CLUSTER SCALE DECENTRALIZED WATER MANAGEMENT SYSTEM IN SINT MAARTEN

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ABSTRACT

Water is one of the long-standing problems in Sint Maarten. Water supply is scarce while water demand is high. Water pollution and incomplete infrastructure also needs to be tackled. How can a cluster scale decentralized water management system solve water challenges in the hurricane-prone environment of Sint Maarten is the research question. This paper answers this question from the following aspects. First, an analysis of existing water consumption amounts, water management systems, and water flows. Second, a case study of water management systems in other countries and regions, combined with a literature review to analyze how each system works. Third, develop a set of evaluation systems and analyze and evaluate each case. Then choose a new water management system for the Sint Maarten.

KEYWORDS: *Decentralized water management system; circular housing cluster; water supply; greywater purification; wastewater treatment; assessment standard.*

I. INTRODUCTION

The Sint Maarten is an island in the northeast of the Caribbean. In the twentieth century, local tourism began to flourish, and immigrants caused a rapid increase in population in the region[1].The current population is 40913, with an average annual growth rate of 0.95%. Hurricane Irma hit the island in September 2017, hitting the houses, infrastructure and economy. The reconstruction has been carried out so far, and the situation on the island has yet to be restored.

The water issue is one of the long-standing problems in Sint Maarten. Resources are scarce because of the limited land area. The expansion of the city and the surge in the tourist population have placed a huge burden on the water supply. Many groundwater wells have been unable to provide daily water use due to high salinity. Seawater desalination has become the main source of fresh water on the island. Meanwhile, the proportion of water pollution remains high while the management strategies are not optimistic. Dilapidated and incomplete infrastructure needs to be upgraded. Hence, the water challenge that Sint Maarten has to deal with is very serious.

1.1 Isolated island --- Lack of resources

The area of Sint Maarten is 34km^2. Almost all food, energy resources and manufactured goods are imported. Because of urban expansion, renewable resources such as clean water and wood have become scarce due to over-exploitation. There is now a scarcity of drinking water on this island while the demand is quite large. The demand of the local population and the influx of tourists during the dry season have created a huge demand for fresh water[2]. Drinking water supply of Sint Maarten has been

[1] Andel, J. (1986).Caribbean traditional architecture. 1st ed. Leiden: Koninklijk Instituut voor taal-, land en volkenkunde, Caraíbische afdeling.
[2] Saif, S. (2010).Environmental profile of St. Martin's Island. 1st ed. [ebook] Research Gate.

increased by 60 m^3 a day[3] for the whole island.

Seven Seas Water which is a company to provide desalination technique can produce about 26119 m^3 water per day, while they can barely meet the demand for fresh water in Sint Maarten. Deforestation and large scale expansion of agriculture have adversely impacted the groundwater level of the island. And groundwater salinity is too high to be used due to soil erosion and pollution. Rainwater harvesting has not been widely used by residents as an effective method, and it is not possible to collect enough rainwater during the dry season due to the small amount of rainfall.

1.2 Bad water infrastructure --- High pollution risk

There is still a lack of complete water infrastructure in Sint Maarten. The dilapidated and aging drainage has caused many pollution problems. In many areas, people directly dump the untreated sewage into open ditch and drainage which are directly connected to rivers. As the rivers pass through the residential areas, including many that are not connected to urban sewage system, they become contaminated. Urban storm water runoff and resulting flash flooding are a persistent problem, partly from bad drainage system and increased coverage of areas with impervious surfaces[4].

Furthermore, the unsound sewage system results to pollution. Sewage is the main source of nitrates. Sewage enters waterways in inadequately treated wastewater from sewage treatment plants, in the effluent from illegal sanitary sewer connections, and from poorly functioning septic systems. According to a test of the water quality, the highest level of nitrates was recorded in the Great Salt Pond at 0.7 ppm, which is a relatively high number. A test also showed that water samples from the inshore zone of Sint Maarten were contaminated with fecal coliform bacteria up to 6 cfu/100 ml. This is a proof that the blackwater treatment from the toilet is in urgent need of improvement[5].

1.3 Information about the chosen site

Through the field trip, I visited most of the villages and communities. The ideal site for me is the Belvedere community in the Lower Princes Quarter. Belvedere was one of the first sugar plantations, and one of the last to be in operation on Sint. Maarten[6]. This land has a good location near the boundary on the east side, close to Rice Hill and Billshop Garden.

The choice of this site is based on the following considerations. Firstly, the urban sewage system is undergoing an upgrade project in the Dutch Quarter. Belvedere, as a nearby community, is also about to connect to the upgraded urban sewage network, which will bring great convenience and cost savings to residents. Secondly, Belvedere is already a well-planned community. The majority of the residents living in the Belvedere community now are middle-income residents. Micro-finance can be an effective way to consider during initial equipment installation. The community is fully equipped with public buildings and spaces such as playgrounds, basketball courts, schools, community centers and more. The government has also built a Red Cross senior nursing home and some social houses here, and it proves the good living environment of Belvedere. Thirdly, compared to other villages such as Cole Bay and Philipsburg, the Upper Princes Quarter does not have as many urban water storage tanks. But as the most populous village, the community must need more fresh water supply

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3 Eastern side of St. Maarten placed on restrictive water consumption. [online] Available at: https://www.bearingpointcaribbean.com/en/government-news/eastern-side-of-st-maarten-placed-on-restrictive-water-consumption/ [Accessed 11 Mar. 2019].

4 Sint Maarten National Recovery and Resilience Plan. (2017). 1st ed. The World Bank.

5 Nature Foundation Conducts First Water Quality Assessments of Wetlands and Beaches Since Hurricane Irma.|Nature Foundation St Maarten. [online] Available at: https://naturefoundationsxm.org/2018/08/26/nature-foundation-conducts-first-water-quality-assessments-in-wetlands-and-beaches-post-hurricane-irma-has-serious-concerns-regarding-water-quality-at-kim-sha-beach/ [Accessed 18 Mar. 2019].

6 Davis, L. (2019). The Daily Herald -Belvedere Historical Park. Retrieved from http://www.thedailyherald.info/index.php?option=com_content&view=article&id=47310:belvedere-historical-park&catid=24:weekender&Itemid=37

and a better water system. Therefore, residents will be more accepting the installation of better water systems in this community.

1.4 Thematic Research Question

The research question is:

How can a cluster scale decentralized water management system solve water challenges in the hurricane-prone environment of Sint Maarten?

(1) Sub-question 1: (Water demand)
- What are the main sources of water in Sint Maarten?
- What is the amount and water quality of household water usage categorizes including drinking, washing, flushing, irrigating and so on.

(2) Sub-question 2: (Current system and situations)
- What is the existing water flow in Sint Maarten?
- Do they have already applied water supply or treatment systems? If so, how they work? Do they satisfy the needs of the local population?

(3) Sub-question 3: (Technical solutions)
- What water management systems in cluster scale have been applied or are being developed now in the world?
- How to make the system more resilient, easier be recovered from damage and bring social and ecological benefit to the neighbourhood?
- What is a reasonable standard to evaluate a water system?
- Based on the water condition in Sint Maarten, how to use the systems to optimize the local water cycle? How can these practices be applied to Sint Maarten?

II. METHODOLOGY

The first part is to understand the current water usage and situation. Data about annual water demand, pollution index and groundwater extraction will be found from interviews with residents and literature studies. For some data that is difficult to collect specific exact figures, assumptions will be made based on data from other similar cases. In addition to literature study, a field trip will also be conducted from 12th to 22th of May. During these days, water conditions, drinking water quality and accessibility, local water flow as well as existing water management systems will be investigated. Interviews to local residents about daily water consumption amount or their average water fee per month will also be conducted.

The second part of paper will be case studies on water management system. Case study in a cluster scale could be the best way to learn practices about rainwater harvesting, water purification, gray water reuse and wastewater disposal. A large number of successful cases have been implemented in many countries. It should be noted that the choice of case is better based on the same scale, and the site has similar conditions such as climate issues, resource shortage or island condition. The basic approach is to understand the background information, the system working process, and each of the components in a water management system case. Then mainly use the book named "Compendium Sanitation Systems and Technologies" and some other websites information as a reference to list the specific working principle of each component.

After analyzing the typical cases, a complete evaluation system needs to be established based on the literature review of assessment system. The standard will be elaborated from these four aspects: Technical and physical condition; Social and consumer satisfaction; Financial, operational and maintenance sustainability and Ecological and environmental value. This evaluation system will serve as a criterion to judge the workability and suitability of water systems in each case so the advantages and disadvantages are clearly showed.

Finally, a new water system suitable for the context of Sint Maarten will be proposed to provide a better water environment for residents. This new system will be applied in an architectural design for a housing cluster. The spatial requirement of facilities should be calculated and to use drawing and modelling to form and test different design concept.

III. CURRENT WATER CONDITIONS, EXISTING WATER FLOW AND SYSTEM

3.1 Current Water Conditions

3.1.1 Water source

Seawater desalination is the most important fresh water source in Sint Maarten. There are three desalination plants of Seven Seas Water on this island. Cole Bay Plant produces 3.3-3.6 million gallons of water per day; Point Blanch Plant produces 2.2 million gallons and Cupecoy Plant produces 1.1 million gallons. Hence, Seven Seas Water provides 6.6-6.9 million gallons water (approximate max. 26119 m^3/d) in total per day[7]. This has become the most important source of household, industrial and agricultural water source in Sint Maarten.

The annual average precipitation is 1007 mm, and residents can collect more rainwater during the rainy season. Most of the collected rainwater will be stored in their underground cistern for the hurricane season, and a small number of people will use it daily. However, due to the damage caused by the hurricane and the continuous dry season, this has not become a method of widespread popularity. Groundwater extraction is not used for daily consumption nowadays, because groundwater salinity is too high. Meanwhile, the ecological damage and land subsidence result from groundwater over-extraction will cause living problems of residents.

The main source of drinking water comes from two ways. The first one is GEBE water which is purchased from the Seven Seas Water. People will boil it or install a filter on the supply pipe. The second is to purchase bottled water. The majority of bottled water is imported from other countries, while there are also local brands and producers on this island.

3.1.2 Household water consumption

According to the interview, residents did not have an accurate estimate of the monthly water consumption. Therefore, the water consumption can be roughly estimated based on the money and the tariff standard by collecting or asking the residents' GEBE water bill. The interviews show that the average monthly water consumption of residents varies greatly from each other, and the water consumption in the same community is also significantly different. Generally, a house in four family members uses 18-22 m^3 of water per month, hence, the monthly water consumption in Sint Maarten is 4.5-5.5 m^3 per person[8].

Based on the interviews of residents and literature review, the water habits of each family are also different. GEBE water is the main source of domestic water for most residents. In terms of drinking water(6.4% of total water consumption), the filtered and boiled GEBE water(85%) are more acceptable; many residents also buy bottled water (15%) as a higher quality for drinking and cooking. GEBE water is also used for cleaning(4%), showering(31.4%), laundry(12.9%), gardening(4%), flushing(31.6%), washing-up(6.4%) and others(3%). Rainwater will also be collected sometimes in the household bottled water tank as an additional water source in daily life.

[7] Appendix I. Information from the Seven Seas Water.
[8] Appendix III. Interviews of residents.

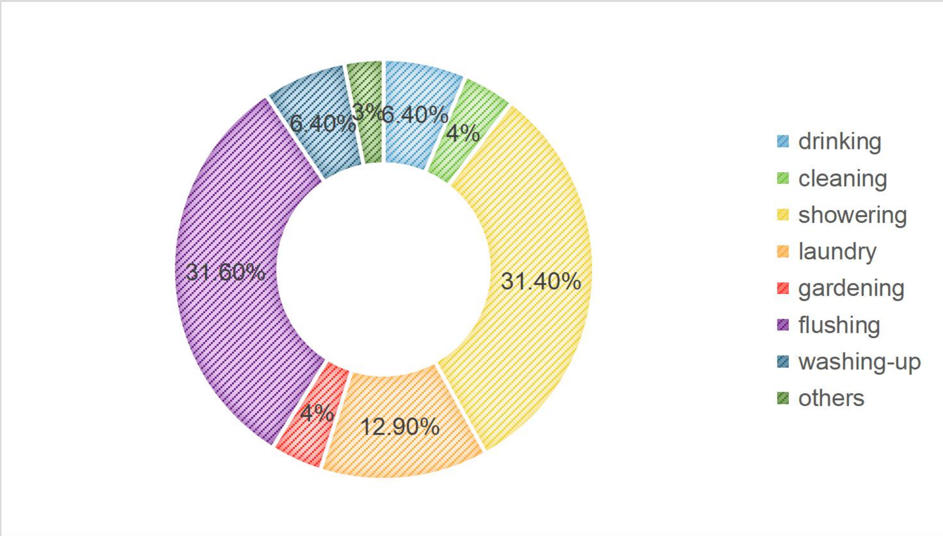

Figure 3-1. Current household water consumption categories and ratio in Sint Maarten. Drawn by author.

3.2 Existing Water System And Flow

3.2.1 Water systems

(1) Urban water system and facility.

Water supply system is mainly the desalination technology provided by Seven Seas Water. Basically they are using reverse osmosis techniques. The whole system are made up with 4 parts. The first one is the pre-treatment system including an intake system and an activated carbon filtration system; Second one is a membrane-filter system; The third one is a reverse osmosis membrane stack system and the last one is freshwater storage tanks and an energy recovery system.

