SWEET WASTEWATER: IRRIGATING SUGARCANE WITH SOAPBERRY EFFLUENT – RIO COBRE, JAMAICA

by

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ABSTRACT

Wastewater reuse for irrigation is common in countries faced with water supply shortages. The Rio Cobre Basin of Jamaica is faced with water supply shortages because of the competing uses of the limited resources of the basin.

The research investigated whether an integrated water resources management (IWRM) approach of reusing the treated effluent from Soapberry wastewater treatment plant to irrigate sugarcane would better manage the water resources of the basin.

Assessment of the quality of the treated effluent and its suitability for sugarcane irrigation; farmers' acceptance of using wastewater for irrigation; wastewater volumes and sugarcane water requirements; were done through document analysis, semi-structured interviews and literature review.

The findings established that Soapberry can be safely used for irrigation, meeting 71% of crop water requirement; farmers' accepted the use of treated effluent for irrigation; and the proposed effluent reuse scheme is economically viable but financial viability is limited by funding options.

Key words: treated effluent; wastewater reuse; agriculture; farmers' attitudes; integrated water resources management

EXECUTIVE SUMMARY

1 INTRODUCTION

Jamaica is an island with abundant water resources; however, because of the distribution of the water resources across the island, certain areas have a limited supply. This is true for the Rio Cobre Basin, where 70% of the freshwater sources are used for irrigation (mainly sugarcane) and the remainder for domestic and industrial uses. This allotment is proving inadequate for the domestic water market because of the rapid urbanisation of the area.
Nevertheless, additional abstractions from the main river in the basin (Rio Cobre River) for domestic uses by the local water utility company, the National Water Commission (NWC) is not permitted. As a result, there is a current (2015) deficit in the potable water supply of 22 MLD, which is expected to worsen as the population increases (NWC, 2011).

On the other hand, there is a wastewater water treatment plant in the same area, which treats 75,000m^3 of domestic wastewater daily, before discharging it to the Rio Cobre River (at a point close to the sea). This treated effluent could be reused for other purposes which do not require water of potable quality, in order to increase the available quantities of water from the river. This research therefore investigated the potential to reuse treated effluent from Soapberry wastewater treatment plant to irrigate sugarcane. This is because the greatest user of the water resources of the basin is the National Irrigation Commission (NIC) to supply irrigation water to farmers, whose primary crop is sugarcane. The research objectives are therefore:

i. To establish whether Soapberry WWTP can meet national effluent reuse standards for irrigation and be safely used for sugarcane irrigation
ii. To determine the acceptance level of treated wastewater for irrigation among sugarcane farmers in the Rio Cobre Basin
iii. To compare the quantities of water available from Soapberry WWTP with the irrigation water demands.
iv. To economically evaluate the proposed irrigation source against the existing source

2 LITERATURE REVIEW

The reuse of wastewater for irrigation is not a new practice and has been around for centuries. There are several benefits to using treated wastewater for irrigation, these are: reduction in the need for fertilizers (cost saving), increased crop yields (Blumenthal et al., 2000), environmental improvements because of reductions in the amount of waste (treated or untreated) discharged into water courses, and the conservation of water resources by lowering the demand for freshwater abstraction (Khouri, Kalbermatten and Bartone, 1994, p. xi). There are also negative effects, which pose threats to human health and the environment. These include: the creation of habitats for disease vectors (mosquitoes and flies), contamination of ground water, accumulation of toxic chemical pollutants in soil and crops (Khouri, Kalbermatten and Bartone, 1994) and human exposure to pathogens from excreta causing sickness. Fortunately, these health risks can be reduced by several protective measures, given by the World health Organization, (WHO, 2006). These are:

- wastewater treatment to remove pathogens,
- crop restriction (crops eaten raw would require a better quality irrigation water as compared with crops that will be cooked or processed)
- human exposure control methods (wearing gloves and shoes to limit contact with wastewater)
- wastewater application techniques (the irrigation method determines the level of contact the wastewater will have with the crop and the farm worker),
- cessation of irrigation (where irrigation is stopped and time is allowed for the pathogens to die)

2.1 Guidelines and Standards

The second edition of the WHO guidelines (WHO, 1985) and the recommended revisions to those guidelines by Blumenthal et al., (2000) have proposed maximum allowable limits of thermotolerant coliforms (i.e. indicator for faecal bacteria) and helminth eggs (i.e. parasitic worms) for treated wastewater to be used for irrigation. Based on research of the actual occurrences of disease contracted, Blumenthal et al., recommends that the maximum allowable number of thermotolerant coliforms in treated wastewater used to irrigate crops that will be eaten raw is 1000MPN/100ml with <0.1 helminth eggs/litre(if children under 15 years will come in contact with the wastewater) otherwise <1 egg/litre is recommended. They have also provided other limits for crops that will be eaten cooked, which are more relaxed. These limits are supported by other qualified professionals, who indicate that it is safe for human health (Mara, 2004).

