1).

Recommendations for ‘the Florida Water Use Story’ to collaborate with the ‘Caribbean Water Reuse Story’

Peters (2015) described small levels of water reuse production in the Eastern Caribbean and emphasized a water reuse-desalination nexus to promote its growth. He also estimated water reuse could meet up to 38% percent of the hotels and resorts water supply needs in a case study. While Peters (2015) promoted expansion, he noted the social, cultural, and financial challenges as well as overall wastewater supply limitations. Similar challenges have been outlined by Longworth (2014) but she did link water reuse to water security for a general public audience. Working within the GEF CReW+ program (UNEP 2021a) Corbin’s (2021) recent seminar revealed results from a water reuse barriers survey and some major answers included infrastructure, public perception, public education, and enforcement.

Looking forward, GEF CReW+ represents one program to work towards solving infrastructure as well as perception and education challenges (UNEP 2021a). The World Bank embarked on an awareness program for Caribbean and Latin American policy makers to demonstrate wastewater is a resource and can have many benefits including water reuse production (Rodriguez et. al 2020). While a Global Water Partnership (2021) recent review (prepared by A. Cole and A. Cashman) primarily documented freshwater storage needs, it also referenced water reuse’s potential importance in the region. Interestingly, a local newspaper (Jamaica Gleaner 2021) focused first on the water reuse portion of the report and in a positive manner.

Some initial recommendations for the Florida and Caribbean Water Sectors to consider:

- Continue to build the Caribbean water reuse dialogue by developing working relationships with global water reuse experts, including from Florida. This could include virtual seminars and eventual in person workshops and field demonstrations (after COVID of course).
- Develop a catalog of water reuse projects, programs, and professionals in both Florida and Caribbean for a collaborative database. This effort also could identify which Caribbean utilities are most interested in exploring or growing water reuse as a resiliency tool.
- Develop work groups, such as a community of change, focused on a) regional feasibility assessment to identify gaps and opportunities b) political support c) public education d) laws and regulations e) engineering and technical considerations and f) finance.
- Develop water reuse twinning programs between the Caribbean and Florida for current facilities and to prepare future operators.
- Working with the CWWA, determine appropriate means to promote water reuse with policy makers such as the High Level Forum (HLF) of Caribbean Ministers Responsible for Water (see CWWA 2019b).
- Working with CWWA, determine feasibility to expand water reuse in the RSAP implementation.

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Cashew Gardens A Model Community: A case study of Community Waste Management (CWM) in Trinidad and Tobago

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Abstract

The Cashew Gardens Community Council (CGCC) is a community of concerned citizens living in central Trinidad and Tobago, whose goal is to educate the community about becoming more climate resilient and to make eco-friendly choices. Recognizing that methane gas and plastic pollutants are also biggest contributors to the negative impact on landfills in Trinidad and Tobago, the CGCC has always been concerned about pollution and ways in which we, as a community, can reduce our carbon footprint by sending less recyclable waste to the landfill.

In order to address our community's waste, the CGCC implemented two important projects. Firstly, the Cashew Garden Community Recycling Programme, which was established in 2016 and by 2021 has shown a 90% increase in recyclables collected. This project is still ongoing and to date has successfully diverted over five tonnes of plastic, cans, glass and tetra packs from entering our landfills. According to our National Recycling Policy 2015, these four waste types account for almost 40% of the waste that goes to our landfills. Additionally, the project has also evolved from two hundred households that were part of the initial study, to three other communities around us, with a total of over six hundred households now included. The items collected are sent to the Solid Waste Management Company (SWMCOL), where they are bailed and shipped to recycling facilities outside of Trinidad and Tobago.

Secondly, the most recent project is the Cashew Gardens Community Composting (CGCC) initiative, which involves community collection and processing of organic waste to create fertilizer, which is used in the community garden. Organic waste contributes to the highest amounts in the nation's four landfills at 22%. The community composting project, which began in August 2020, is the first of its kind in the country and was introduced as a pilot project involving 16 households in order to reduce greenhouse gases in landfills. On average, the project diverted over 490 kg of organic waste from the landfills which has yielded over 68 kg of compost material in a nine month period with a 20% increase in household participation in 2021.

This paper aims to review the recycling activities of the Cashew Gardens community and its contribution towards reducing waste by 1% in the Beetham landfill. It will also explore the change in behaviour which has been ongoing over the past 5 years and how this change has positively contributed to the achievement of environmentally friendly waste management practices in this community.

Introduction

Waste management is an important consideration for most small island developing states (SIDs) since they produce on average 2.3 kg municipal solid waste (MSW) per person, 48% higher than the world average. Within SIDS, even though landfilling space is an issue, more than 90% of the municipal waste is recyclable (Figure 1).

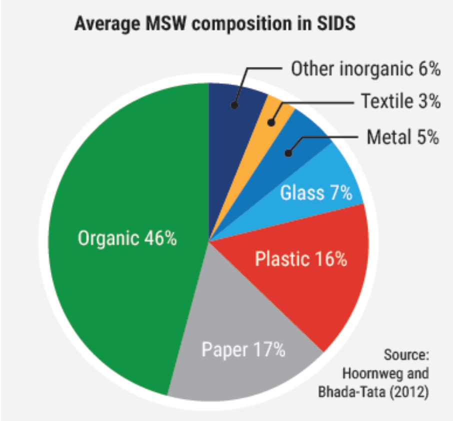


Figure 1. ***Average Municipal Solid Waste (MSW) composition in SIDS. Taken from Seadon & Giacovelli (2019).***

The Caribbean ranks second of the three SIDS regions in terms of its waste generation (Seaton & Giacovelli 2019). Ewing-Chow (2019), in a Forbes article states that "Caribbean Islands Are The Biggest Plastic Polluters Per Capita In The World" and claims that "The biggest culprit is Trinidad & Tobago, which produces a whopping 1.5 kilograms of waste per capita per day—the largest in the world".

The National Integrated Waste Management Policy (NISWMP) 2014 establishes the plan for managing Trinidad and Tobago's waste in accordance with a hierarchy that minimizes land-filling, with an increased focus on reduction of toxicity and volume of waste, through reuse, recycling and source separated organic waste management (Government of the Republic of Trinidad and Tobago 2015.) Additionally, waste management in Trinidad is handled by the Municipal Corporations while the Solid Waste Management Company Limited, a state-run limited liability company, manages, collects, treats and disposes of all wastes. In Tobago, the Tobago House of Assembly (THA), through the Local Health Authority, is responsible for the collection and disposal of solid waste. (Government of the Republic of Trinidad and Tobago, 2015).

In 2021, the Government of Trinidad and Tobago launched its new Waste Management Rules aimed to establish a legal framework to improve national waste management, including hazardous and non-hazardous waste, by requiring generators and handlers of waste to apply for and obtain permits prior to carrying out their waste-related activities (Government of the Republic of Trinidad and Tobago 2021).

According to our National Recycling Policy (2015), a 2010 waste characterization study that was commissioned by the Ministry of Local Government shows that 60% of recyclable materials were being disposed of in the four (4) major landfills (Table 1). The top two waste types were organics and plastics which account for almost 42% of the waste that goes to the four landfills. Overall, the state of waste management in Trinidad and Tobago is in desperate need of innovative ways to deal with recyclables in order to have significant positive impacts on the capacity of the existing landfills to meet the final waste disposal needs of the country.