The National Water Authority which is also known as GEBE is responsible for water storage and distribution. They maintain and repair for urban water facilities such as fire pump and urban water storage tanks. They also have a quality laboratory to test the water quality everyday and the lab research report will guide them on the need to temporarily close certain water tanks. There are 14 tanks in Sint Maarten before hurricane Irma and 10 tanks now in use. GEBE purchases fresh water from Seven Seas Water and transports it to these storage tanks. The fresh water is then piped through supply pipes to various communities and houses.[9]

Figure 3-2. All desalination plants and urban water storage tanks in Sint Maarten. Drawn by author.

[9] Appendix II. Information from the GEBE.

The urban sewage system has been upgrading in various communities led by the Dutch Quarter. This project will improve existing wastewater treatment and other infrastructure. All houses will be connected to a new sewerage system. Meanwhile, the installation of a large pumping station and the replacement of the road sections, pavements, drainage facilities and lighting will also be conducted. There are three wastewater treatment plants in Sint Maarten, which belong to the governmental department. All wastewater collected through the urban sewage system will be treated there and discharged into the ponds. The wastewater treatment plant mainly has the following equipment. Primary sedimentation tank for removing suspended solids; Aeration tank and secondary sedimentation tank for oxygen consumption technology and advanced treatment; And finally sludge treatment equipment.

(2) Household water system and facility.

Household water facilities commonly used by residents are simple. Usually they use water tanks for rainwater collection, an underground cistern for water storage, a filter for water filtration installed in a water supply pipe, and a septic tank.

Generally people place an underground cistern or water tanks in their house. The cistern contains an average of 10-20 m^3 of water, and water tank contains 1-1.5 m^3 of water. The rainwater is collected via the gutters on the roof which run into the cistern or water tanks. Purification and reuse equipment for greywater and part of blackwater are rarely used in households of Sint Maarten. Some people collect the gray water and discharge it into the sewage pipe. However, some residents will build an open ditch on the side of the house and then discharge the water from washing directly to it. Most houses are connected to the urban drainage system. Some houses which are lower than the roads or in the areas which system are still upgrading are using a septic tank. They call a truck from every three months to one year to clean their septic tank.

3.2.2 Water Flow

Since my research is about the integration of the decentralized water system and housing cluster, the water flow is mainly discussed about the part of household water.

The main source of household water is fresh water stored in urban water tanks. These tanks are managed by GEBE and provides water for several communities. GEBE purchases these fresh water from the Seven Seas Water and then distributes to consumers including residents, factories and farms. GEBE water is boiled or filtered to be used as a drinking water with purchased bottled water, and very few households are also used for cooking. Most of GEBE water does not require further water quality improvement, and will be used directly in daily life such as washing, gardening, showering and so on. The water that flows out of the kitchen, bathroom and sinks is greywater. They will be discharged directly into the open drainage around the house or through the pipe into the urban drainage system. The open drainage and ditch are not good for the environment because they are directly connected to the ponds and streams. The blackwater from toilets will flow into the urban sewage system network through the sewage pipe and finally into the wastewater treatment plants. Blackwater is also possible to first flow into residents' own septic tank and be transported to wastewater treatment plants by a septic truck. The wastewater treatment plants will discharge the treated water into ponds and streams and then to the seas.

The rainwater is collected as a main source of all households water during the hurricane season. While it is also used as a supplement in daily life of a small parts of residents.

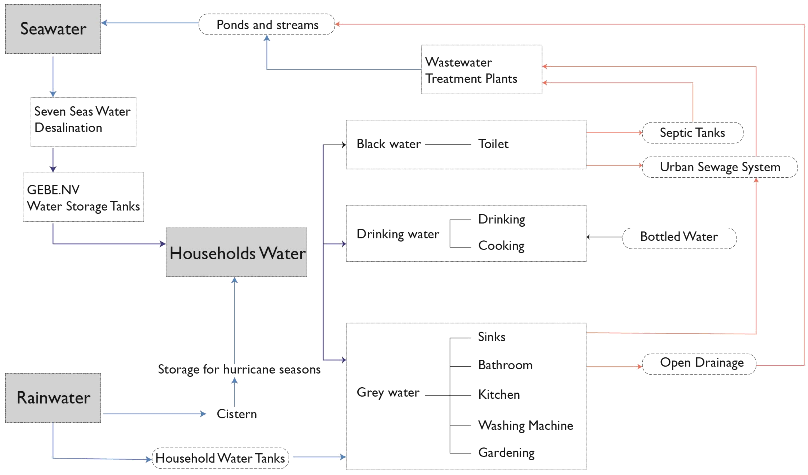

Figure 3-3. Current local water flow in Sint Maarten. Drawn by author.

IV. Case Study Of Water Management Systems

The decentralized water management system can be used to upgrade small-scale facilities for existing water flows, increasing water use efficiency and saving water. So this chapter will analyse three water system cases in Brazil, India and Ghana to learn more about the water management facilities.

4.1 Agua Carioca, Brazil

4.1.1 Introduction

Agua Carioca is addressing water pollution and scarcity issues. The water bodies of Rio de Janeiro and Guanabara Bay have suffered from serious environmental pollution. The reason is that untreated or improperly treated sewage is discharged into natural ecosystems. According to statistics, about 20 m^3 of wastewater flow into the bay every second.

The municipality of Rio are addressing this issue by improving wastewater infrastructure. This long-standing problem is the result of relying on traditional centralized systems. Traditional methods have brought about a high cost of transporting wastewater pipelines, as well as the need for labor-intensive work to make the system effective. Meanwhile, there is 70% of the population in Rio, that is 16 million people, not connected to the urban sewer network. Hence, the largest wastewater treatment plant only achieves 10% of its operating capacity.

Agua Carioca utilizes three main methods which are rainwater harvesting, septic tanks and constructed wetlands to address the lack of sanitation, water quality, scarcity and environmental improvement issues. This important shift from a centralized model to a decentralized model uses a series of small interventions to close water loop, purifying and reusing wastewater, and restoring natural cyclical processes. Engagement and inclusive participation of all stakeholders is quite important. The methods include interviews with all participants like public sectors, researchers and local residents, explaining the design with video and exhibitions, and more.

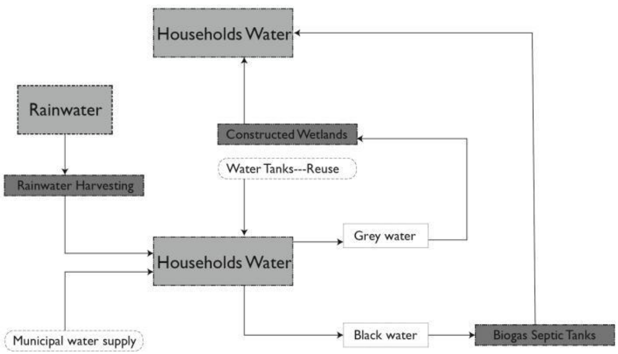

Figure 4-1. The water flow in this case. Drawn by author.

The key is the simultaneous integration of spatial, social, technical and ecological aspects into water system and infrastructure design. And finally, four design schemes of different scales were developed, ranging from a school to the entire urban area. Specifically in a cluster scale, they design for CIEP School in the favela of Mare. There are 900 pupils who use 15m^3 of water every day. The design proposal for this site combines the Água Carioca system with a communal school garden and outdoor play areas and facilities. Water storage doubles as a pavilion and rainwater harvesting takes place on the roof of an outdoor classroom. The system seamlessly integrates with the existing toilets, ensuring no barriers to use the system. The design creates a live classroom, where the water cycle is made visible, fun and beautiful. [10]

4.1.2 Technical Facilities Used In This Case Study

(1) Rainwater Harvesting

In many areas, rainwater flows as surface runoff. This runoff can be captured and used to replenish the aquifer by employing an appropriate method. For the households, the roof becomes a catchment and rainwater can be collected from the roof of the house. The system is mainly composed of the following sub-components: catchment, transportation, filtering and storage. The catchment is the surface that receives the rainfall directly and is the catchment area of the rainwater harvesting system. Transportation means that rainwater from the roof should enter the storage facility through pipes. Filters are used to treat water, effectively removing turbidity, color and microbes. The filter should be cleaned after each rain. Storage is to clean the collected rainwater for next use.

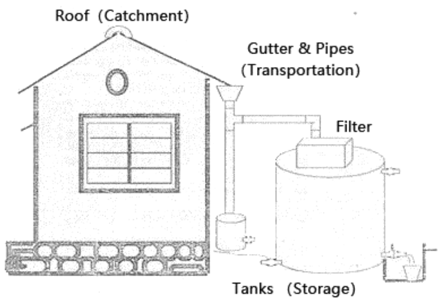

Figure 4-2. The system of Rooftop Rainwater Harvesting. Drawn by author.

The main difference between systems is the choice of filtering and storage devices. Common filtering devices are: Sand Gravel Filter, Charcoal Filter, PVC Pipe Filter and Sponge Filter. The Sand Gravel Filter is constructed of brickwork and is rounded with pebbles, gravel and sand. Charcoal filter can be made in-situ or in a drum, then fill the chamber with pebbles, gravel, sand and charcoal. Each layer is separated by a wire mesh. The PVC Pipe filter is made of PVC pipe from 1-1.20 m long and the pipe diameter depends on the roof area. The pipe is divided into small compartments by wire mesh. Each compartment should be filled with gravel and sand, or a layer of charcoal can be inserted between the two layers. The filter can be placed horizontally or vertically in the system. Sponge Filter is a simple filter made of PVC drum with a sponge in the middle of the drum. It is the simplest and cheapest form filter for residential units. Common storage devices are: Storage Tank/ Container and Cistern, which can be built on the ground or underground according to actual needs.[11]

[10] Água Carioca. (2019). Retrieved from http://www.aguacarioca.org/
[11] Padmanabhan, G. (2019). Methods of Rainwater Harvesting -Components, Transport and Storage. Retrieved from https://theconstructor.org/water-resources/methods-of-rainwater-harvesting/5420/.

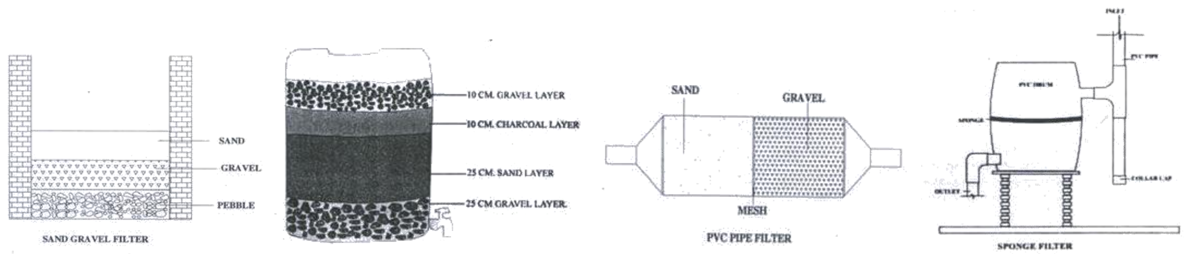

Figure 4-3. From left to right: Sand Gravel Filter, Charcoal Filter, PVC Pipe Filter and Sponge Filter. (https://theconstructor.org/water-resources/methods-of-rainwater-harvesting/5420/)

(2) Septic Tank

The Septic Tank should have at least two chambers. The first chamber should account for at least 50% of the total length, and when there are only two chambers, it should account for two-thirds of the total length. The solid matter settles in the first chamber and will be anaerobicly degraded and then enter Biogas Reactor. The baffle between the chambers is to prevent scum and solids from entering the next chamber along with the effluent. The septic tank should be vented to control the release of odors and harmful gases.[12]

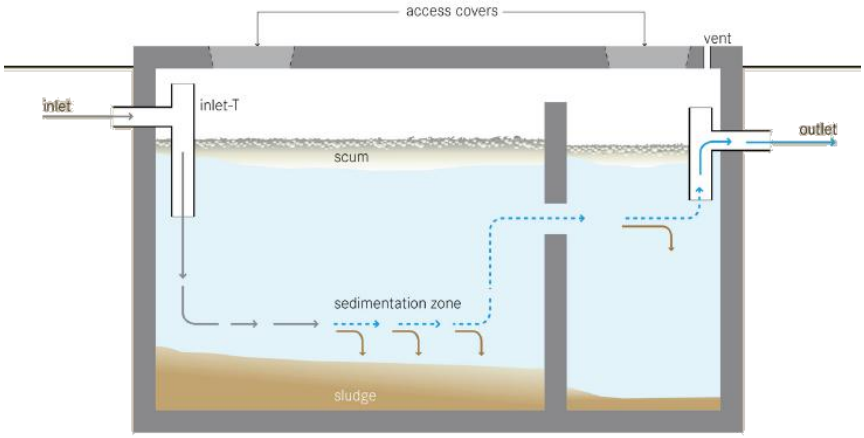

Figure 4-4. The Septic Tank (Tilley et al., 2014, p.74)

(3) Vertical Flow Constructed Wetlands

Applied in this case is the Vertical Flow Constructed Wetland. Vertical flow constructed wetland is a planted filter bed that collects wastewater at the bottom. The wastewater is introduced into the surface of wetlands through a pipe from above, and the water flows vertically downward through the soil to the bottom of the basin and then collected in the drain. Vertical flow constructed wetlands are a good treatment for communities with primary processing equipment like septic tanks, because it can greatly reduce the blockage of system. Moreover, since there is no water on the surface of the soil, the risk of mosquito breeding is low.