In addition to human safety, crop and soil safety are also of concern. Ayers and Westcot (1985) have indicated three main factors that tend to affect crops irrigated with treated wastewater. These are: salinity (measured as electrical conductivity and at high values can prevent the crop from extracting the water it needs), specific ion toxicity (normally results in impaired growth and reduced yields), sodium absorption ratio, SAR (can cause soil infiltration problems and therefore affect crop growth). Ayers and Westcot (1985) have provided limits for these parameters and their degree of restriction on use for irrigation based on the quality of the treated wastewater.

3 METHODOLOGY

The study adopted a case study approach, which utilized various qualitative and quantitative methods to collect the data. These methods were:

- Document analysis - Soapberry Monthly Operational Reports, 2010-2015, were reviewed to obtain data on the treated effluent quality and discharge volumes
- Semi-structured interviews with sugarcane farmers to determine their attitudes and perceptions towards reusing effluent for irrigation
- Literature review – to obtain information on sugarcane water requirement

Analytical methods include the use of: graphs and charts, statistical analysis and thematic coding.

4 RESULTS AND DISCUSSION

4.1 Establishing whether Soapberry can meet the Jamaican effluent reuse standards for irrigation and be safely used for irrigation

It was found that the effluent from Soapberry is fully compliant for Oil and Grease, partially complaint (approximately 80% complaint) for BOD, COD and TSS and 0% compliant for thermotolerant coliforms (946 MPN/100ml) – when compared to the Jamaican standard of 12 MPN/100ml.

The water and soil salinities were found to be 0.99dS/m and 1.7dS/m respectively, and in-keeping with sugarcane tolerance levels given by Ayers and Westcot (1985). It was determined that the irrigation with effluent would not pose serious threats to ground water quality, however, if treated effluent was the sole irrigation source, then this would necessitate additional nitrogen removal from the wastewater before using for irrigation.

Despite not meeting the Jamaica standard in terms of bacteriological quality, the treated effluent can be safely used for irrigation based on the recommendations by Blumenthal et al., (2000). This is because the mean number of thermotolerant coliforms in Soapberry's effluent is less than the maximum allowable limit of 1000MPN/100ml. Furthermore when coupled with various protective measures, the number of pathogens are further reduced. Some of these measures include:

Crop restriction – restricting the crop to be irrigated with the effluent to sugarcane would reduce the potential health risks for the following reasons: 1) Sugarcane does not have surface properties that protect pathogens from exposure to radiation (its exterior is hard and smooth) and is easily washed off with rain and post-harvest washing (WHO, 2006, p. 27). 2) 98% of the sugarcane grown in the Rio Cobre basin is used to make sugar or rum, and is therefore expected to have minimal health effects because the sugarcane is not eaten raw but is processed. The process of making sugar involves six major stages - three of which involve heat. These are: clarification, evaporation and crystallization.

Cessation of irrigation - is done days before harvest to improve crop quality by reducing bacteria numbers (i.e. allowing time for "bacteria die-off") (WHO, 2006, p. 78). The cessation of irrigation is a normal requirement for sugarcane cultivation in order to ripen the cane and increase its sucrose content.

Human exposure control measures – protective measures must be implemented to safeguard the health of persons who will come in contact with the wastewater (e.g. farm workers and their families and nearby communities). One of the six farmers interviewed uses mechanical harvesters, which drastically reduces exposure to irrigation water. Of the remaining five farmers interviewed; manual harvesting of the sugarcane is done, and as such, the use of protective clothing is critical. However, the exercise of burning the cane prior to harvesting eliminates much of the risk due to pathogens.

4.2 Social Aspects of Wastewater reuse for Irrigation

The results of the social survey revealed that five of six farmers accepted the use of treated effluent for irrigation and even welcomed it, while one farmer was vehemently opposed to it. They also indicated an acceptable willingness to pay, by indicating that they would pay the same (or less) for treated effluent as they currently pay for irrigation water – provided it is safe for human health and the crop.