Table 1: 2010 Waste Character study for the nation's 4 landfills (Sourced from the Waste Recycling Policy, 2015)

Type of waste	Beetham	Forres Park	Guanapo	Guapo
Organics	32.0 %	22.4 %	21.7 %	10.5 %
Paper	21.4 %	13.7 %	18.0 %	18.7 %
Glass	8.7 %	11.6 %	10.3 %	23.0 %
Metals	2.8 %	4.0 %	6.3 %	3.5 %
Plastics	16.0 %	26.0 %	19.1 %	17.0 %
Textiles	8.2 %	7.8 %	6.6 %	8.6 %
Other	1.8 %	2.7 %	5.2 %	5.5 %
Total	**90.9 %**	**88.2 %**	**87.2 %**	**86.8 %**

Plastics in Trinidad and Tobago

Trinidad and Tobago is one of the top 10 global polluters per capita in the world (Pic 1 and 2). In 2010, the average plastic waste was 0.29 kg per person per day with 1.75 million tonnes per year generated in the country (Ritchie and Roser 2018; Ewing-Chow 2019). According to a 2019 report by researchers from the Rochester Institute of Technology (RIT), Trinidad and Tobago discards up to 26,000 tonnes of PET plastics per year (Millette et. al. 2019).

Picture 1 & 2: Marine pollution in Trinidad and Tobago (right is the Diego Martin River)
Source: (Institute of Marine Affairs, 2019; Newsday, 2019)

According to a 2011 report by the Ministry of Planning and Development, organics account for over one-third of the waste dumped at the Beetham Landfill (GoTT 2011). Furthermore, the four landfills are beyond their capacities and are not designed to decompose food or other waste material (picture 3). The decomposition of organic waste produces greenhouse gases such as methane which is 72 times over that of carbon dioxide (The UWI 2012).

Picture 3: Forres The Forres Park Landfill in Claxton Bay. Photo: Trevor Watson
Source: (Express, 2019)

The Cashew Gardens Community Council (CGCC)

The CGCC is concerned about pollution and ways in which this community can reduce its carbon footprint by sending less recyclable waste to the landfills, in educating the community and endorsing waste management systems that reduce the volume of noxious greenhouse gases emitted into the atmosphere, thus contributing to a cleaner and healthier environment

The goal of this paper is to examine Community Waste Management by looking at the CGCC, a cluster-based case, within the local Trinidad and Tobago context, and to assimilate whether the findings lead to a circular economy.

This case study evaluates the impact of the CGCC's projects on waste reduction in landfills and addressing plastic pollution in the environment and climate change from landfill gases. The following will be reviewed in this discussion:

- Overview of plastic and organic waste flow locally, which will identify all the key players in this case study and where they fit into the life cycle;
- Summary of the services provided by CGCC as a driver in the plastic and organic symbiotic cluster;
- Summary of the environmental, social and economic impacts of the cluster in the following ways:
    - ➢ Environmental impact of tonnes diverted from landfill;
    - ➢ Economic impact of product and sales
    - ➢ Social impact of change of habits, youth involvement and jobs created

In order to address community waste, the CGCC implemented two important projects:

1. **Cashew Gardens Community Recycling Programme (CGCRP)**

   i). Water Quality Testing

2. **Cashew Gardens Organic Waste Project**

Cashew Gardens Community Recycling Programme

Firstly, the Cashew Garden Community Recycling Programme (CGCRP) was established in 2016 after a river cleanup initiative. Prior to the river cleanup in 2016, the CGCC partnered with the Social Justice Foundation and the Adopt a River Programme, in conducting water quality testing for two years at the Caparo watershed and 20 youths were trained. The water testing is currently ongoing on a monthly basis under the CGCRP which has been running from 2016 to present. In 2020, the programme received funding for expansion from the Green Fund Execution Unit, Ministry of Planning and Development, Trinidad and Tobago.

The river cleanup for World Rivers Day 2016 (picture 4) highlighted large amounts of waste present in the waterways, with solid waste (PET bottles) being the major contributor. The presence of this waste in the river was directly linked to flooding in the Chaguanas area and environs as seen during Storm Bret. The CGCC took the initiative and developed the country's first community based recycling programme in order to change the culture with respect to solid waste disposal, especially relating to recyclables.

Picture 4: World Water Day 2016 cleanup at Caparo river, Ravine Sable

CGCC recycling initiatives collection

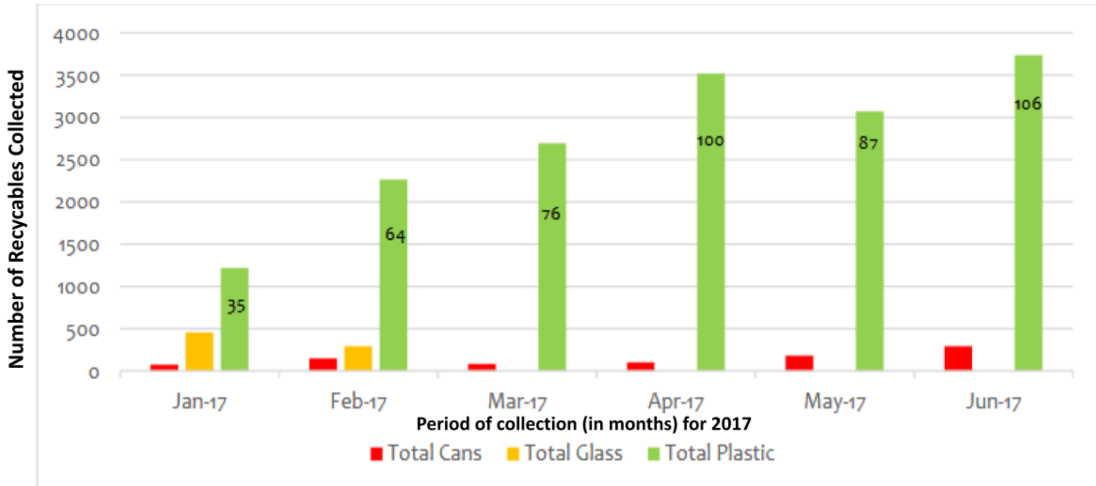
The Cashew Gardens community is part of the industrial symbiosis process and this is shown by the community collecting the recyclables and providing them to the companies that process namely Carib Glassworks Ltd, Recycling in Motion and Solid Waste Management Company (iCare collected and transported to SWMCOL). The community recycling project started with a community meeting in order to engage stakeholders. Once the community was educated, the CGCC received 8 bins which were donated by Carib Glassworks Limited (CGL) and were distributed throughout the community, mainly along street corners. The CGCC designed recycling stickers which were placed on the bins in order to make the recycling bins distinguishable.

Bags were provided by Recycling and Waste Logistics (RWL) Limited, a recycling company specializing in plastics and cans and assisted in easily distinguishing recyclables from general waste, as the bags were clear and purple in colour (picture 5). The Adopt A River Programme provided transportation, as well as, technical support in terms of how to collect the data. The bins were emptied by community members, mainly youths and members of the CGCC on a weekly basis or as deemed necessary. Over 20 volunteers came out weekly to assist, with a combination of 60% youth involvement and 40% adults of which 75% were women.The process involved the volunteers taking the bags back to the community centre, emptying them and sorting based on brands, type and colour (picture 6).