A surface area of about 1-3 m^2 per person is usually required. Wetlands require an impervious liner and effluent collection system. Vent pipes connected to the drainage system are good for aerobic conditions in the filter. By venting the wetlands 4-10 times a day, the entire wetland filtration zone undergoes oxygen saturation and unsaturated processes, which facilitates aerobic and anaerobic conditions. A layer of at least 200 mm of gravel is first laid for drainage, followed by sand and gravel layers. Plant selection is according to climate. Reeds and cattails are common plant choices.[13]

12 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 74-75.

13 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 118-119.

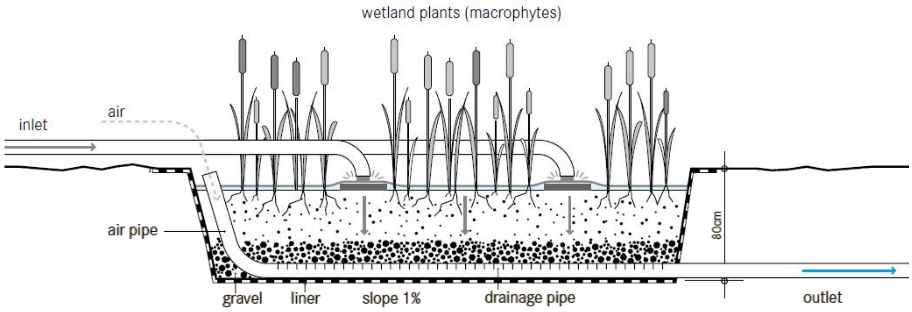

Figure 4-5. Vertical Flow Constructed Wetlands (Tilley et al., 2014, p.118)

4.2 Anil Agarwal Environmental Training Institute, New Deli.

4.2.1 Introduction

The Anil Agarwal Environmental Training Institute (AAETI) covers 40,468.56 m^2 of area in Nimli village, New Deli. This training institute is neither connected to urban water supply nor sewerage network. In order to save groundwater and improve water efficiency, they constructed a decentralized wastewater treatment system and used the treated water in irrigation and other non-potable purpose.

The system consists of two-chambered settlers, five-chambered anaerobic baffled reactors (ABR), five-chambered anaerobic filters (AF) a gravel filter (PGF) bed and a polishing pond. The wastewater generated by the teaching area buildings firstly enters the settler to remove solids. The effluent is delivered to ABRs through two filtration chambers. In this process, the anaerobic degradation process of microorganisms can reduce biochemical oxygen demand (BOD). Next, the effluent will enter the PGF bed for tertiary treatments. The PGF bed consists of gravel with Canna indica on top to remove nitrogen and phosphate. The bottom of the PGF bed is designed with a 1% slope to ensure that treated water flows directly to the polishing pond without a pump. The polishing pond removes pathogens and odors with the help of natural ventilation and sunlight. The final treated water will be pumped for horticultural purposes.[14]

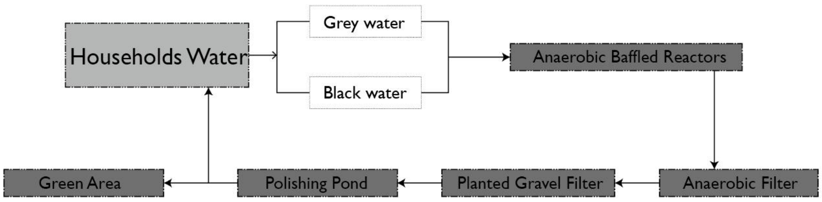

Figure 4-6. The water flow in this case. Drawn by author.

The system will provide treated water which is used to maintain green area of in an area of 2023.42 m^2. This would also help to save approximately 8 m^3 of fresh water.

4.2.2 Technical Facilities Used In This Case Study

(1) Anaerobic Baffled Reactor (ABR)

The Anaerobic Baffled Reactor (ABR) consists inlet pipes, settling areas, reaction areas, access covers, vents and outlet pipes. The reaction zone is equipped with a series of baffles, and the wastewater is in full contact with the active biomass as it flows through each chambers. This upward flow can better remove and digest organic matter. The final BOD can be reduced by 90%, which is much better than in a conventional septic tank.

[14] Decentralised wastewater treatment system at AAETI, Nimli. (2019). Retrieved from http://www.cseindia.org/decentralised-wastewater-treatment-system-at-aaeti-nimli-8330.

In general, the daily inflow is 2-200 m^3. The key parameters of design include the following aspects. The first is the hydraulic retention time (HRT), which is the average reaction time of the action of microorganisms in sewage and bioreactors. This data should be 48-72 hours. The second is that the upflow rate of the wastewater should be less than 0.6 m/h, and the third is that the number of upflow chambers needs 3-6. All three data ensure that the wastewater is adequately treated. The connections between the chambers can be designed as vertical ducts or baffles. Biogas produced by the anaerobic process in the ABR can be used for energy harvesting. The entire unit should also be equipped with vents and access covers to control the release of odorous and harmful gases.[15]

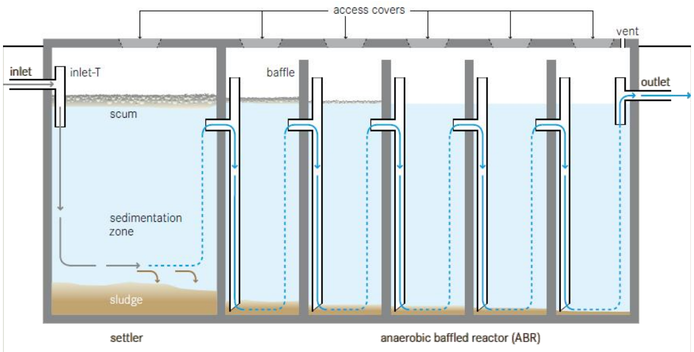

Figure 4-7. Anaerobic Baffled Reactor (Tilley et al., 2014, p.76)

（2) Anaerobic Filter (AF)

The anaerobic filter is a fixed bed bioreactor with a plurality of interconnected filter chambers. As the wastewater flows through the filter, the active biomass on the surface of the particulate and organic matter filter material adsorbs and degrades. Using this technology, suspended solids and BOD removal rates can be between 50% and 80%, usually in combination with ABR.

Anaerobic filters are typically operated in an upward flow mode with a water level covering at least 0.3 meters of filter media. Hydraulic retention time is recommended for 12-36 hours. The ideal filter should have a large surface area for bacterial growth. Ideally, the material should provide a surface area of from 90-300 m^2 per m^3 of reactor volume. Typical materials for typical filter materials include gravel, gravel or brick, cinder, pumice, and sizes ranging from 12-55 mm in diameter. The tank should be ventilated to control the release of odorous and potentially harmful gases.[16]

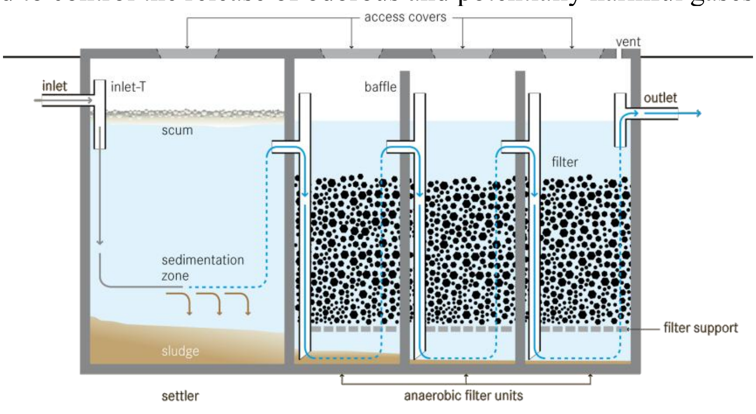

Figure 4-16. Anaerobic Filter (Tilley et al., 2014, p.78)

（3) Horizontal Subsurface Flow Constructed Wetland

15 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 76-77.
16 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 78-79.

Horizontal Subsurface Flow Constructed Wetland is a large gravel and sand-filled basin that is planted with local wetland vegetation. It is the component that acts as Planted Gravel Filter (PGF) in this case. When the wastewater flows horizontally through the basin, the filter material filters out the particles, and the aerobic bacteria grow at the roots of the plants and degrade the organic matter. Plant roots play an important role in maintaining the permeability of the filter.

The design of a Horizontal Subsurface Flow Constructed Wetland depends on the treatment target and the quantity and quality of the influent. Typically, a surface area from about 5-10 m^2 per person is required. Influent water can be ventilated through the inlet tube for BOD reduction and nitrification. The bed should be lined with a watertight gasket such as clay to prevent water leaching. The outlet pipe should be more to adjust the water level. Small, round, uniform-sized gravel, which is 3-32 mm in diameter, should be chosen for packed beds with a depth of 500-1000 mm. The water level in the wetland is kept 50-150 mm below the surface. Natural plants with deep, wide roots are suitable, and they can grow in moist and nutrient-rich environments.[17]

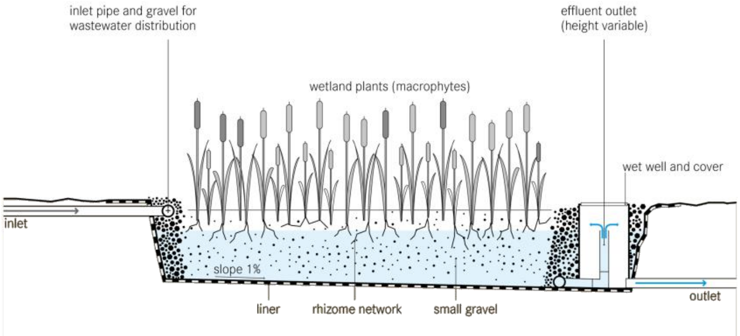

Figure 4-9. Horizontal Subsurface Flow Constructed Wetland (Tilley et al., 2014, p.116)

（4) Polishing Pond

The Polishing Pond can be a Floating Plant Pond or a Fish Pond. Fish can effectively reduce the number of algae and mosquitoes. Although the fish itself does not significantly improve water quality, its economic value can offset some of the cost. Floating plant ponds are plants such as water hyacinth or duckweed floating on the surface, while the roots of the water absorb nutrients and filter the water flowing through. The root of the water hyacinth can be a growth environment for bacteria, thereby degrading the organic matter in the passing water. Fresh or dried duckweed can be used as a food for fish or poultry. It can significantly remove large amounts of nutrients from water.[18]

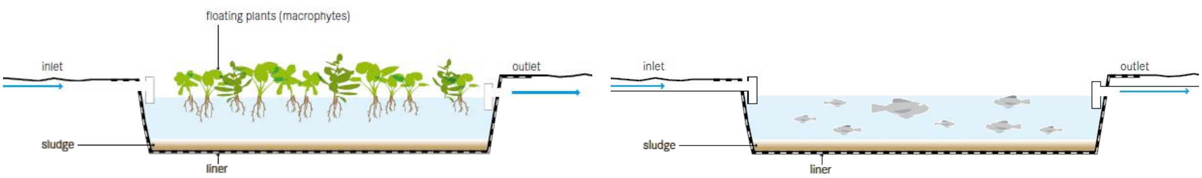

Figure 4-10. The Floating Plant Pond and the Fish Pond (Tilley et al., 2014, p.156,158)

4.3 Accar Water management system project

4.3.1 Introduction

Ga-Mashie is the home of the original Ga settlers and the original name of Accra which is the capital of Ghana. This project proposes the combination of open public spaces along Ga Mashie's waterfront with standing reserves of public water supply and upgrades the water treatment system. Through the strategic placement of water infrastructure, the role of open space in Ga Mashie can contribute to the

17 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 116-117.
18 Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 156-159.

strengthening of this coastal fabric.

(1) Water supply system

Weija and Kpong Headworks are two main dams to supply Accar. But Ga Mashie can only obtain the "leftover" water due to its location. The dams currently produce about 360,000 m^3 water per day, while total demand in Accar is approximately 540,000 m^3 and there are currently no plans for expansion. To enhance stability, Ga Mashie can upgrade urban infrastructure while providing a better water supply condition through private and collective water systems.

Accra's annual rainfall of more than 1000 mm is enough to meet most of the residents' water needs. In addition to water tanks, gutters and water pipes, the system can be equipped with water-filing stations and pumps for community use. In the appropriate area, a "back-up" tank connected to the merry-go-round playpumps is also useful. Lifting these "back-up" tanks to create a water tower which can have a strong visual identity and become a landmark to provide information.