4.3 Irrigation Water Requirements

It was determined that only 82% of the effluent from Soapberry can be safely used to irrigate sugarcane based on nitrogen levels. This would provide 71% of the crop water requirement (for a land area of 2,160ha), and therefore irrigation would still be necessary from other sources.

4.4 Preliminary engineering of the proposed effluent scheme

The proposed effluent reuse scheme would require: chlorination to reduce thermotolerant coliforms, 10km pipeline from Soapberry to Bernard Lodge sugarcane lands, storage and pumping to overcome the 57m difference in elevation. This is estimated to cost $29,211,375USD, with an annual operation and maintenance (O&M) cost of $420,000USD.

4.5 Economic and Financial Implications

The proposed tariff to cover both these costs, over a twenty year period came out at 0.14USD/m^3, based on the average incremental approach. This is 15% higher than the cost of the current source and is considered financially non-viable, unless other financing options are explored. However, the proposed effluent reuse scheme has several advantages including the potential cost savings of no longer requiring fertilizers, which amounts to $300USD/ha annually.

5 CONCLUSIONS

The water resources of the Rio Cobre Basin can be more effectively managed by reusing the treated effluent from Soapberry to irrigate sugarcane. Soapberry can be safely used for sugarcane irrigation - based on the quality of the current treated effluent - despite not meeting the Jamaican standard for thermotolerant coliforms; and famer acceptance.

6 RECOMMENDATIONS

Some of the recommendations include:

Pilot testing with small sugarcane fields immediately adjacent to Soapberry (this will provide useful information without the capital outlay)

- Provide a generator or alternate power source for Soapberry (in the event of power outages) as well as ensure the timely delivery of cationic polymers, to guarantee good quality effluent is produced at all times
- Public education campaigns to sensitize and train farmers about the safe use of treated effluent for irrigation, including the various human exposure control techniques, such as wearing gloves and shoes while working with effluent.

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ABBREVIATIONS AND ACRONYMNS

BOD	Biological Oxygen Demand
CAPEX	Capital Expenditure
COD	Chemical Oxygen Demand
EOJ	Electoral Office of Jamaica
EPA	Environmental Protection Agency
GIS	Geographical Information System
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
IWRM	Integrated Water Resources Management
JIS	Jamaica Information Service
KSA	Kingston and St. Andrew
MGD	Million Gallons per Day
MLD	Mega Litres per Day
MoA&F	Ministry of Agriculture and Fisheries
MOH	Ministry of Health
MWLECC	Ministry of Water, Land, Environment and Climate Change
NEPA	National Environment and Planning Agency
NIC	National Irrigation Commission
NWC	National Water Commission
O&G	Oil and Grease
O&M	Operation and Maintenance
OUR	Office of Utilities Regulation
PIOJ	Planning Institute of Jamaica
WRA	Water Resources Authority
RWSL	Rural Water Supply Limited
SIA	Sugar Industry Authority
SIRI	Sugar Industry Research Institute
Soapberry	Soapberry Wastewater Treatment Plant
STATIN	Statistical Institute of Jamaica
TN	Total Nitrogen
TSS	Total Suspended Solids
$USD	United States Dollar
UV	Ultraviolet Light

WRA	Water Resources Authority
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

1.1 Chapter Introduction

As implied by the word itself, wastewater has traditionally been regarded as waste. This is particularly true for the Jamaican context where there are very few instances of wastewater reuse. However, in actuality, several reuse applications exist worldwide, especially for treated wastewater, which may be used for irrigation, industrial cooling processes and even for groundwater recharge. These various reuse potentials arise because not all activities using water require it to be of potable quality. In fact, and as expressed in the EPA Guidelines for Water Reuse (EPA, 2012), water should be “fit for purpose”. That is, the intended water use dictates the quality of water required.

Chapman (1996,p.111) is in agreement with this notion, and states that, “use-oriented assessments determine the quality of water required for specific purposes, such as drinking water supply, industrial use or irrigation”. This has been long recognized in Jamaica, and is evident by the fact, that the various uses of water have specific requirements with respect to physical and chemical variables or contaminants. As such, there are national standards for drinking water quality, irrigation water quality and even standards for the use of treated wastewater for irrigation.

Yet, even with the formulation of these various water quality standards, treated wastewater is not used for irrigation; instead, agricultural water needs are satisfied solely by freshwater sources (rivers and ground water). This water use behaviour has become a challenge in the Rio Cobre Basin of Jamaica, because water demand is fast approaching available supply. The current proportioning of the basin’s available water resources is 70/30, with the agricultural sector receiving 70% (more than half is used to irrigate sugarcane) and the remaining 30% used for domestic uses after treatment to potable quality (WRA, 2014). However, this current allotment is proving inadequate for the domestic water market because of the rapid urbanization of the area. Urbanisation has drastically increased the population and, as a result, the water demand.