Picture 5: Bins donated by CGL, purple bags by RWL and recyclables collected by volunteers

Picture 6: Youths and CGCC members assist in community recycling, 2017

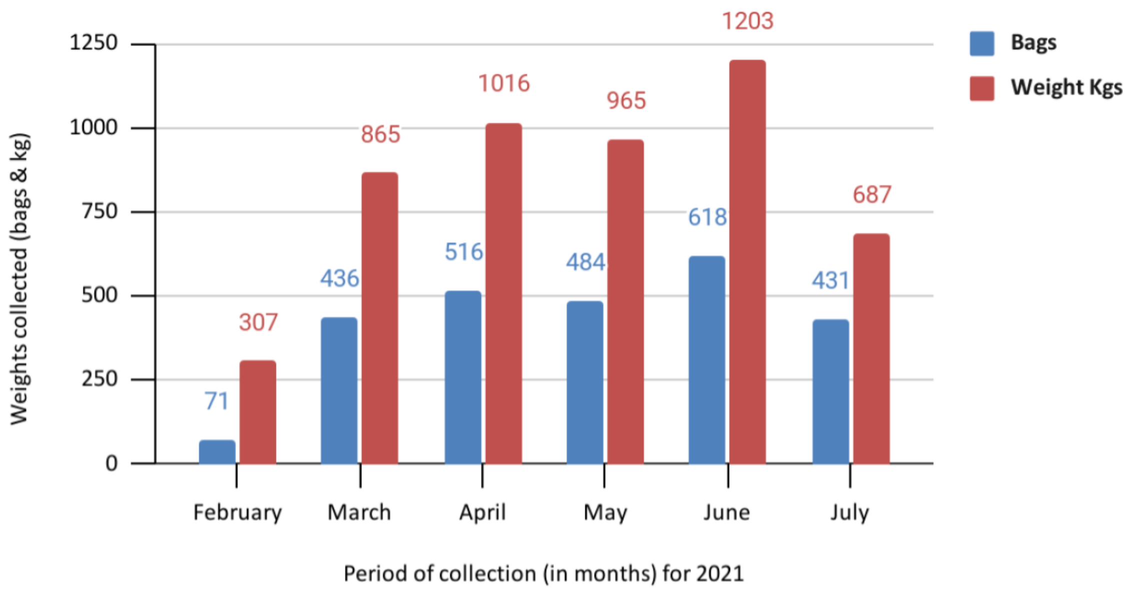
The different brands were then counted and recorded and the data compared for six months, from January to June of 2017 (Graph 1). The total number of plastic bottles and their weights increased more than twice within the six months and then leveled off gradually. **In total, within the six months, the programme was able to remove 468 kg of plastics from the environment.**



Graph 1: Total recyclables collected by the Cashew Gardens Community Council between January to June 2017

Collection continued from 2017 to 2021, however due to weight issues at the delivery site, the quantities could not be recorded until early 2021. The CGCRP has successfully diverted plastic, cans, glass and tetra packs from entering our landfills with **over 5 tonnes being recorded from February to July 2021** (Graph 2). According to our National Recycling Policy, these four waste types account for almost 40% of the waste that goes to our landfills.

Additionally, the project has also evolved from **two hundred households** that were part of the initial study, to three other communities around us, with a total of **over six hundred households** now included. **Essentially, Cashew Gardens is contributing towards the reduction of this type of waste in landfills.**



Graph 2: Recyclables collected by the CGCRP for the period February to July 2021

The items collected are sent to the Solid Waste Management Company (SWMCOL), where they are bailed and shipped to recycling facilities outside of Trinidad and Tobago (picture 7).

Picture 7: Recyclables collected by the CGCRP and taken to SWMCOL

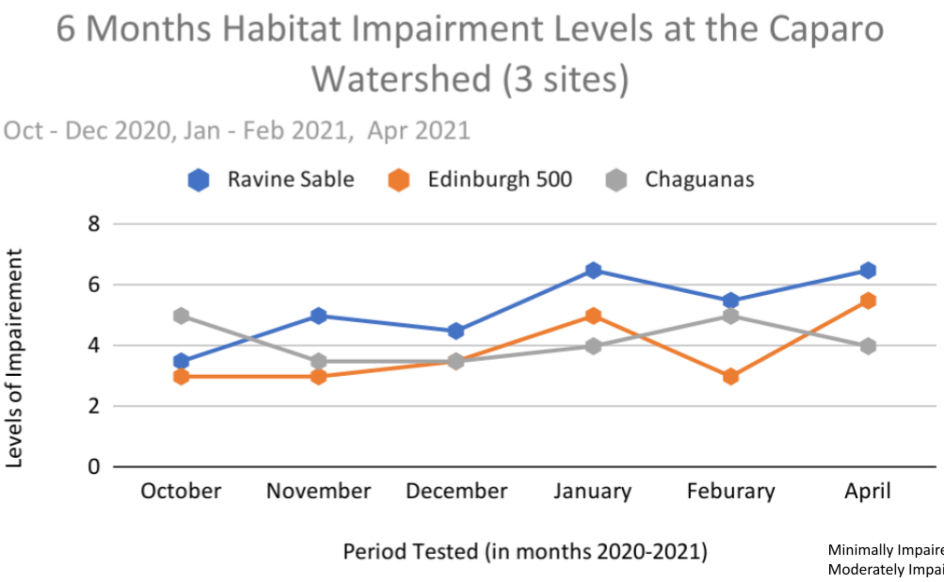
Water Quality Testing

The youths of the CGCC conduct monthly water testing at 3 sites of the Caparo river watershed (picture 7). The areas covered are Ravine Sable (Site 1), Edinburgh 500 (Site 2) and Chaguanas (Site 3). This activity was initially started in 2017 with over 20 youths in the community who were trained in carrying out water quality testing by the Adopt a River Programme (AARP). The AARP aims to build awareness concerning issues impacting local watersheds and to facilitate the participation of public and private sector entities in sustainable and holistic projects aimed at improving the status of rivers and watersheds throughout Trinidad and Tobago (AARP, n.d).

The monthly data is uploaded on the AARP app which is shared with the Water and Sewerage Authority. Prior to 2020, the entire activity was carried out by volunteers however, upon receipt of funding by the Green Fund, **these volunteers are now integrated into CGCRP and continue to conduct testing on a monthly basis.**

Picture 7: Members of the CGCRP team conducting water quality testing at the Caparo River

Based on the data shown on Graph 3, the habitat impairment levels at Site 1 were severe while Site 2 and Site 3 were at moderate levels. This data was taken over a period of six months and started between the wet season into the dry season. It should be noted that there was insufficient data to analyze the reasons for the severe impairment levels at the Ravine Sable area and testing was restricted due to pandemic constraints.



Minimally Impaired: 0 - 1.5
Moderately Impaired: 1.6 - 4.4
Severely Impaired: above 4.5

Graph 3: Habitat Impairment levels of the Caparo watershed

Cashew Gardens Organic Waste Project

The second project addresses organic waste (OW) which is the largest waste type that is sent to the four landfills at 22%. The Cashew Gardens Community Composting initiative involves community collection and processing of organic waste to create fertilizer, which is used in the community garden (Picture 8). This project was funded by the GEF Small Grants Programme, which began in August 2020, and is the first of its kind in the country. It was introduced as a pilot project involving 16 households with an average collection of over 160 kg of organic waste in a 3 month period, from October to December 2020. This yielded an average of 22.5 kg of compost for this period.

The composting programme involved a train the trainer model where five CGCC members were trained in composting at Wa Samaki Ecosystems. Initially, the training was planned with 16 participants on a face to face basis but this changed due to the Covid-19 pandemic and Government restrictions on gathering in public spaces in large numbers.