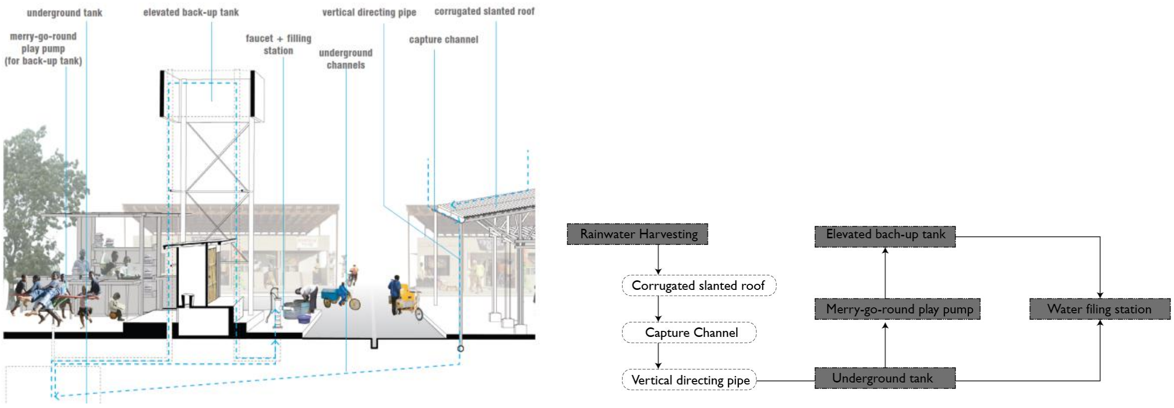

Figure 4-11. Diagram and flow for the water supply system
(Left: Urban Development in Accra, Ghana. P.47; Right: Drawn by author.)

(2) Water treatment system

When household wastewater is discharged into the drain. Contaminants and debris also enter the drainage system. Building a filter that connects the main drain and houses can ensure that the contaminants do not enter the system. The household greywater will be treated in the greywater filtration tank which is filled with sand and gravel. The perforated pipe will duct the water to neighbourhood drain. A drain with a cover can be built to prevent solid waste, while also ensuring that pedestrians can walk on it normally.

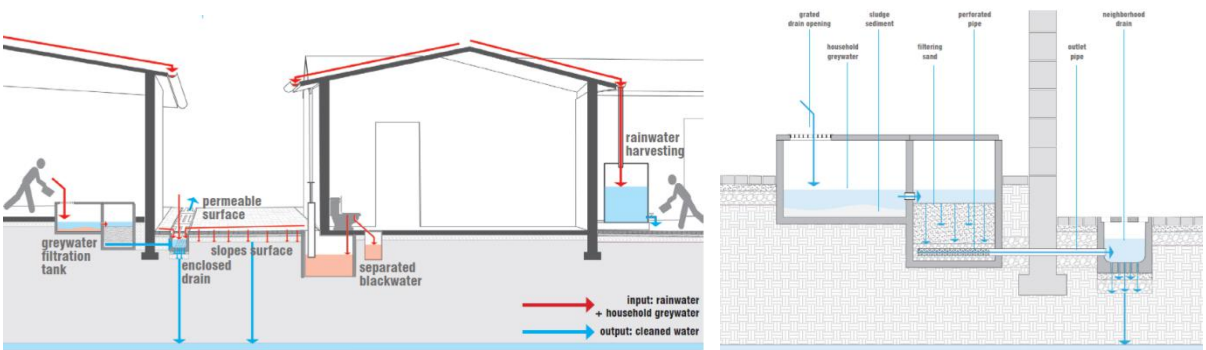

Figure 4-12. Diagram for the greywater and drainage treatment system (Urban Development in Accra, Ghana. P.41-42)

Compost toilets can be a good starting point to upgrade blackwater system for Ga Mashie. These toilets come with a tank that can be emptied out and will also need to be pumped out on a regular basis, which provides a small-scale business opportunity. The collected blackwater will first enter the anaerobic digester, also known as the biogas reactor, for preliminary treatment. The sludge is precipitated into a fertilizer for local vegetation cultivation, and the biogas produced in the process is used for cooking gas.[19]

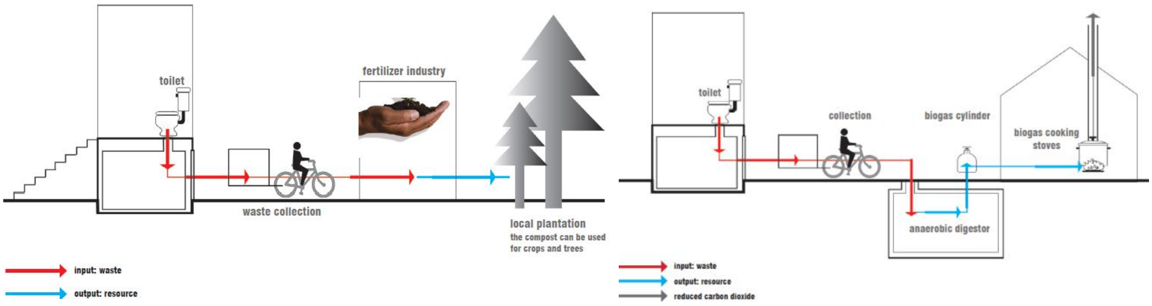

Figure 4-13. Diagram for the blackwater treatment system (Urban Development in Accra, Ghana. P.45,49)

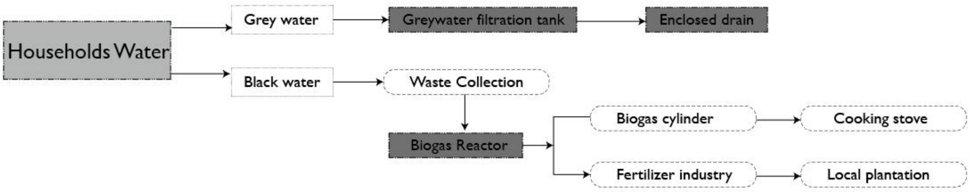

Figure 4-14. Flow of water treatment system. Drawn by author.

4.3.2 Technical Facilities Used In This Case Study

(1) Marry-go-round Playpump

Playpump is a roundabout that drives the pump while playing with children. This pump design converts the child's rotational motion into a reciprocating linear motion of water within the tube through a drive mechanism consisting of only two components. Playing at the roundabout has always been fun for kids, so it is no worry about the equipment stopping for a long time. As it rotates, water is pumped from the ground into a tank about 7 meters above the ground. Then people can install a faucet to use clean water. Excess water (overflow) flows back from the tank to the borehole. At the same time, the water tank can be made into a billboard for community promotion or business.[20]

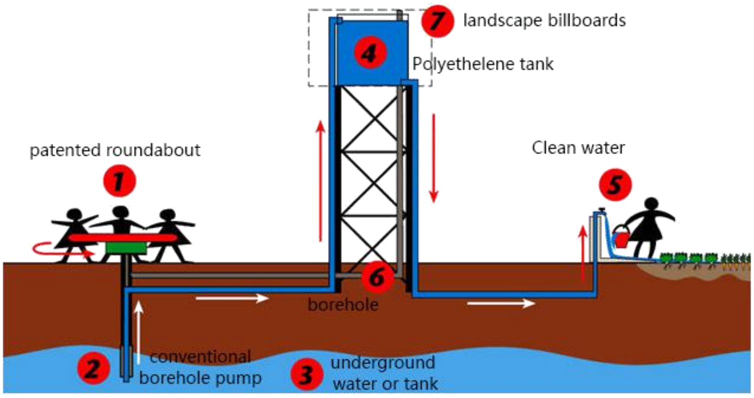

Figure 4-15. A working method of playpump (Drawn by author)

[19] UN Studio.(2017). Urban Development in Accra, Ghana. [Ebook] (1st ed.). Amsterdam. P41-50.
[20] Playpumps | All children have the right to clean water and the right to play. (2019). Retrieved from http://www.playpumps.co.za/

(2) Biogas Reactor

The Biogas Reactor will directly replace the septic tank in some places. The Biogas Reactor can be a brick dome or a prefabricated tank. It is installed on the ground or underground, depending on space requirements, soil properties and so on. Floating dome reactors are more commonly used, and the dome rises and falls with the generation and discharge of gases. The hydrostatic residence time (HRT) in the reactor should be at least 15 days in hot climates and 25 days in temperate climates. Typically, the biogas reactor operates at a mesophilic temperature range of 30 to 38 ℃. At the household level, the reactor can be made of plastic containers or bricks. Sizes range from 1 m^3 for a household toilet to 100 m^3 for public restroom.[21]

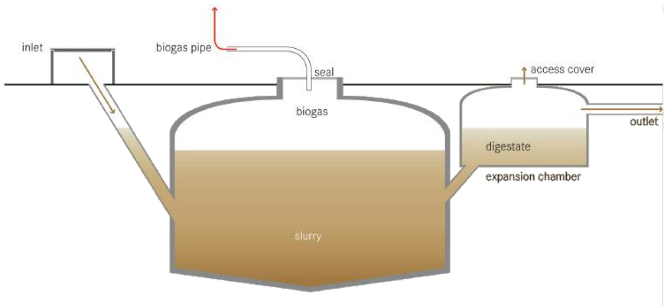

Figure 4-16. The Biogas Reactor (Tilley et al., 2014, p.80)

V. The new decentralized water management system in Sint Maarten.

In general, the local water flow does not close the water loop, nor maximize the water utilization. The parts that need to be improved are the following aspects. First, rainwater harvesting needs to be applied to each household as a more common method. Second, residents should use more gray water and a part of blackwater collection to achieve reuse through purification, which can save a large amount of water cost; Third, all families need to connect to the urban sewage system as soon as possible. And septic tanks can be combined with or replaced by energy equipment to produces biogas, and sludge can also be used in more aspects.

According to the interview with Seven Seas Water, the desalination technology is now almost close to saturation, and there is no way to increase the water supply capacity in a short time. In the face of increasing water demand, the only way is to find new water sources from existing water systems and improve existing water usage efficiency. This is also the proposal to select this new decentralized water management system. Based on the current local system and flow, the following facilities are added or improved.

The first is to improve rainwater harvesting equipment. Considering that the emergency treatment time after the hurricane occurs is about one week to half a month, the stored rainwater may be the only source of water for residents. Then the total amount of rainwater collected should meet the sum of the minimum water consumption of all family members during this time. This part of the water will be stored in the underground back-up tanks. The tank connected by playpump will be responsible for the storage of daily water, the source is the excess rainwater collection and filtered reuse water. Biogas Reactor will replace the original Septic Tanks. The Biogas Reactor converts a portion of the sludge into fertilizer. This part of the fertilizer can be used as a catalyst to accelerate the reaction time of other equipment and can also be sold to farms. The biogas produced at the same time can provide fuel for residents. The remaining sludge will enter the municipal sewage system, and the treated

[21] Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies (2nd ed.). Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. P 80-81.

wastewater will enter the Anaerobic Baffled Reactor and Anaerobic Filter for secondary filtration. After this, the effluent will go directly into the Vertical Flow Constructed Wetland with the graywater for tertiary filtration. The treated water can be directly used for irrigation and flushing, and can also be stored in the tank. Since the tank is equipped with a filtering device, this part of the water has basically reached a high water quality and can be used for washing, flushing, showering and so on.

The new system not only saves residents water and energy costs, but also creates potential benefits. Because fertilizers and vegetation grown on wetlands can be sold, even excess water can be sold to factories and farms. Part of the revenue generated can be used to pay for the maintenance of the equipment, thus ensuring that the system can run for a long time. At the environmental and architectural levels, residents have better water habits, and a good water system is conducive to reducing water pollution. The wetlands bring green space to the residents and can improve the microclimate and the environment. At the same time, the combination of equipment and public space design can create more living space for residents.

The following figure shows the proposed new water flow. The calculation is based on a social housing cluster of about 30 people in a total of 8-10 households.

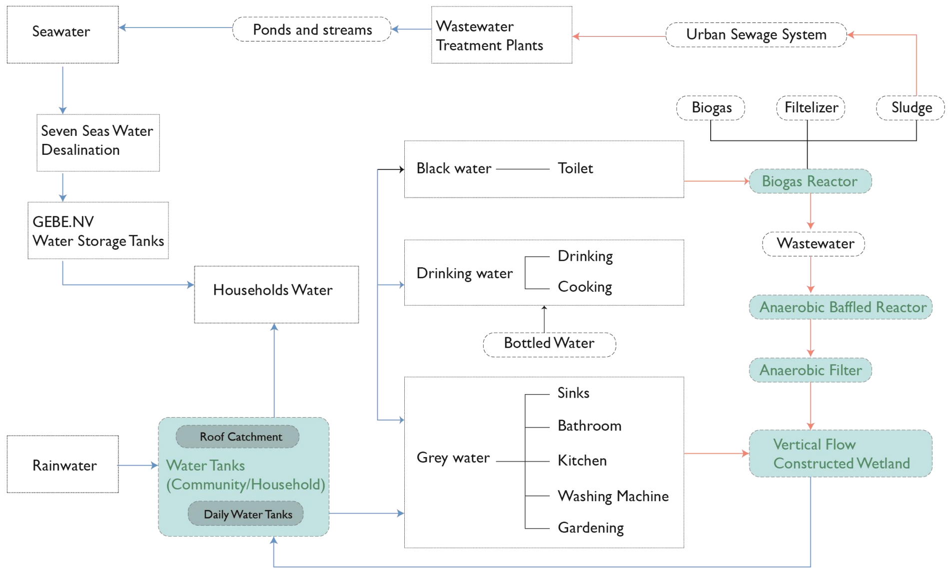

Figure 5-1. The new designed water flow. Drawn by author.[22]

VI. Conclusion

This paper is about to answer the research question: How can a cluster scale decentralized water management system solve water challenges in the hurricane-prone environment of Sint Maarten? For existing contexts, improving some facilities on existing water flows can create a better water usage environment. A decentralized water management system with low installation and low maintenance costs is very much needed by Sint Maarten.