On the other hand, Soapberry wastewater treatment plant (WWTP) is a potential irrigation water source, and is situated in the Rio Cobre Basin amidst thousands of hectares of irrigation-dependent sugarcane farmlands (see Figure 1.1. for an aerial view of Soapberry WWTP and Figure 1.10 for the relative locations of Soapberry and the farmlands). The plant produces approximately 75,000m^3 of treated wastewater daily, which could be used directly for irrigation, but is instead discharged to the Rio Cobre River.

It is therefore evident that an integrated water resources management approach is needed because of the competing water demands and uses. This research, therefore adopts a case study approach to investigate the potential of the direct reuse of treated effluent from Soapberry wastewater treatment plant, to irrigate sugarcane in the Rio Cobre Basin of Jamaica. If feasible, this could change the perception of wastewater from mere waste to a valuable resource – "Sweet Wastewater".

Figure 1.1 Aerial View of Maturation Ponds at Soapberry Water Treatment Plant

Source: Jamaica Observer (2014)

1.1.1 Adopted Terminologies

There are different terms used to describe wastewater and the understandings of these terms also differ. As such, definitions of the various terms referring to wastewater are provided in this section. The wastewater terminologies adopted for this research are as defined by Drechsel (2010).

1. ***Wastewater*** - the term "wastewater" as used in this report refers to wastewater of different qualities, ranging from raw, diluted, to treated, and has been generated by various urban activities, which may be a combination of the following:

- Domestic effluent consisting of black-water (excreta, urine and faecal sludge, i.e. toilet wastewater) and grey-water (kitchen and bathing wastewater).
- Water from commercial establishments and institutions
- Industrial effluent where present

- Storm-water and other urban run-off

2. ***Treated wastewater*** - is wastewater that has been processed through a wastewater treatment plant up to certain standards in order to reduce its pollution or health hazard; if this is not fulfilled; the wastewater is considered at best as partially treated.

3. ***Reclaimed (waste) water or recycled water*** - is treated wastewater that can officially be used under controlled conditions for beneficial purposes such as irrigation.

The typology of the wastewater used for irrigation can be describes as either, direct or indirect. These are defined as follows:

- ***Direct use of untreated wastewater*** refers to the use of raw wastewater from a sewage outlet, directly disposed of on land where it is used for crop production.
- ***Indirect use of untreated wastewater*** refers to the abstraction of usually diluted wastewater (or polluted stream water) for irrigation.
- ***Direct use of treated wastewater*** refers to the use of reclaimed water that has been transported from the point of treatment or production to the point of use without an intervening discharge to waters.
- ***Indirect use of treated wastewater*** refers to the abstraction of treated wastewater that has been discharged to a water course, and abstracted for irrigation after mixing.

1.1.2 Chapter Overview

This chapter includes sections describing Jamaica's geography and hydrology (section 1.1.2), as well as the island's regulatory and institutional framework governing the water and agricultural sectors (sections 1.1.3 and 1.1.4). This is done in an attempt to put the research in context for readers unfamiliar with Jamaica.

The chapter then ends with a Background to the problem identified for research (section 1.2), the problem statement (Section 1.3) and finally, the research aims and objectives (section 1.4)

1.1.3 Geography and Hydrology

Jamaica is the largest Anglophone island in the Caribbean and has an approximate area of 10,991 square kilometres (JIS, no date). Jamaica's climate is predominantly a tropical maritime one, with an average annual temperature of 28° Celsius, and average annual rainfall of 198 centimetres (WRA, 2012). Most of the island's rainfall is recorded during the "wet season" (June – November), corresponding with the Tropical Atlantic Hurricane Season.

The island consists of fourteen administrative districts or parishes, as shown in Figure 1.2 below (JIS, no date). The capital city is Kingston, and Kingston is the smallest parish in terms of geographical area (JIS, no date). The parish borders of Kingston and St. Andrew are usually unclear to the general public, and as such the parishes' names are usually used interchangeably. Combined they are referred to as KSA (i.e. Kingston and St. Andrew) with a single mayor and single parish council representing them under the local government arrangement. For the purposes of this report, the geographical areas will be used in reference to either parish specifically, or KSA when referring to both parishes. The neighbouring parish of St. Catherine (see Figure 1.2) is the second most populated parish on the island (STATIN, 2011, p.4). It is also the parish in which the Soapberry wastewater treatment plant and several sugarcane plantations are situated. Kingston, St. Andrew and St. Catherine are located in the south-eastern section of the island.