Picture 8: Volunteers and members of the CGCRP team engaging in community composting activities

By utilizing social media tools such as Whatsapp and Facebook, the CGCC was able to successfully engage 16 households in sorting their organic waste at the household level. The funding for the project ended in December 2020 but the CGCC continued with the aid of volunteers. The volunteers consisted of youths and adults with the former being between the ages of 11 to 22. Female volunteers were significantly higher at 70%. In 2021, the project grew to over 20 households and collected an average of **490 kg of organic waste for a period of nine months,** from October, 2020 to June, 2021. This yielded compost material for use in gardening of approximately 66 kg. **The CGCC is contributing to the reduction of this type of waste in the landfills.**

The key points in the success of both recycling programmes were the easy accessibility of bins and the weekly collection of recyclable waste. In 2021, a sample survey of 20 households was conducted with an average of **80% of respondents confirming that they recycle and compost which shows a significant increase of 90% from 2017.**

Observations were made by participants that persons outside the Cashew Gardens and environs have dropped off recyclables in the community bins while others reported that more households needed to join the recycling effort.

The survey conveyed that an average household had four to five persons who were aware of the recycling and composting programmes with participation at 90% and 75% respectively.

Evidence has shown that the combination of community recycling and composting has contributed to a 1% reduction of Cashew Gardens waste in landfills. Subsequently, the replication of this project in other communities can result in a measurable reduction of recyclable waste in the landfills (Figure 1). As a SIDS, land for landfilling is limited and hence, this is an important contribution for this reason as well.

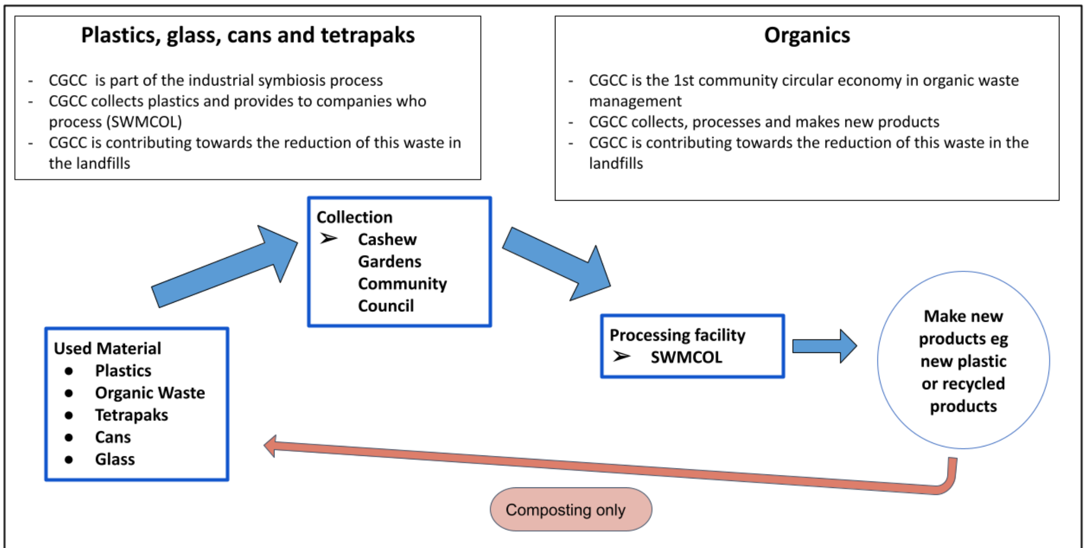


Fig. 1. Process of the CGCC's contribution to reduced waste in landfills

Social, Economic and Environmental benefits of the CGCC

According to the World Bank's ***What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*** report, without urgent action, global waste will increase by 70 percent on current levels by 2050. Plastics are a major problem and without proper management they will contaminate waterways and ecosystems for hundreds, if not thousands, of years (World Bank 2018). A review of the economic, social and environmental impacts of the CGCC's programmes is explained in relation to reduced waste being sent to the nation's landfills.

One of CGCC's purposes is to implement a good waste management system to help build a circular economy so that products are designed and optimized for reuse and recycling. On an economic purview, innovatives ways are being used to process the organic waste and create products for sale; social impact speaks of change in behaviour of communities and jobs created; and environmental impact is the tonnes of recyclable waste diverted from landfills. Additionally, the CGCC is exploring options for repurposing the recyclables collected in the community recycling programme. The following highlights smart and sustainable ways the CGCC is managing waste so that economic growth is promoted with minimal environmental impact.

The aim is to create smart and sustainable ways to manage waste that will assist in promoting efficient economic growth while minimizing environmental impact.

1. **Economic:**
   I. Savings in terms of organic waste being used in the garden for instance using compost as fertilizer and saving on average $1,500 USD per year (figure 2);
   II. Producing compost for sale ($7 USD per bag) with an average yield of 490 kg;

III. Reduced cost of waste processing by SWMCOL of at least 1% with the possibility of increased reduction if programmes are replicated in other communities.

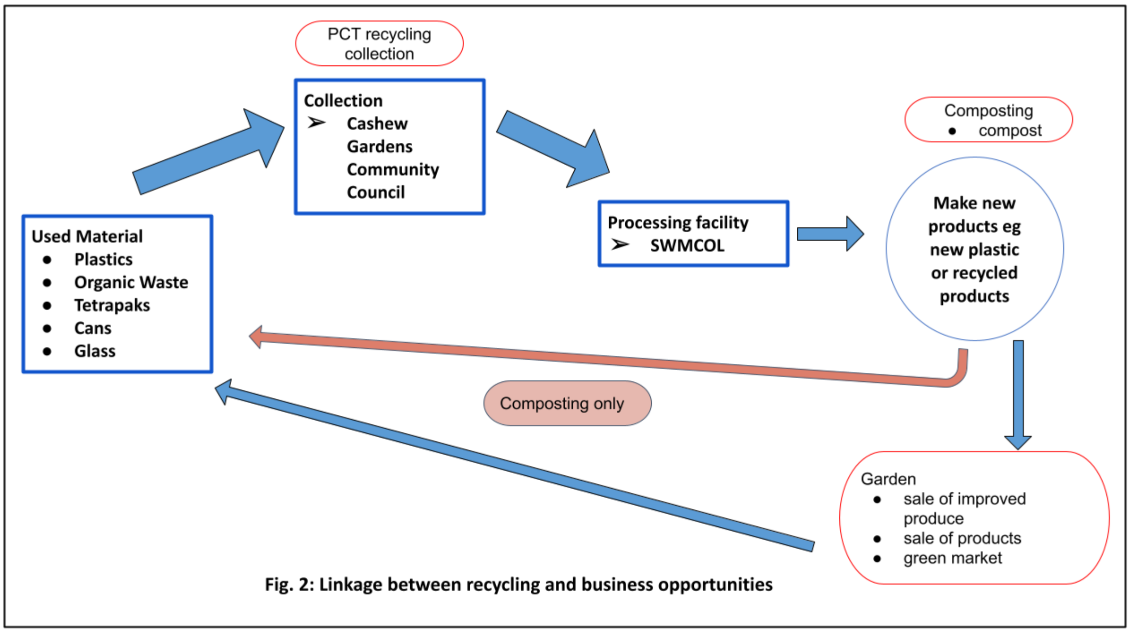


Fig. 2: Linkage between recycling and business opportunities

2. **Environmental:**

I. The CGCRP grew by 90% in 2021 with over 5 tonnes of recyclables being diverted from landfills;
II. Over 490 kg of organic waste collected by the CGCC and was prevented from ending up in landfills in a 9 month period from 20 households;
III. Participated in over 20 environmental events, over 8 beach and river cleanups, and mangrove tree planting.