But there are also certain limitations. It scales water issues down to the cluster level but it is not a completely separated system. In other words, although it relieves some of the problems of the traditional centralized system to a certain extent, such as high transportation costs, large-scale water stoppages and so on. It still works better with the large water supply system and sewage treatment system. Many large-scale technologies cannot be implemented on the basis of decentralized systems. For example, desalination technology, its enormous cost and space requirements make it necessary to operate effectively at the national or city level. Another example is that it does not deviate from the urban sewage system. There is still a large amount of sludge and wastewater to be concentrated in a

[22] See calculation in Appendix VI.

larger sewage treatment station and tackled.

This research paper will be followed by an architectural design proposal for the area. Next in the design section, first calculation should be done for the current monthly greywater, blackwater amount and water supply amount at the scale of the self-set eight households and 30 households. With this and the processing capacity of each device, the floor area required for each system is obtained. Then to consider how to combine it with public space to create a good living environment. At the same time, in order to make the research more convincing, how to operate and manage the system at the economic level, the person responsible for the operation and other economical consideration should be taken into account.

During the process of writing this paper, I deeply realized that resource sustainable development is a very important issue at any scale, from independent houses to a community to a city to a country, and the challenge of sustainability is a long-term and persistent topic. The research of decentralized water management system provides me with the idea that when we cannot create more new resources, we should create more recycling opportunities and improve the existing equipment by improving the existing equipment and energy efficiency,that is, to be strength from within. But its complexity is huge, and there is still a lot of work to be done.

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Appendix I Information from Seven Seas Water

Based on the interview with Christopher Cilliers who is the Operations Engineer of Seven Seas Water (Sint Maarten).
Date: 21st May 2019, 3.00pm.

1. The general idea of how system works?
Basically we are using reverse osmosis desalination techniques. The whole system are made up with 4 parts.

(1) pre-treatment system:

The seawater is pumped from the intake system into the pre-treatment system, After adding some chemicals, it is filtered through an activated carbon filtration system.

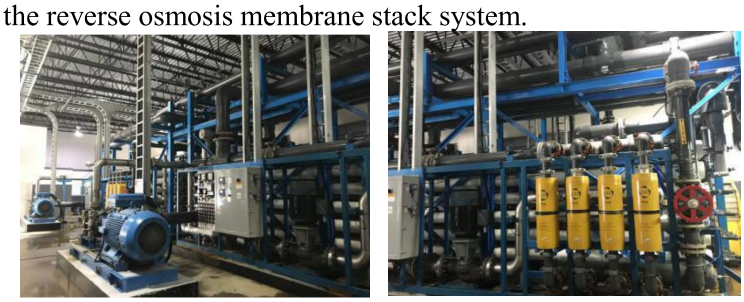
(2) The membrane-filter system:

The water then enters the high pressure pump and the water flows through the membrane material. The pressure is increased to allow some of the pure water in the seawater to pass through the membrane into the collection tube out of the device, while the salt is blocked with most of the seawater exiting the device.

(The membrane-filter system, photo by author)

(3) The reverse osmosis membrane stack system:

After filtering, the filtered water enters another filtration system after steps such as the pH adjustment, and water is pressurized by the high-pressure pump, and then enters the reverse osmosis membrane stack system.



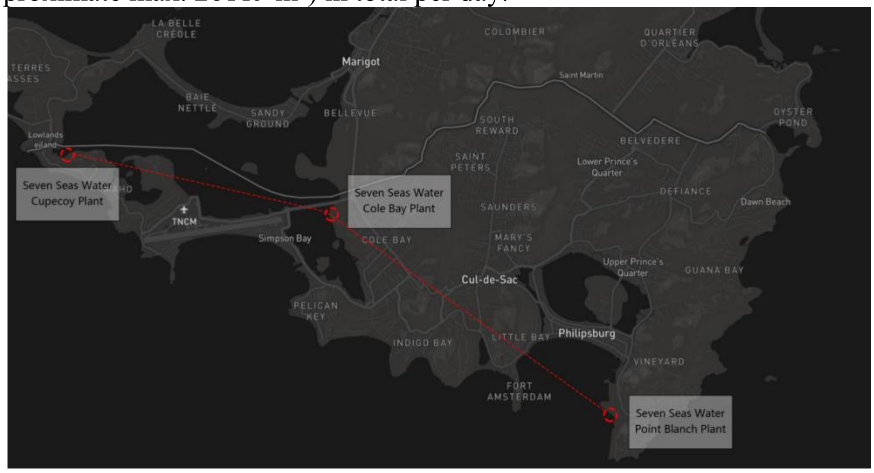
(The reverse osmosis membrane stack system, photo by author)

(4) Freshwater storage tank and energy recovery system:

Part of the high-pressure water passes through the membrane and becomes fresh water. After the water quality is adjusted, it enters the fresh water tank for storage. The remaining high-pressure concentrated water will be discharged into the sea after energy recovery.

(Freshwater storage tank and energy recovery system, photo by author)

2. Water source? How many stations in this island? Amount and quality?
We have three factories on the island, each located in Cole Bay: 3.3-3.6 million gallons per day; Point Blanch: 2.2 million gallons per day and Cupecoy: 1.1 million gallons. So 6.6-6.9 million gallons (approximate max. 26119 m^3) in total per day.



(Three desalination plants of Seven Seas Water of Sint Maarten, illustrated by author)

3. The corporation with GEBE?
GEBE has a close working relationship with us. In fact, we have about 10-15 GEBE employees in each plant, which are responsible for transporting water to our water storage tanks. They are also responsible for the commissioning and maintenance of the facility.

4. Can you meet the need of the whole island and export for benefices?
The water we produce every day basically meets the island's demand, but it is also only for Sint Maarten. French Saint Martin has their own factory and we don't have extra water to export to other islands.

Appendix II Information from GEBE

Based on the interview with Mr Abram Eugene who is the Supervisor of GEBE Water Operations. (abeam.eugene@nvGEBE.com)
Date: 22nd May 2019, 9.30am.

1. What is the main task of water for GEBE? Are you a private company or a department of the government?
We take charge of the electricity and water in this country. In terms of water, we mainly focus on water storage and distribution. We also do maintenance and repair of urban water equipment. We have a quality lab to test the water quality everyday. Lab research reports will guide them

on the need to temporarily close certain water tanks. We are a governmental department. We are a kind of National Water Authority.

2. What is the tariff standard in different region? Do you have any data about water consumption?

The water price per unit is the same. The difference in water bills will only be different between the amount of water used and the maintenance costs paid. We have the daily water report to show storage tank situation; water production; water received amount; water storage and statistics.

DAILY WATER REPORT

NV GEBE Distribution Department

Present:	21	May	2019	(Tue)
Previous:	20	May	2019	(Mon)

Nr.	Tank Location	Ton / Meter	Operational Capacity	Operational Level /m	Previous Level /m	Present Level /m	Present Vol. / %	Present Vol. / m3	Previous Vol. / m3	Tank Mutation
1	Cay Bay I	350		11.5	4.0	5.6	40%	1,610	1,050	560
2	Cay Bay II	400	4,600	11.5	4.0	5.6	40%	1,840	1,200	640
3	Cay Hill I	500	3,750	7.5	3.8	4.2	53%	2,000	1,800	200
4	Cay Hill II	500	3,750	7.5	0.0	0.0	0%	0	0	-
5	Mnt Williams	85	400	4.7	3.4	3.8	77%	306	272	34
7	Sth Reward	70	399	5.7	6.5	6.4	96%	385	392	(7)
8	Pt. Blanche	269	2,475	9.2	9.7	8.0	83%	1,991	2,448	(457)
9	Pt. Blanche	269	2,475	9.2	9.7	8.0	83%	1,991	2,448	(457)
11	Mullet Bay							0	0	-
14	Jail	448	2,464	5.5	0.0	0.0	0%	0	0	-
15	Concordia	-	-	3.6	0.0	0.0	0%	0	0	-
16	Pelican Key	-	-	5.6	0.0	0.0	0%	0	0	-
17	Monte Vista	-	-	4.6	0.0	0.0	0%	0	0	-
18	Guana Bay	-	-	4.9	0.0	0.0	0%	0	0	-
19	Almond Grove	48	221	4.6	3.1	4.3	89%	197	139	58
20	Weymouth Hill	95	428	4.5	4.0	5.0	102%	456	361	95
			20,960				51%	10,775	10,110	665

WATER RECEIVED in approx.		1	day
Meter Readings	Previous	Present	Total in m3
GEBE Pointe Blanche	2661736	2665926	4,190
Air Fin Pointe Blanche	0		0
GEBE Cupecoy	8465880	8468420	2,540
GEBE Cay Bay	22200730	22210660	9,930
Air Fin Cay Bay	33537971	33547898	9,927
			16,659

15.000

WATER STORAGE		of Tot. %
Total Storage Previous Date:	10,110	48.2%
Total Storage Present Date:	10,775	51.4%
Approx. Distribution Days Storage:	0.64	day
WATER DISTRIBUTED		
Total Water Distributed:	15,994	m3

WATER PRODUCTION (Begin Month to Date)		
A-F Pointe Blanche	96,346	m3
A-F Cupecoy	54,720	m3
A-F Cay Bay	204,628	m3
A-F Pointe Blanche year	655,011	m3
A-F Cupecoy year	380,510	m3
A-F Cay Bay year	1,338,667	m3

STATISTICS	
(Begin month to date) Distributed Avg:	16,942
Total (Begin month to date)Prod. Avg:	16,938
Total (Begin Month to date) Distributed:	355,791
Total (Begin Month to date) Received:	355,694
Total (Begin Year to date) Distributed:	2,375,463
Total (Begin Year to date) Received:	2,374,188

5/22/2019 9:04 AM readings by: E. Abram

Water Operations May21

(GEBE daily water report in 21st of May, photo from GEBE)

3. How many water storage tanks and their information?

14 tanks before hurricane Irma and 10 tanks now in use, some of them are repairing because of leaking and external pipe damage. Some date about Aquastore treatment tank are shown below:

- Diameter: 25.58m;
- Height: 8.664m;
- Capacity: 4296m^3;
- Design Liquid Level: 8.359m.

(Picture of water tank, photo by author)

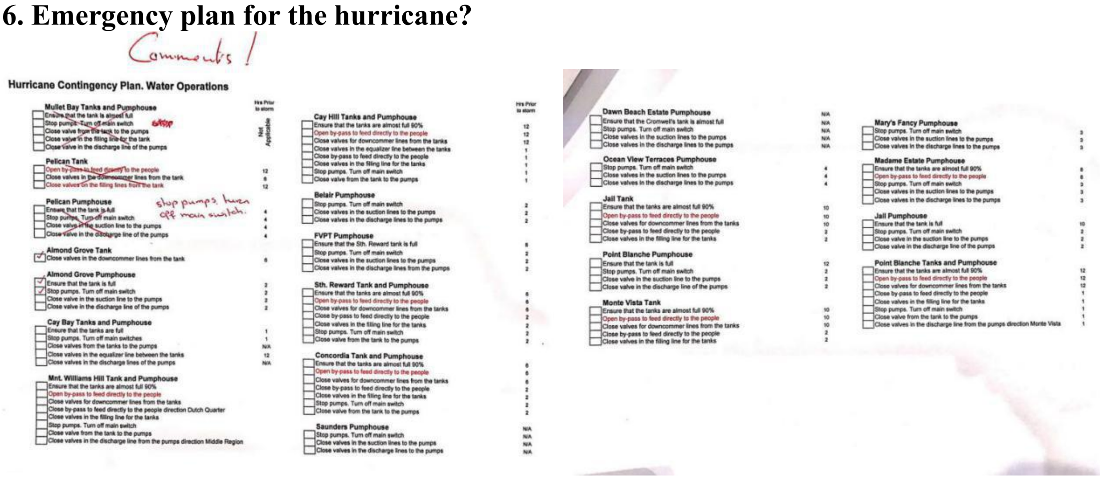
(All water tanks on Sint Maarten, illustrated by author)

4. Water distribution: how much amount of water and the main spots?
The way it works now is that Seven Seas Water's three plants are fully serviceable to all Water storage tanks, and we send water from these tanks to communities. As you can see, we have a water station at each desalination plant that supplies electricity and equipment to transport water to the tanks on the mountain.

(GEBE water station and water tanks near Point Blanch desalination station, photo by author)

5. Water source? No groundwater and rainwater? All water from desalination?
The main source of water supply in our country is to buy fresh water from Seven Seas Water. This company is responsible for desalination technology, and there is no other way to provide a large amount of fresh water.

6. Emergency plan for the hurricane?



Comments!

Hurricane Contingency Plan. Water Operations

Mullet Bay Tanks and Pumphouse	Hrs Prior to storm
Ensure that the tank is almost full	Not Applicable
Stop pumps. Turn off main switch (stop)	
Close valve from the tank to the pumps	
Close valve in the filling line for the tank	
Close valve in the discharge line of the pumps	

Pelican Tank	
Open by-pass to feed directly to the people	12
Close valves in the downcommer lines from the tank	6
Close valves on the filling lines from the tank	12

Pelican Pumphouse (stop pumps, turn off main switch.)	
Ensure that the tank is full	4
Stop pumps. Turn off main switch	4
Close valve in the suction line to the pumps	4
Close valve in the discharge line of the pumps	4

Almond Grove Tank	
Close valves in the downcommer lines from the tank	6

Almond Grove Pumphouse	
Ensure that the tank is full	2
Stop pumps. Turn off main switch	2
Close valve in the suction line to the pumps	2
Close valve in the discharge line of the pumps	2

Cay Bay Tanks and Pumphouse	
Ensure that the tanks are full	1
Stop pumps. Turn off main switches	1
Close valves from the tanks to the pumps	N/A
Close valves in the equalizer line between the tanks	12
Close valves in the discharge lines of the pumps	N/A

Mnt. Williams Hill Tank and Pumphouse	
Ensure that the tanks are almost full 90%	
Open by-pass to feed directly to the people	
Close valves for downcommer lines from the tanks	
Close by-pass to feed directly to the people direction Dutch Quarter	
Close valves in the filling line for the tanks	
Stop pumps. Turn off main switch	
Close valve from the tank to the pumps	
Close valves in the discharge line from the pumps direction Middle Region	

Cay Hill Tanks and Pumphouse	Hrs Prior to storm
Ensure that the tanks are almost full 90%	12
Open by-pass to feed directly to the people	12
Close valves for downcommer lines from the tanks	12
Close valves in the equalizer line between the tanks	1
Close by-pass to feed directly to the people	1
Close valves in the filling line for the tanks	1
Stop pumps. Turn off main switch	1
Close valve from the tank to the pumps	1

Belair Pumphouse	
Stop pumps. Turn off main switch	2
Close valves in the suction lines to the pumps	2
Close valves in the discharge lines to the pumps	2

FVPT Pumphouse	
Ensure that the Sth. Reward tank is full	8
Stop pumps. Turn off main switch	2
Close valves in the suction lines to the pumps	2
Close valves in the discharge lines from the pumps	2

Sth. Reward Tank and Pumphouse	
Ensure that the tanks are almost full 90%	6
Open by-pass to feed directly to the people	6
Close valves for downcommer lines from the tanks	6
Close by-pass to feed directly to the people	2
Close valves in the filling line for the tanks	2
Stop pumps. Turn off main switch	2
Close valve from the tank to the pumps	2

Concordia Tank and Pumphouse	
Ensure that the tanks are almost full 90%	6
Open by-pass to feed directly to the people	6
Close valves for downcommer lines from the tanks	6
Close by-pass to feed directly to the people	2
Close valves in the filling line for the tanks	2
Stop pumps. Turn off main switch	2
Close valve from the tank to the pumps	2

Saunders Pumphouse	N/A
Stop pumps. Turn off main switch	N/A
Close valves in the suction lines to the pumps	N/A
Close valves in the discharge lines to the pumps	N/A

Dawn Beach Estate Pumphouse	N/A
Ensure that the Cromwell's tank is almost full	N/A
Stop pumps. Turn off main switch	N/A
Close valves in the suction lines to the pumps	N/A
Close valves in the discharge lines to the pumps	N/A

Ocean View Terraces Pumphouse	
Stop pumps. Turn off main switch	4
Close valves in the suction lines to the pumps	4
Close valves in the discharge lines to the pumps	4

Jail Tank	
Ensure that the tanks are almost full 90%	10
Open by-pass to feed directly to the people	10
Close valves for downcommer lines from the tanks	10
Close by-pass to feed directly to the people	2
Close valves in the filling line for the tanks	2

Point Blanche Pumphouse	
Ensure that the tank is full	12
Stop pumps. Turn off main switch	2
Close valve in the suction line to the pumps	2
Close valve in the discharge line of the pumps	2

Monte Vista Tank	
Ensure that the tanks are almost full 90%	10
Open by-pass to feed directly to the people	10
Close valves for downcommer lines from the tanks	10
Close by-pass to feed directly to the people	2
Close valves in the filling line for the tanks	2

Mary's Fancy Pumphouse	
Stop pumps. Turn off main switch	3
Close valves in the suction lines to the pumps	3
Close valves in the discharge lines to the pumps	3

Madame Estate Pumphouse	
Ensure that the tanks are almost full 90%	8
Open by-pass to feed directly to the people	8
Stop pumps. Turn off main switch	3
Close valves in the suction lines to the pumps	3
Close valves in the discharge lines to the pumps	3

Jail Pumphouse	
Ensure that the tank is full	10
Stop pumps. Turn off main switch	2
Close valve in the suction line to the pumps	2
Close valve in the discharge line of the pumps	2

Point Blanche Tanks and Pumphouse	
Ensure that the tanks are almost full 90%	12
Open by-pass to feed directly to the people	12
Close valves for downcommer lines from the tanks	12
Close by-pass to feed directly to the people	1
Close valves in the filling line for the tanks	1
Stop pumps. Turn off main switch	1
Close valve from the tank to the pumps	1
Close valves in the discharge line from the pumps direction Monte Vista	1

Appendix III Interviews of residents

1. Cole Bay (20th May)

(1) A couple in a white house

- **Location:**
- **People:** 3 persons; we rent here for $500 every month.
- **Water fee:** $100 per month; (appro. 18m^3 water use; 6 m^3/p)
- **Water source:** GEBE water;

(2) A woman in a white house

- **Location:**
- **People:** 2-3 persons, her daughter may live for some days;
- **Water fee:** almost $200 per month in GEBE bill; approximately $90 for water, sometimes with fixed charge $15-20 at a time. (appro. 15m^3 water use; 5-7.5 m^3/p)
- **Water source:** GEBE water; rainwater collection.
- **Drinking water source:** Buying bottle water;
- **Water facility:** No water tank and no filters;
- **Sewage system:** We connect to the city drainage system.
- **GEBE service:** They stop the water maybe twice a month. The only thing is to call the GEBE staff and wait.
- **Hurricane season:** We installed a cistern ourselves for the hurricane, mainly to store the collected rainwater. The system was built around 1960 and buried underground.

(3) A man with his mother in a red house

- **Location:**
- **People:** 2 persons;
- **Water fee:** Almost $120 per month in GEBE bill; approximately $50 for water. (appro. 12m^3 water use; 6 m^3/p)
- **Water source:** GEBE water; rainwater collection.
- **Drinking water source:** Boiling GEBE water;

- **Water facility:** No filters to purify water; but we have a water tank to collect rainwater, a pipe is connect to the tank and the roof pipe. We only use this water for planting.

(The tank that they are using and a tap at the bottom, photo by author)

- **Sewage system:** We built our own septic tank in around 1969. We contact a septic truck to clean up the tank every two months, $80 at a time.
- **GEBE service:** They only wait GEBE when the system is broken. GEBE fix it very quickly maybe one hour but sometimes quite long even a day.

(4) A woman in a white house

- **Location:**

- **People:** 3 persons; live with her husband and child.
- **Water fee:** $160 per month in GEBE bull; approximately $65 for water. (appro. $17m^3$ water use; $5.67\ m^3/p$)
- **Water source:** GEBE water;
- **Water facility:** No rainwater collection and no filters.

(5) A man in a green house

- **Location:**

- **People:** 2 persons;
- **Water fee:** $40 per month; he was super surprised of other people's high bill and said maybe mostly people were talking about their GEBE bill including water and electricity. (appro. $10m^3$ water use; $5\ m^3/p$)
- **Water source:** GEBE water; rainwater collection.
- **Drinking water source:** Boiling GEBE water;
- **Water facility:** No filters; I have a tank to collect rain water and I use this water for washing and sometimes taking a shower.

(The tank he is using, photo by author)

- **Sewage system:** We have a septic tank and no regular time to clean it, maybe every half of a year. We also ask for a truck and $70-100 at a time.
- **GEBE service:** For him the tap water is good enough to use.

(6) A woman in a white house

- **Location:** 


- **People:** 1 person;
- **Water fee:** $50-75 per month; I take showers for three times in summer and during the festival I have twice the water bill than usual. (appro. 15-18m^3 water use; 15-18 m^3/p)
- **Water source:** GEBE water; rainwater collection.
- **Drinking water source:** Buying bottled water;
- **Water usage:** I use GEBE water for showering, washing and planting, and use bottled water for drinking and cooking.
- **Water facility:** I have a filter and change it every 3 months. The water is drinkable after this process but I never drink it because I don't trust in GEBE water. I always have bottled water in my kitchen.

(The filter which connect the pipe and GEBE water pipe, photo by author)

- **Sewage system:** I have a septic tank. I clean it not very often, normally 1-2 years per time. The truck service is $100-125 at a time.
- **GEBE service:** The GEBE water is bad. Even I have a filter, the quality is still not good. The city sewage system is also pretty bad, GEBE should pay more attention on it. Every morning at around 5am when I am walking on the street, I see the sewage water flooding to the street which smells super bad.
- **Hurricane season:** I have a cistern underground to collect and store rain water.

(The underground cistern in the lady’ s house. Photo by author)

2. Middle Region (19th May)

(1) A woman in a one-storey yellow house.

- **Location:** 


- **People:** 5 houses and 11 families in total. I live with my mom in this house; my grandparents; my 3 brothers with their families are also living here.
- **Water fee:** I pay $260 per month which is very high, but that is for 5 families. ($35m^3$ water use; $3.18\ m^3/p$)
- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water;
- **Water facility:** No water tank, filter and no rainwater collector;
- **Sewage system:** We use a pipe to collect all gray water and we also connect to the city drainage system which is under the Middle Region Rd. And we only pay the money for pipe and no fee for implementation and maintenance.

(The black pipe is connect to the washing machine and the sewage pipe.)

- **GEBE service:** The quality is quite okay for them.

(2) A woman in a two-storey green house

- **Location:**
- **People:** 4 persons;
- **Water fee:** \$50-70 per month; (15-18m^3 water use; 3.75-4.5 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water and buying bottle water;
- **Water facility:** We use a blue water tank temporarily for water storage. No filters.
- **Sewage system:** We connect to the city sewage system. Kitchen and bathroom are all connected but in two different pipes.
- **GEBE service:** The quality is good. Water stop is not often.

(3) A man in a white house.

- **Location:**
- **People:** 3 persons;
- **Water fee:** \$120 per month for water and electricity, about \$50 for water; (15m^3 water use; 5 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water;
- **Water facility:** No water tank, rainwater collection and no filters;
- **Sewage system:** Our house has no way to connect to the urban sewage system because the terrain is lower than the road. We can use a pump to connect but we don't do it, so we have our own septic tank. We will contact the local company and they will use a truck to clean up, about \$75 at a time.
- **GEBE service:** The quality is not good you can not drink it directly, you should boil before you drink it. They don't stop the water often, but they will announce the time on the website and paste a paper on the street.

(4) A man who live in Upper Princes Quarter but works there.

- **Location:**
- **People:** 4 persons;
- **Water fee:** \$90 per month which is very high for him; (appro. 20m^3 water use; 5 m^3/p)

- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water;
- **Water facility:** No water tank, rainwater collection;
- **Sewage system:** Our house has connected to the urban sewage system.
- **GEBE service:** They stop the water maybe once a month, but they can fix it very quickly.

3. Other Communities

(1) A man in Belvedere

- **People:** 4 persons;
- **Water fee:** About $80 per month; (appro. 18m^3 water use; 4.5 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Bottled water, but it is too expensive;
- **Water facility:** No water tank, rainwater collection but we have a filter;
- **Sewage system:** We have our own septic tank, but I think we have already connected to the sewage system.

(Left: Filter in this family; Right: the hole of their septic tank. Photo by author)

- **GEBE service:** The water is too dirty, even if we use a filter.

(2) A woman in Philipsburg

- **People:** 2 persons;
- **Water fee:** Sometimes it is quite high due to the leaking, and normally I pay $50 per month and I think that is high; (appro. 15m^3 water use; 7.5 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Filtered GEBE water and bottled water;
- **Water facility:** No water tank, rainwater collection, no cistern;
- **Sewage system:** Our house has connected to the urban sewage system, but I also use a septic tank. We seldom clean it since it never full at all.
- **GEBE service:** We use the filter and we can drink. Sometimes GEBE stop the water but not often maybe twice a month, and only few minutes.

(3) A woman in Dutch Quarter

- **People:** 5 persons;
- **Water fee:** About $90 per month; (appro. 20m^3 water use; 4 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water and bottled water;
- **Water facility:** No water tank, rainwater collection, no filter;
- **Sewage system:** Our house has septic tank and you see the urban sewage system is under construction.

(4) A woman in Point Blanch

- **People:** 2 persons;
- **Water fee:** $25-30 per month; (appro. 8m^3 water use; 4 m^3/p)
- **Water source:** GEBE water;
- **Drinking water source:** Boiling GEBE water;
- **Water facility:** Have a water tank, no filter;

- **Sewage system:** Our house has connected to the urban sewage system.