3. **Social:**

I. Conducted over 10 educational and awareness session at schools and other organisations throughout the country;
II. Participated twice in the United Nations Commission on the Status of Women (2018 and 2019) and shared recycling projects;
III. Created an avenue for social sharing at the homework and activity centre and community climate smart garden with 10 women and 20 youths consistently volunteering;
IV. Jobs created for more than 10 persons in the community and more jobs expected as the projects expand;
V. The overall trend in terms of total recyclables collected indicate that there is an increase in the amount of recyclables collected per month. This is evidence that there is a change in behaviour within the community since they are not putting their recyclables in general waste and are instead, sending them to be recycled. There is strong evidence that this change in behaviour was influenced by the youths.

The CGCC is fundamental to the success of waste management in Trinidad and Tobago and is a vital part of the industrial plastic cluster. If similar projects can be replicated in other communities then a significant amount of waste can be diverted from landfills. Furthermore, the CGCC is directly contributing to the country's 2030 UN Sustainable Development Goals (SDGs) 1[1], 2[2], 4[3], 6[4], 13[5].

In summary, the recycling programmes initiated by the CGCC are examples of key waste management systems that are needed in every community in Trinidad and Tobago. There are opportunities for profitable activities in recyclables (inorganic and organic waste) which can directly reduce the amount of waste for disposal, save space in landfills, and conserve natural resources. These two areas, plastic pollution and greenhouse gases in landfills, are two major environmental issues locally.

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[1] SDG Goal 1: No Poverty - End poverty in all its forms everywhere;

[2] SDG Goal 2: Zero Hunger- End hunger, achieve food security and improved nutrition and promote sustainable agriculture;

[3] SDG Goal 4: Quality education- Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;

[4] SDG Goal 6: Clean water and sanitation - Ensure availability and sustainable management of water and sanitation for all;

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Onsite Wastewater Management Programme in the Cayman Islands
Where did we come from, where are we now, and where are we going?

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Abstract
In the Cayman Islands, like many other jurisdictions in the Caribbean, a substantial proportion of wastewater is treated by onsite systems. A recent review for PAHO estimated that 23% of the population is connected to the central sewage system and 77% relies on onsite treatment systems, consisting of aerobic treatment units (23%), septic tanks (50%) or no form of treatment (less than 1%). The Water Authority of the Cayman Islands is tasked with the regulatory oversight of onsite wastewater treatment and disposal. The paper titled *Onsite Wastewater Treatment: Here to Stay, How to Manage?* presented by Catherine Crabb at the 2003 CWWA conference reviewed the challenges and opportunities of developing the Onsite Wastewater Management Programme (OWMP) in the Cayman Islands. At the 2009 CWWA conference the same author presented the paper *Performance Assessment of Onsite Wastewater Treatment Systems in the Cayman Islands,* this paper showed that for a variety of reasons many onsite systems were not performing to their design standard.

This paper provides an update of the 2003 and 2009 presentations. The challenges and opportunities of onsite wastewater treatment in the Cayman Islands are repeated throughout the Caribbean region, with regulatory oversight being exercised by relatively small agencies with limited staff and resources. The Water Authority's OWMP has evolved recognizing that onsite wastewater treatment will remain the most practical and viable solution in many areas in the Cayman Islands for wastewater management.

The Authority continues to assess the effectiveness of its OWMP resulting in ongoing evolution and improvement of the programme. The OWMP relies on a strong partnership between the Authority, property owners and private sector service providers. It is supported by software to manage relevant data. The Authority has an accredited laboratory that conducts water and wastewater testing. The programme is supported by an in-house developed training and education programme for service providers, property owners and certification of wastewater technicians. Whereas the OWMP has addressed many challenging issues, there remains a need to further develop it in response to new challenges and ongoing rapid development in the Cayman Islands.

Keywords
Wastewater Treatment, Onsite Wastewater Treatment, Onsite Wastewater Management Programme, Cayman Islands, Caribbean

Onsite Wastewater Management Programme in the Cayman Islands
Where did we come from, where are we now, and where are we going?

1. Introduction

In the Cayman Islands, like many other Caribbean jurisdictions, a substantial proportion of wastewater is treated by onsite systems. The Cayman Islands Government has the strategic objective to expand the existing public sewerage system[1], however this will take significant resources and the reality is that for the foreseeable future the Cayman Islands will rely on onsite wastewater treatment. As a result, the Water Authority of the Cayman Islands will continue to carry out its role to manage and regulate onsite wastewater treatment as it is charged under the Water Authority Act and Regulations, enacted in 1982 and 1985[2] respectively. This role is primarily exercised by the Water Resources and Quality Control Department of the Water Authority of the Cayman Islands.

Other Caribbean nations face similar challenges as the Cayman Islands, such as rapid expanding urban populations, poorly planned development, inadequate or poorly designed and malfunctioning sewage treatment facilities and limited resources to manage these challenges[3]. It is realistic that onsite wastewater treatment is a long-term option in the Caribbean, rather than a transitionary solution until central sewerage has been expanded to provide overall coverage. Therefore, each jurisdiction will have to continue developing its own programmes and strategies to manage and optimize onsite wastewater treatment. Since inception of the Water Authority in 1982, it has done so and its Onsite Wastewater Management Programme (OWMP) has evolved and developed over the years. The aim of this paper is to share the experience of the Cayman Islands and to provide a follow up of earlier papers presented by Catherine Crabb at the annual 2003 and 2009 Caribbean Water and Wastewater Association conferences that discussed the evolution of the Water Authority's OWMP[4, 5].

2. Country profile of the Cayman Islands

The Cayman Islands are located in the Caribbean, south of Cuba and west of Jamaica. The Cayman Islands consist of 3 islands: Grand Cayman, Cayman Brac and Little Cayman, refer to figure 1[6]. The vast majority of the population is located on Grand Cayman (97.4%)[7]. The population at the end of 2020 was estimated at 65,786, this was a reduction of 6% from the end of 2019[7], likely caused by the impact of the coronavirus pandemic that resulted in significant job losses in the tourism sector.

Figure 1 **Map of the Cayman Islands**

The main source of the country's income is derived from off-shore financial services and tourism. Despite impacts from severe storms such as hurricane Ivan in 2004 and hurricane Paloma in 2008, the global financial crisis in 2008 and the current pandemic, the population of the Cayman Islands continues to grow rapidly as illustrated in figure 2[7].

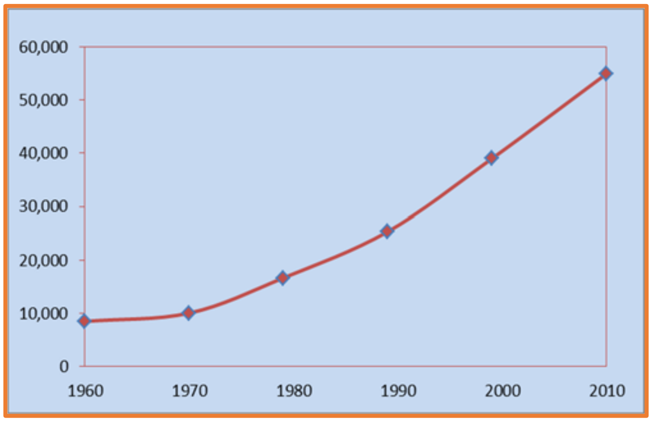

Figure 2. Cayman Islands Population, based on Census data 1960-2010

The 3 islands are formed of carbonate rock through successive deposition erosion cycles over the last 30 million years. Due to the karst terrain and highly porous bedrock there are no rivers. Both Grand Cayman and Little Cayman have limited elevation with many developed areas being less than 10 ft above mean sea level, both islands have extensive wetland areas. Cayman Brac has more elevation and is dominated by the Bluff, a limestone outcrop that reaches 140 ft above sea level in the eastern part of the island. The coast of the three islands are generally protected by offshore reefs and in some places by a mangrove fringe that sometimes extends into inland wetlands[8].

3. Development of the Onsite Wastewater Management Programme

The Water Authority Act and the Regulations[2] provide the framework for the water and wastewater sector and management and protection of groundwater. The Water Authority, established in 1982, is a Statutory Government Authority, 100% owned by the Cayman Islands Government and governed by the Water Authority Board, appointed by Government. The key tasks and duties of the Authority are summarized in figure 3.

Key Tasks and Duties of the Water Authority

- Establish public piped water supply in areas where it is feasible (water utility);
- Establish general sewerage scheme in areas where it is feasible (wastewater utility);
- Manage and protect groundwater (environmental and public health);
- Principle advisor to Government on matters relating to water supply, sewerage and protection and management of groundwater (advisor to Government); and
- Regulator of onsite wastewater collection, treatment and disposal (regulator).

Figure 3. **Role of the Water Authority**

The Water Authority developed the central wastewater system in the late 1980s. The West Bay Beach Sewerage Scheme (WBBSS) collects wastewater from the heavily populated tourism West Bay Beach Area and treats it at the Sequencing Batch Reactor Wastewater Treatment Plant. The impetus to develop the WBBSS was the concern that the majority of onsite treatment systems of the hotel and condominium complexes was performing poorly, thus affecting marine water quality of the West Bay Beach Area. The area not served by the Authority's central wastewater system relies on onsite wastewater treatment systems, consisting mainly of septic tanks (STs) and aerobic treatment units (ATUs). Refer to figure 4 for the area served by the central system and onsite systems respectively. With no significant industrial activities in the Cayman Islands the nature of wastewater is predominantly domestic.

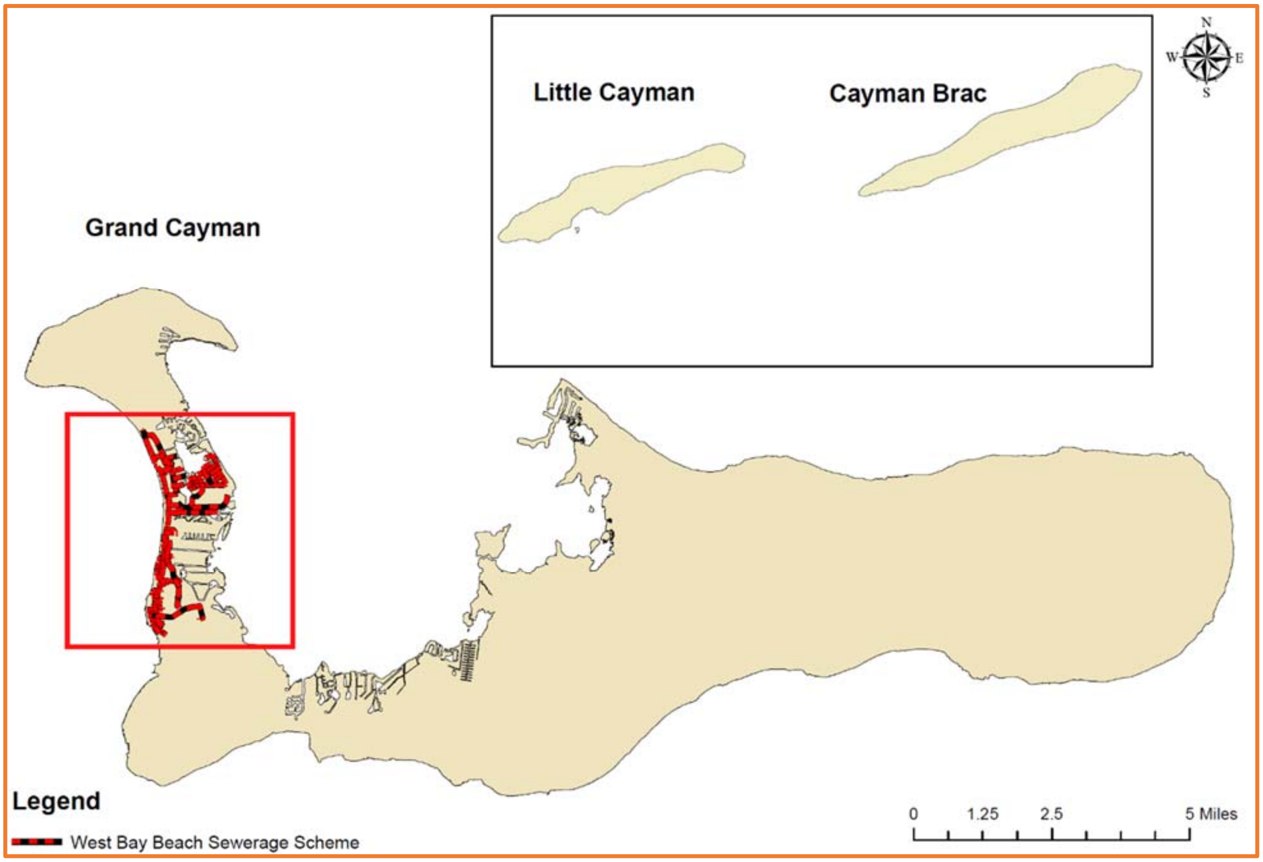

Figure 4. **Cayman Islands – Central wastewater collection system (WBBSS, inside red box) and onsite wastewater treatment systems (outside of red box).** *Lands and Survey Department © Cayman Islands Government 2021 All Rights Reserved. Source: www.caymanlandinfo.ky. Portions of this figure include data of the Cayman Islands Lands and Survey Department and are used herein by permission.*

In December 2020 the Water Authority reviewed and updated its statistics for wastewater treatment for the Pan American Health Organization (PAHO) and estimated that 23% of the population is connected to the central sewage system and 77% relies on onsite treatment systems, consisting of aerobic treatment units (total 610 systems, treating 23% of all wastewater), septic tanks (estimated 17,700, treating 50% of all wastewater) or no form of treatment (less than 1%). These figures are similar to the estimate provided by Catherine Crabb in 2003[4]. The 2020 review also estimated the performance of the various treatment systems in respect of meeting the effluent criteria of the Water Authority Regulations[2]. These are a maximum of 30 mg/l Biochemical Oxygen Demand (BOD) and 30 mg/l Total Suspended Solids (TSS), typically referred to as the 30/30 standard. A summary of the data provided to PAHO is presented in table 1. The performance data of onsite systems is similar to the estimate provided by Catherine Crabb in 2009[5].

Table 1. **Current status of wastewater treatment in the Cayman Islands by treatment system, treatment type, volume and meeting the 30/30 standard of the Water Authority Regulations**.