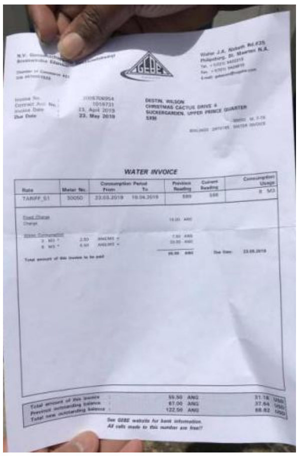
4. Investigation with the Red Cross

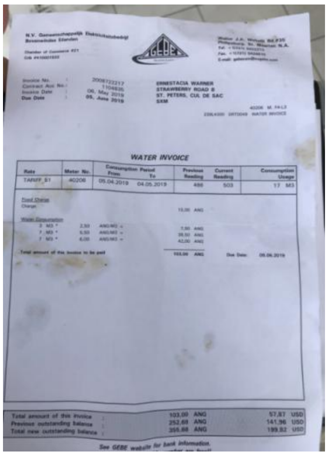
(1) Christmas Cactus Drive #4, Sucker Garden, Upper Prince Quarter.

- **People:** 2 (1 adult + 1 kid)
- **GEBE Water Bill:**
  Amount: 23/3-19/4: 9m^3 (4.5 m^3/p)
  Money: 3m^{3}x2.5=ƒ7.50; 6m^{3}x5.5=ƒ33; Fixed charge: ƒ15; Total: ƒ55.50=$31.18;

(2) Strawberry Road #8, Sint Peters, Cul De Sac.

- **People:** 4 (Grandma, two grandson aged at 14 and 4, a granddaughter aged at 4.)
- **GEBE Water Bill:**
  Amount: 5/4 - 4/5: 17m^3 (4.25 m^3/p)
  Money: 3m^{3}x2.5=ƒ7.50; 7m^{3}x5.50=ƒ38.5; 7m^{3}x6.0=ƒ42; Fixed charge: ƒ15;
  Total: ƒ103=$57.87.





(GEBE bill of three house above, photo by author)

(3) Strawberry Road #8, Sint Peters, Cul De Sac.

- **People:** 7 (Grandparents, two sons, a daughter with her husband and daughter)
- **GEBE Water Bill:**
  Amount: 4/4 - 6/5: 32m^3 (4.57 m^3/p)
  Money: ƒ385=$216.29.

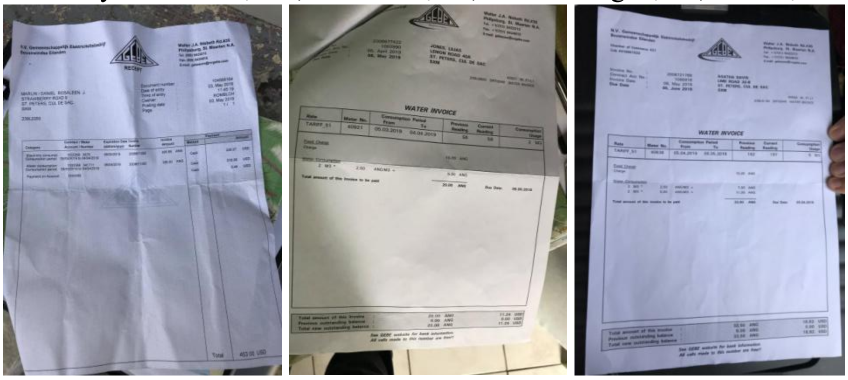
(4) Lemon Road #40A, Sint Peters, Cul De Sac.

- **People:** 1
- **GEBE Water Bill:**
  Amount: 5/3 - 4/4: 2m^3 (2 m^3/p)
  Money: 2m^{3}x2.5=ƒ5.0; Fixed charge: ƒ15; Total: ƒ20=$11.24.
- **Water facility:** Have water tank and a filter. There is no need to buy drinking water after installing the filter on the water pipe. The water tank is no longer used after the hurricane, but will be used after the roof is repaired, previously used for washing, irrigation, mapping the floor.


(The tank and filter. Photo by author)

(5) Lime Road #32B, Sint Peters, Cul De Sac.

- **People:** 2 (A couple)
- **GEBE Water Bill:**
  Amount: 5/4 - 5/5: 5m^3 (2.5 m^3/p)
  Money: 3m^{3}x2.5=ƒ7.5; 2m^{3}x5.5=ƒ11; Fixed charge: ƒ15; Total: ƒ33.5=$18.82.



(GEBE bill of three house above, photo by author)

Conclusion

1. **Community composition:**

・Village: Cul De Sac, Philipsburg, Lower Princes Quarter;

・Community: Dutch Quarter, Union Farm, Belvedere, Middle Region; (They have their own community center)

・Street: Villa Road, Low Estate Road, Golden Grove Estate Road...

・Housing: Its housing number.

(The way of community composition, illustrated by author)

2. **Family:**

In general, residents live with their families. Residents of poor communities have more family members, and sometimes they live with all children and their children’s families. The way of living is to live independently rather than group life. Although in some poor communities, different relatives and their families will live in several houses in the same block, there is no obvious settlement or cluster composition. Residents are not familiar with their neighbors.

3. **Water fee and water usage amount:**

The water consumption of residents in different regions is significantly different, but the overall average is between 4.5 and 5.5 m3/p per month. Most people think that water bills are high. However, residents believe that this graded fee is reasonable.

4. **Water source:**

Almost all residents on the island use fresh water from GEBE as the main source of daily raw water. A considerable number of people, estimated to be about 50%, use rainwater collection, but the way they are used is different. Most people will store it for the hurricane season, and a small number of people will use it in their daily lives, such as watering flowers, washing and so on. Residents seldom use groundwater in their daily lives because of poor water quality and high salt concentration. However, some trucks extract groundwater for construction usage.

5. **Drinking water source:**
The main source of drinking water, one is GEBE water, people will boil it or install a filter on the supply pipe.The second is to purchase bottled water. Generally the majority of bottled water is dependent on imported, while there are also local brands and local bottled water producers on this island.

6. **Water facility:**
Household equipment commonly used by residents for water is: a water tank for rainwater collection, an underground cistern for water storage, a filter for water filtration installed in a water supply pipe, and a septic tank.

7. **Sewage system:**
Most houses are connected to the city drainage system. Some houses which are lower than the roads or in the areas which system are still upgrading are using a septic tank.

8. **GEBE service:**
GEBE stop the water maybe once twice a month. The only thing is to call the GEBE staff and wait. But they can fix it soon, normally few minutes or one hour. Most people think the quality is good enough for daily use. But there are still about 30% of people do not trust GEBE water.

9. **Hurricane season:**
Normally people will install a cistern by themselves for the hurricane, mainly to store the collected rainwater. The system was built quite early and buried underground.

Appendix IV Information Summarize

1. Drinking water:

(1) Nikini bottled water:

- Purified water by reverse osmosis(反渗透), UV lights, carbon filter and ozonization systems(臭氧化系统).
- Water source: Deep well; Volume: 1 gallon (3.7L); Price: $3.35
- Imported from the Puerto Rico.

(2) LASCO iCool water:

- Ingredient: Purified water, sodium, chloride, magnesium sulphate, potassium chloride.

- Imported from the Jamaica.
- Volume: 6L; Price: $5.35

(3) Heavenly water:

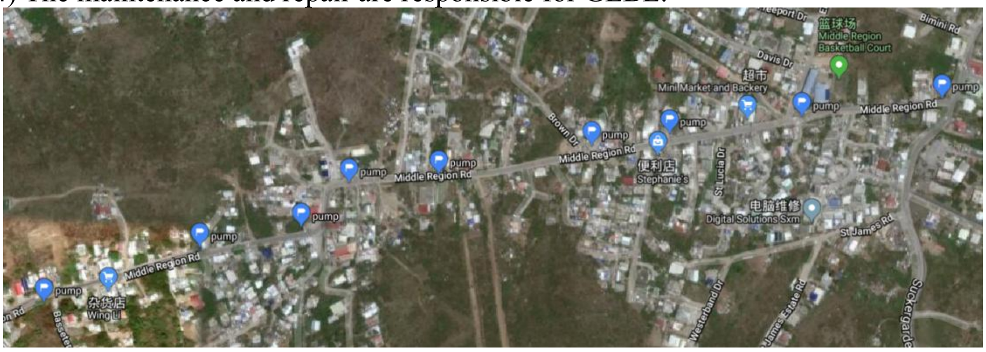
- Ultra purified water, sodium free.
- Heavenly water N.V.: Philipsburg, Sint Maarten.
- Volume: 5L (1.32 gallon); Price: $3.40

(4) Niagara water

- Imported from the USA; Volume: 500 mL; Price: $1.25
- Purified by reverse osmosis.

2. Urban fire pump

(1) This fire pump is red like most cities.
(2) The arrangement distance is approximately 200-300 meters.
(3) The level of maintenance is not ideal mostly but it is not bad in some areas.
(4) The maintenance and repair are responsible for GEBE.



(The location of pumps in the Middle Region Road, illustrated by author)

(Two pumps in the Middle Region Road, photo by author)

3. Urban water system components

(1) Ocean and fresh water

(Ocean, Seven Seas Company and their desalination facilities, photo by author)

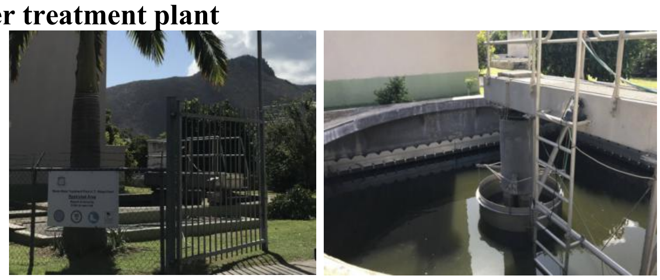
(2) Water body and ponds

(Left: Lagoon. The Great Salt Pond; Right: Drain. Urban ditches. Photo by author)

(3) Drainage system

(Urban sewer ditch, well and drainage pipe. Photo by author)

(4) Wastewater treatment plant



(Wastewater treatment plant A.T.Illidge Road, photo by author)

(5) Water storage and distribution

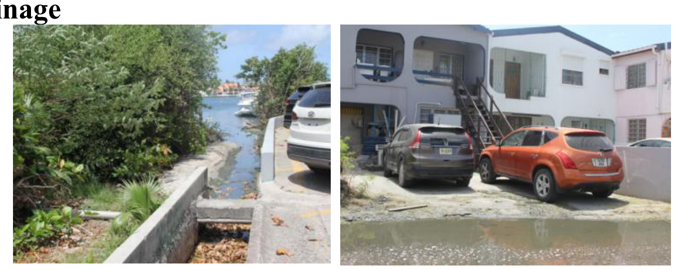
(GEBE office, their water storage tanks and supply pipe, photo by author)

(6) Household water facilities

(Cistern, water tank and septic tank hole, photo by author)

5. The Water Condition

(1) Open drainage



(Left: Open drainage which directly connect the lagoon;
Right: Water on the road surface caused by impermeable pavement and bad urban drainage system, photo by author)

(Residents dig a drain near the house and discharging domestic wastewater or directly to the urban drain, photo by author)

(Drainage near urban roads and in a community, photo by author)

(2) Facility physical condition

(Left: Water supply pipe that is leaking; Right: Gutter which was damaged by the hurricane. Photo by author)

(Left: The water supply pipe exposed to the external environment is extremely vulnerable; Right: Aging and poor facilities. Photo by author.)

(The exposed water pipes are easily damaged by animals. Photo by author)

(Water facilities in a good protected condition in Dutch Quarter Community, photo by author)

(3) Polluted water body

(4) Groundwater extraction

(The only well, which is in Cole Bay, I see during the field trip. Photo by author)

- Water is clear but taste is a bit salty.
- The car was driven in a nearby renovated house. It extracts groundwater for concrete mixing.
- This well is very susceptible to pollution and damage. There is only one wooden board on it, it is easy to pick up.

(5) Rainwater collection

(Meaningless rainwater collection pipe in Belvedere community, photo by author)

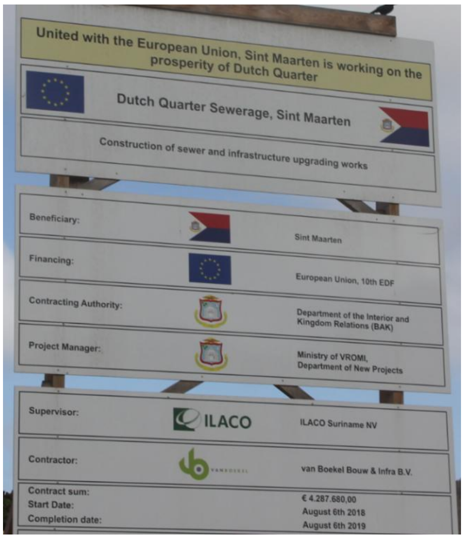
(Rainwater collected by gutter enters an open pipe, photo by author)

(Open water tanks without any pipe accumulates a very small amount of rainwater, photo by author)

Appendix V Dutch Quarter Sewerage system

Construction of sewer infrastructure upgrading works



(Bulletin board standing in the Dutch Quarter, Image source: author)

1. Basic information:

Beneficiary: Sint Maarten;
Financing: European Union;
Contracting Authority: Department of the Interior and Kingdom Relations (BAK)
Project Manager: Ministry of VROMI (Public Housing, Spatial Planning, Environment and Infrastructure), Department of New Projects;
Supervisor: ILACO Suriname NV;
Contractor: van Boekel Bouw& Infra B.V.;
Contract sum: \$4,287,680;
Date: Aug. 6th 2018-Aug. 6th 2019.