Treatment System	Treatment type	Volume (mgd)	Volume (%)	Meets 30/30 standard (mgd)	Meets 30/30 standard (%)
WWTP	secondary	1.2	23	1.2	23
ATU (onsite)	secondary	1.4	27	0.4	8
ST (onsite)	primary	2.6	50	0	0
none	n.a.	0	0	n.a.	n.a.
Total		**5.2**	**100**	**1.6**	**31**

Notes: WWTP = Water Authority Wastewater Treatment Plant that receives wastewater from the WBBSS

ATU = onsite Aerobic Treatment Unit

ST = Septic Tank

mgd = million US gallon per day

The paper presented by Catherine Crabb at the 2003 CWWA conference[4] provided a comprehensive overview of the OWMP and the plans for further development of the programme, based on the guidance of the United States Environmental Protection Agency for development and managing onsite systems. The Water Authority has followed this guidance and adopted it to the Cayman Islands' specific situation. The paper presented by Catherine Crabb at the 2009 CWWA conference[5] discussed the performance of ATUs, following the Water Authority's comprehensive testing programme of BOD and TSS of effluent of ATUs and septic tanks. The study confirmed that effluent from septic tanks did not meet the 30/30 standard, this was no surprise as septic tanks provide primary treatment only. It also found that the majority of ATUs did not meet the required effluent criteria, only 13% met the criteria. The OWMP has been developed further and refined to address the performance of ATUs and in response to the continued development of the Cayman Islands. The rapid development of the Cayman Islands has resulted in additional impacts on the environment, consequently requirements for new development have become more complex and advanced.

Table 2 provides an overall overview of the evolution of the Water Authority's OWMP over the various decades from 1980 to current. Details of these key elements are briefly discussed further on in this paper, but given the scope of this paper the review is of a cursory nature. At this stage the focus of the OWMP is on improving the performance of ATUs as these systems provide secondary treatment and are capable of meeting the 30/30 standard, provided they are operated and maintained properly.

Table 2. **Development of the key elements of the Water Authority Onsite Wastewater Management Programme, 1980 - current**

Element	Description	1980-1990	1990-2000	2000-2010	2010-current
Enabling Legislation	Water Authority Act and Regulations	Enacted in early and mid-1980s	No major changes	No major changes	No major changes
Onsite treatment system requirements	Septic Tanks (ST)	Sizing based on daily flow	No major changes	No major changes	Additional technical and installation details
	Aerobic Treatment Units (ATU)	No requirements	Basic requirements	• ATU to have NSF or equivalent approval • Approved installers	Additional technical and installation details
	Onsite Pumping Stations	No requirements	Basic requirements	Basic requirements	Additional technical and installation details
	Effluent Disposal Wells	Basic specifications for casing and grouting	No major changes	No major changes	Site specific minimum casing length Wells to be grouted Well logs required
New development	Requirements for new development through the Planning Process	Basic requirements	• ATU if WW flow > 1,800 gpd • ST if WW flow < 1,800 gpd	Additional technical specs	Advanced technical specs O&M contract required for ATUs
Inventory of onsite systems	Inventory records of onsite systems	No records	Excel spreadsheet	• GIS based inventory • Dedicated software	• Improved GIS based inventory • Dedicated software further developed
Inspections by WA staff	New installations	none	none	• ATUs: inspected • ST: not inspected	• ATUs: detailed inspections • ST: inspected if development exceeds duplex
	Existing installations	none	none	Complaint based	• Complaint based • Periodic for representative systems
O&M records	Tracking of O&M of onsite systems	none	none	• Introduction of web-based database for ATUs • Database used by WA to track performance of ATUs	• Service providers required to enter O&M records in web-based database • Database used by WA to track performance of ATUs • Data available to owners/developers/service providers

Table 2. continued

Element	Description	1980-1990	1990-2000	2000-2010	2010-current
Effluent testing	Testing of BOD and TSS by WA Laboratory	none	occasionally	• 2005 Lab accredited for BOD and TSS • Sampled representative systems • All ATUs tested in 2008	• Sampled representative systems • Complaints • When requested by system owner/developer
Public outreach	Education and outreach for owners and developers	Basic information	Basic information	• Website developed • Periodic media campaigns	• Detailed information on website • Periodic media campaigns • Social media
Service providers	WA interaction with service providers who install and maintain onsite systems	No specific activities	Reactive: Review of systems when installation is completed	Proactive • Develop education materials and outreach for service providers. • Detailed website	Proactive • Registered service providers • Training and CEU for service providers • Website further developed
Staffing	Water Authority staff dedicated to OWMP	None	Partial position combined with Engineering	2 Full time staff: 2 Development Control Technologists Part time: Lab staff and Water Resources staff	4 Full time staff: 1 Senior Development Control Technologists 1 Development Control Technologist 1 Trainer/Inspector 1 Inspector Part time: Lab staff and Water Resources staff
Enforcement	Intervention in case of violation of Law	Complaint-based	Complaint-based	• Complaint-based • Enforcement notices	• Complaint-based • Enforcement notices

Enabling Legislation

The relevant sections relating to the requirements for onsite wastewater treatment in the Water Authority Act and Regulations have not substantially changed since they were originally enacted in the 1980s[2]. They provide the Authority with a comprehensive framework to perform its task as regulator. There is currently no need for revision of the relevant parts of the Act and Regulations.

Onsite treatment system requirements

Requirements for onsite systems have been refined over the years, especially requirements for ATUs. The Authority only accepts ATUs that have NSF/ANSI Standard 40 or equivalent certification[9]. This certification ensures that the system is capable of meeting the 30/30 standard. ATUs need to be installed by a registered service provider; this is important to ensure that the system is installed per manufacturer's requirements. Registered service providers have a working relation with the system manufacturer and serve as the local representatives. An example of how the Authority ensures that the registered service provider can provide adequate service is by requiring them to maintain an on-island inventory of critical spares. The Authority's specifications for ATUs have advanced over the years, for instance when a new ATU is installed the proponent has to provide installation details for approval by the Authority, before the system is installed.

Requirements for new development

The Cayman Islands Central Planning Authority supported by the Planning Department decides on proposed new development[10]. Part of the Planning review process for proposed development consists of incorporation of the Water Authority's requirements for wastewater treatment. If the development is within the area served by the central sewerage system (WBBSS, refer to figure 4), the development is required to connect to the system. All other development will have to provide onsite treatment that meets the Authority's requirement. Septic tanks are allowed for developments that generate wastewater up to 1,800 gpd. All development generating over 1,800 gpd wastewater is required to install an ATU. Where applicable pre-treatment such as a grease trap for restaurants has to be installed. In the event non-domestic wastewater is generated a wastewater treatment system that is adequate for the specific waste will have to be installed. In some instances where onsite treatment cannot adequately treat the specific waste, the waste has to be trucked to the central wastewater treatment plant (e.g. brewery and slaughterhouse waste). The Authority provides detailed specifications and installation requirements for ATUs, septic systems, pumping stations and effluent disposal wells. Upon approval of the system proposed by the developer, the Authority follows up with inspections during the construction and installation process. ATUs have to be installed by registered service providers.

Inventory of onsite systems

A GIS-based system (Geographical Information System) is maintained of all ATUs, this is important to track and geo-reference the systems to ensure that when different staff, service providers and owners/developers are dealing with the ATU they refer to the same system. The GIS system also includes relevant details such as make, capacity, well details, pumping station details etc. and is tied in to the database used that manages all information on ATUs.

Inspections by WA staff

Inspections are carried out at critical stages of the installation process for new systems to ensure that it is installed correctly. In addition, staff conducts periodic inspections of systems that are known to have performance issues. In the event a complaint is received staff will conduct an inspection to determine whether the complaint is justified and what the root cause is of the complaint. Where necessary any issues are followed up with the owner/developer and service provider. In response to continued development in the Cayman Islands, the Authority is in the process of employing a full-time onsite wastewater treatment system inspector.

O&M records

Initially record keeping of onsite systems was done in Excel spreadsheets, these were adequate as long as the number of onsite systems and related data was limited, however as the number of systems and data increased the tracking and analysis of information became unmanageable. About 15 years ago the Authority obtained the Carmody database http://www.carmodyuk.com, this is a dedicated database established by a software provider to track all ATUs in the Cayman Islands. For each ATU all relevant information is included to manage and track the system. Service providers are required to enter their standard service O&M reports in the database so there is an ongoing and up to date record of each system. This information is analysed by the Authority on a continued basis. The information is also available to the owner/developer of the system. Over the years the company has customized the database for specific use in the Cayman Islands. A few years ago, the software was improved with an application that facilitates entering O&M data in the field on a mobile telephone. This eliminated the process of filling out forms in the field and transferring this information later on in the office on a computer.

Effluent testing

The Water Authority Laboratory obtained accreditation from the American Association for Laboratory Accreditation in 2002. The accreditation provides independent confirmation that the tests conducted by the Laboratory are reliable, accurate and meet international standards. In 2005 the Laboratory obtained accreditation for BOD and TSS, this ensured that the Laboratory's analytical results of effluent tests are reliable. Testing is conducted on an as needed basis; it provides evidence whether wastewater treatment systems are, or are not performing adequately. The Laboratory also conducted the testing of ATUs that formed the basis of Catherine Crabb's 2009 paper[5] discussed earlier in this paper.

Public outreach and education

Advancing the OWMP is a partnership between the Water Authority as the regulator, service providers who install, operate and maintain onsite systems and homeowners/developers who own the systems. Communication on the OWMP targets service providers and owners/developers to ensure that all stakeholders are engaged. The Water Authority's website has a specific section dedicated to the OWMP https://www.waterauthority.ky/onsite-wastewater-systems. The website includes information specific to onsite treatment in the Cayman Islands, including manuals, application forms and technical brochures. Although generic and general information on onsite wastewater treatment can be found anywhere on the Internet, it is important that the information on the Water Authority's website is specific to the Cayman Islands and that it is up to date.

Registered service providers

The Authority has developed a register of service providers to ensure that when the public deals with a service provider they engage with a business that meets the minimum standard of the Authority. Service providers need to have at least one registered certified technician on staff. This certification is obtained by completing the Authority's training courses for onsite wastewater treatment and successful completion of the exam administered by the Authority. Registered service providers are granted access to the database where they are required to register O&M records. As discussed earlier new ATUs can only be installed by registered service providers. In the event a manufacturer of an ATU wants to introduce a new system in the Cayman Islands, he will have to create a partnership with a local registered service provider. This approach ensures continuity of O&M and service once a new system is installed.

Staffing

The number of staff in the Water Resources and Quality Control Department who deal with the OWMP has increased over the years in response to the growing needs of the OWMP and soon it will consist of 4 full time staff members. The Senior Development Control Technologist is responsible for the overall OWMP and programme development, the Development Control Technologist conducts the ongoing reviews of proposed development, the Onsite Wastewater Trainer-Inspector conducts inspections of systems and provides training to service providers. The Onsite Wastewater Inspector, who will be employed shortly, will focus on inspections of onsite systems. Other departmental staff provide support to the OWMP in combination with other functions they carry out for the Authority.

Enforcement

In the event of malfunctioning systems or systems in disrepair where the responsible entity is not prepared to take corrective action, the Authority issues a Notice of Violation, outlining the required actions. Also, where appropriate the Authority liaises with the Department of Environmental Health, which under the Public Health Act can issue an Abatement Notice for situations that pose a threat to public and environmental health. Usually these notices result in some form of response by the responsible party, be it that in some circumstances the issues are not resolved and in that instance the matter is referred to the Attorney General for resolution through the legal system.

4. Next steps

The OWMP will continue to develop with the needs of the Cayman Islands. With substantial development outside of the area served by the central wastewater system, there is a need for continued review and improvement of the OWMP. The approach will continue to be data driven and evidence based.

Review criteria for allowing septic tanks

A concern is that septic tank systems provide inadequate treatment to meet the 30/30 standard, therefore the Authority will evaluate the threshold for requiring septic tanks. The requirement for septic tanks for new development generating less than 1,800 gpd wastewater will be revisited. Consideration is given to a lower threshold than the current 1,800 gpd wastewater for development. In addition the threshold may be based on the density of the development, as the Planning Department has allowed higher densities over the years. Narrowing the criteria for allowing septic tanks and requiring ATUs instead may result in push back from developers as the associated cost for ATUs in comparison to septic tanks are substantial. The onus will therefore be on the Authority to justify and explain the advancement of these requirements.

Ensure that ATUs are meeting effluent standards

As discussed in Catherine Crabb's presentation at the 2009 CWWA conference[5], ATUs do not meet the 30/30 effluent standard if not operated and maintained properly. Since these findings in 2009 the Authority has improved the OWMP with the registration of service providers, certification of technicians and employing the Onsite Wastewater Trainer-Inspector. Technical specifications and inspections during the installation process of ATUs have also advanced. Inspections of existing systems will improve with the employment of the Onsite Wastewater Inspector. Continued public education and continued training of technicians will be essential to improve the performance of ATUs. Also, the Authority will promote the use of service contracts to ensure that ATUs are adequately serviced on a regular basis.

Expansion of the central wastewater system

Where technically and financially feasible the Authority's central wastewater system will be expanded. Given that certain areas of Grand Cayman are urbanizing at a rapid pace, it will be prudent to expand the central system to these areas rather than installing onsite systems. For practical reasons onsite systems have always been approached on an individual property basis, rather than on a community basis. However, the option of decentralized systems serving particular communities will need to be considered.

Energy use by onsite systems and impacts of climate change

Most ATUs require substantial energy to operate blowers, pumps and other mechanical equipment. Developers typically do not consider the specific energy use of an ATU and mainly consider the capital cost to install a system rather than both capital and operating cost. This is an area for improvement and owners/developers will be encouraged to review the energy cost to operate the systems rather than capital cost only.

The impact of climate change on the Cayman Islands has been given limited consideration so far. An issue of significance to the Cayman Islands is the prediction of the rise in sea level; this will impact many areas in the Cayman Islands that have limited elevation. At this stage the entire planning and development process in the Cayman Islands pays limited attention to climate proofing existing and new development for the anticipated sea level rise. The Water Authority will address this issue by revisiting the minimum elevations of onsite systems so that these systems will adequately function for years to come.

5. Conclusions

In the 40 years since the Water Authority was established it has advanced the Onsite Wastewater Management Programme in accordance with its mandate under the Water Authority Act to regulate onsite wastewater collection, treatment and disposal. During that period the Cayman Islands has seen substantial growth in population, effectively tripling the population since the early 1980s. Given the significant expense and resources to develop the central wastewater system, about three quarter of all wastewater generated in the Cayman Islands is treated by onsite treatment systems. Aerobic Treatment Units treat approximately a quarter of all wastewater generated in the Cayman Islands and about half is treated by septic tank systems.

The Authority has developed all elements of its Onsite Wastewater Management Programme, initially it has placed the emphasis on the installation and performance of Aerobic Treatment Units (ATUs), but the installation and performance of septic tanks systems are now considered as well. The various elements of Programme have been developed in response to data and evidence collected by the Authority. Over the years the Authority has made additional resources available to manage the Programme and intensified its interaction with stakeholders: service providers who install and maintain onsite systems and owners/developers who own the systems.

It is a given that a significant portion of wastewater generated in the Cayman Islands will continue to be treated by onsite systems. Therefore the Authority will continue to develop the Programme.

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