2. Interview with a pipe worker:

- This project is only for the Dutch Quarter community, only residents in this area can use this system. And they will all connect to the main pipe under the road. For the houses which is lower than the road we will use a pump.
- When repairing the system, there is no need to completely break the road, just dig a hole to open the top and clean the top.
- All the water will be ducted to the tank and to the sewage station finally.

(Ground excavation and partially embedded pipeline. Image source: author)

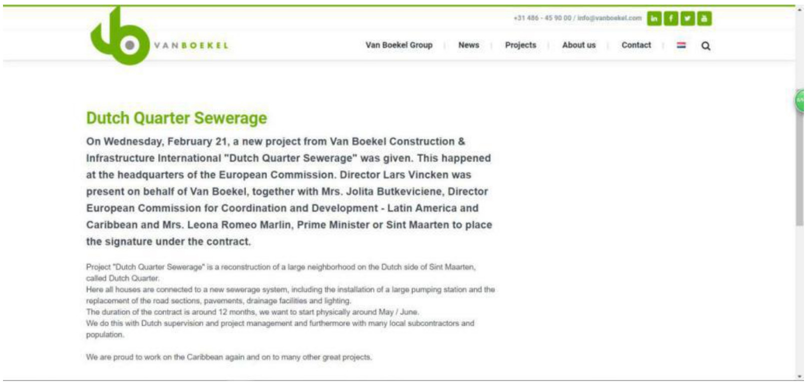
3. Interview with a tank worker:

- This project is a starter and the remaining communities are also planning to have a similar project to connect the sewage system.
- The tank is located near the traffic round and is the intersection of Bishop Hill Road and A.T.Illidge Road.
- Size of the tank: 16 feet(4.88 m) of height and width; 20 feet(6.10 m) of length.
- All the sewage pipe will connect to the tank, and the water will be transferred to a sewage plant or a pond.
- There is another tank on the middle part of the road. And a waste water treatment station is located in the end of the A.T.Illidge Road.



(A large reservoir under construction and its location, Image source: author)

4. Website information:



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Dutch Quarter Sewerage

On Wednesday, February 21, a new project from Van Boekel Construction & Infrastructure International "Dutch Quarter Sewerage" was given. This happened at the headquarters of the European Commission. Director Lars Vincken was present on behalf of Van Boekel, together with Mrs. Jolita Butkeviciene, Director European Commission for Coordination and Development - Latin America and Caribbean and Mrs. Leona Romeo Marlin, Prime Minister or Sint Maarten to place the signature under the contract.

Project "Dutch Quarter Sewerage" is a reconstruction of a large neighborhood on the Dutch side of Sint Maarten, called Dutch Quarter.
Here all houses are connected to a new sewerage system, including the installation of a large pumping station and the replacement of the road sections, pavements, drainage facilities and lighting.
The duration of the contract is around 12 months, we want to start physically around May / June.
We do this with Dutch supervision and project management and furthermore with many local subcontractors and population.

We are proud to work on the Caribbean again and on to many other great projects.

(Screenshot from: https://vanboekel.com/2018/02/22/dutch-quarter-sewerage/)

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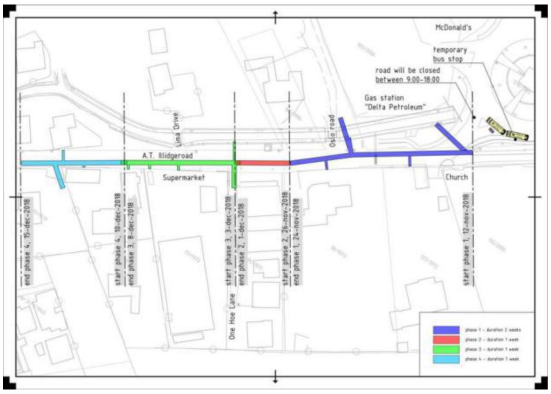
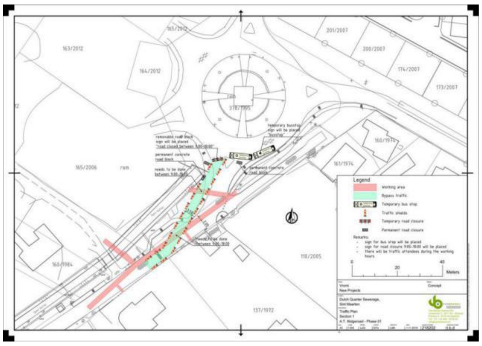
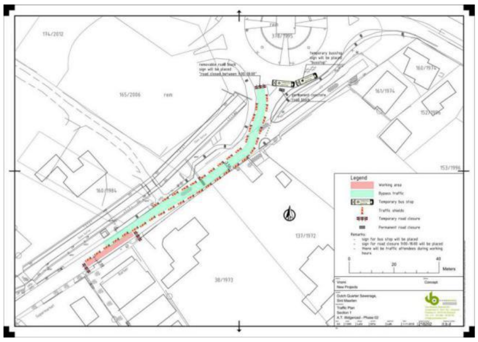
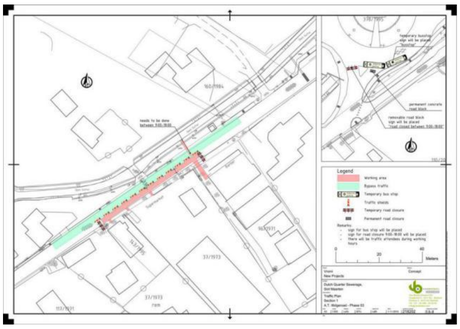
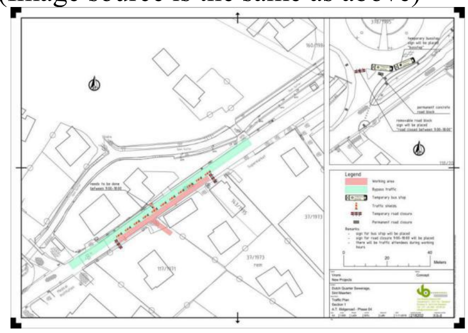
5. Road Closer Phase: from 12th Nov. To 15th Dec. 2018



(The general map of the road closer: from 9.00am to 6.00pm.
https://www.facebook.com/Dutch-Quarter-Sewerage-2200712170161158/?epa=SEARCH_BOX)

Phase 1: Nov. 12th - Nov. 22th 2018. (Image source is the same as above)
Phase 2: Nov. 26th - Dec. 1st 2018. (Image source is the same as above)

Phase 3: Dec. 3rd - Dec. 8th 2018. (Image source is the same as above)
Phase 4: Dec. 10th - Dec. 15th 2018. (Image source is the same as above)

Appendix VI Calculations

1. Rainwater Calculation.

Item	Formula	Number
The amount of water a person needs per day.		0.05-0.1 m^3
average rainfall of rainfall per month		87 mm
amount of water with 1 m^2 of collection surface		0.087 m^3
A household of 4 people amount of water per day	0.05-0.1 m^3 x 4	0.2-0.4 m^3
A household of 4 people amount of water per month	0.2-0.4 m^3 x 30	6-12 m^3
rainwater collection surface	6 m^3 / 0.087	69 m^2

The amount of water a person needs per day to have a low impact on health is 0.05-0.1 m^3.[23] With an average rainfall of 87 mm of rainfall per month in Sint Maarten, people can collect

[23] What is the minimum quantity of water needed?. (2019). Retrieved from https://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/

0.087 m^3 with 1 m^2 of collection surface. A household of 4 people would need between 0.2-0.4 m^3 a day and 6-12 m^3 per month. In an emergency situation 6 m^3 will be sufficient, which means a household of 4 people needs a rainwater collection surface of 69 m^2. It is workable in the architectural design.

2. Water consumption calculation.

This table shows the monthly water consumption of a typical family of four during the survey.

Item	Amount	Proportion
drinking	1.15-1.41 m^3	6.40%
cleaning	0.72-0.88 m^3	4%
showering	5.65-6.91 m^3	31.40%
laundry	2.32-2.84 m^3	12.90%
gardening	0.72-0.88 m^3	4%
flushing	5.69-6.95 m^3	31.60%
washing-up	1.15-1.41 m^3	6.40%
others	0.54-0.66 m^3	3%
Total	18-22 m^3	100%

Water Consumption Calculation

Item	Formula	Number
Daily water consumption		
Proposed households numbers in a cluster		12-15
Max.Population		60
Water amount per person per month		4.5 m3
Monthly water consumption amount	4.5x60	270 m3
Monthly greywater amount	0.1325x60x30	238.5 m3
Toilet waste	0.0015x60x30	2.7 m3
Monthly black water amount	0.03x60x30	54 m3
	54-2.7	51.3 m3
ABR, AF and BR water loss	51.3x(100-15%)	43.61 m3
Proposed volume of community ABR, AF		44-45 m3
Proposed number and size of ABR, AF	3x15 m3	3x2.5x2 m
	2x22 m3	3.6x2.8x2.2 m
Wastewater amount	43.61+238.5	282.11 m3
CW water loss and water amount for reuse	282.11x80%	225.70 m3
Reused water for each household	225.70/15	15.05 m3

Proposed size of household water tanks		
Minimum CW area in total	（225.70/1x10）/30 m2	Min. 80 m2
Minimum rainwater harvesting in hurricane season		
Number of days		15
Minimum water demand per person per day		0.05 m3
15 days minimum water storage amount	0.05x60x15	45 m3
Average monthly rainfall		0.087 m3
Minimum catchment surface	45/0.087	517 m2
Back-up tanks volume	3.14x1.22x2	9 m3
Back-up tanks amount		3

Cost-benefit Calculation

Objective	Cost	Load Capacity
Constructed Wetlands	80-100 euro per m2	A surface area of about 1-3 m2 per person is usually required. 1 m3 water needs 10m2 land per day.
ABR and AF	2800-3500 euro for an ABR; 900-1200 euro for an AF;	In general the daily inflow is 2-200 m3. the following aspects. The hydraulic retention time should be 48-72 hours.
Biogas Reactor	110-130 euro for a household BR	The hydrostatic residence time should be at least 15 days in hot climates.
Water Tower	500-600 euro for a concrete water tower.	50-70 euro for a 3-4 m3 household water tank.
Household water tank	60-70 euro for a 3 m3 household water tank	3-5 years need to maintain or replace the water tank.

For a housing cluster of about 30 people in 8 households, the monthly water consumption per capita is 5.5m3, and the total water consumption is 165m3, of which 6.4% of the water is used for drinking so 154.44 m3 of water is used for others. Each person produces 0.1325 m3 of grey water and 0.0015 m3 of waste per day, with a flushing water then approximately 0.03 m3 of black water. This cluster will have a total of 119.25 m3 of grey water and 25.65 m3 of black water. Black water passing through ABR and BR will have about 10% water loss, the remaining is 23.085m3, plus gray water together is 142.34 wastewater. These wastewaters are filtered through CW. Due to soil and plant uptake, it may result in a 20% reduction in water. The last is 113.87 m3 water for reuse. For a minimum water demand of 15 days during the hurricane season, a roof rainwater harvesting area of at least 258.62 m2 is required.

Appendix VII Assessment Standard

1. Technical And Physical Condition:

(1) Water source:

• Location and type of water source;

• Water amount for supply;

• Condition: The protection equipment around the water source. Maintenance devices and manager? Pollution risk evaluation?

(2) Community population;

(3) Facility condition:

--- Water supply and storage:

• Water tank density (pieces/m^2); Height of tank; Tank capacity (m^3);

• Piping sizes; Type of piping; Type and number of pump;

• The age and condition of the equipment.

• Number or density of taps in a community;(pieces/persons)

--- Water treatment and disinfection system:

• Treatment equipment: age, sizing, condition to be optimized, cost of replacement;

• Chemicals list that are applied in the treatment process, and the potential pollution risk;

• Type of disinfection process, estimated time and disinfectants usage.

• The final level of purification that can be achieved;

• The steps required to achieve this level, time, and financial costs.

(4) Quality requirement;

• The report of mineral elements. (pH value, Fluoride, Ammonia, Nitrate, Iron, Mn, Fecal coliform bacteria...)

• Meet different levels of water treatment requirements, such as drinking water levels, daily water levels for non-potable water, or gray-water levels that can be used for flushing.

2. Social And Consumer Satisfaction:

(1) Community participation under and after construction; (residents engagement, community organizations)

(2) How does this system adapt or even improve the local context; (local resources, local community configuration)

(3) Satisfaction with company service; quantity and quality of water supply; hours of supply; taste, smell, turbidity and color.

3. Financial, Operational And Maintenance Sustainability:

(1) Payers and payment amount of both the water fee and implementation process;

(2) The tariff standard;

(3) Willingness to pay for improvements; (health improvement after the project; incapacity to afford the high fee)

(4) Financial capacity of the community to sustain the system (funds in the community or household tax);

(5) Operational cost assessment; budget review at the end of the project;

(6) Repairman and maintainer;

• Which party is responsible for maintenance?(Residents, community or government);

• Tool stock and use;

• The number of days of regular maintenance; The average length of repair.

4. Ecological and Environmental Value:

(1) The environmental qualities; (green area increased, visual, micro-climate, energy saving ratio)

(2) Connecting decentralized water system construction with waste management training or environmental education.