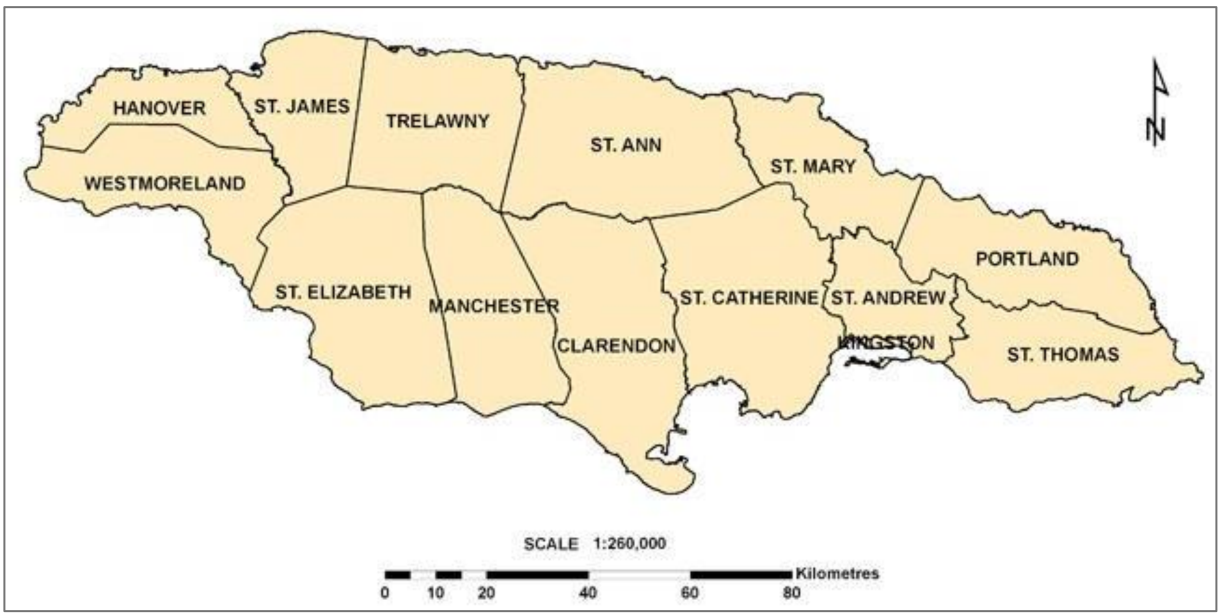


Figure 1.2 Map of Jamaica Showing Parishes

Source: Electoral Office of Jamaica, EOJ (n.d.)

St. Catherine, together with small sections of St. Andrew, Clarendon and St. Ann comprise the geographical area of the Rio Cobre Basin (as indicted in Figure 1.3 below – highlighted in green). The Rio Cobre Basin is one of ten hydrological basins into which Jamaica has been divided, and Figure 1.3 shows these different basins. The basin boundaries are the main surface water divides, but in some instances groundwater divides have been used for the basin division (WRA, 2012). “For planning and management purposes these basins have been further subdivided into sub-basins which are discrete hydrologic sub-units of the basins. These basins and sub-basins are managed by the Water Resources Authority” (WRA, 2012).

Figure 1.3 Hydrological Map of Jamaica

Source: Author (2015)

The Rio Cobre basin occupies 1,283 square kilometres and is sub-divided into two sub-basins, the Upper and Lower Rio Cobre, as shown in Figure 1.4. As can be seen from Figure 1.4, the boundary between the two sub-basins runs approximately East-West. The two principal aquifers in the basin are limestone and alluvial aquifers. These are the main sources for water supply for St. Catherine parish in addition to the Rio Cobre River (surface water source).

The major river draining the Upper Rio Cobre sub-basin is the Rio Cobre with its larger tributaries being Rio Pedro, Rio Magno, Rio Doro and Thomas River, as shown in Figure 1.4. The Rio Cobre River is 52.5 km in length flowing south towards the sea (at Hunts Bay) with an average flow of 1000 MLD (WRA, 2012). The Rio Cobre Diversion Dam (otherwise called the Headworks Dam) is located at the downstream end of the limestone gorge that separates the Upper and Lower Rio Cobre sub-basins (WRA, 2012).

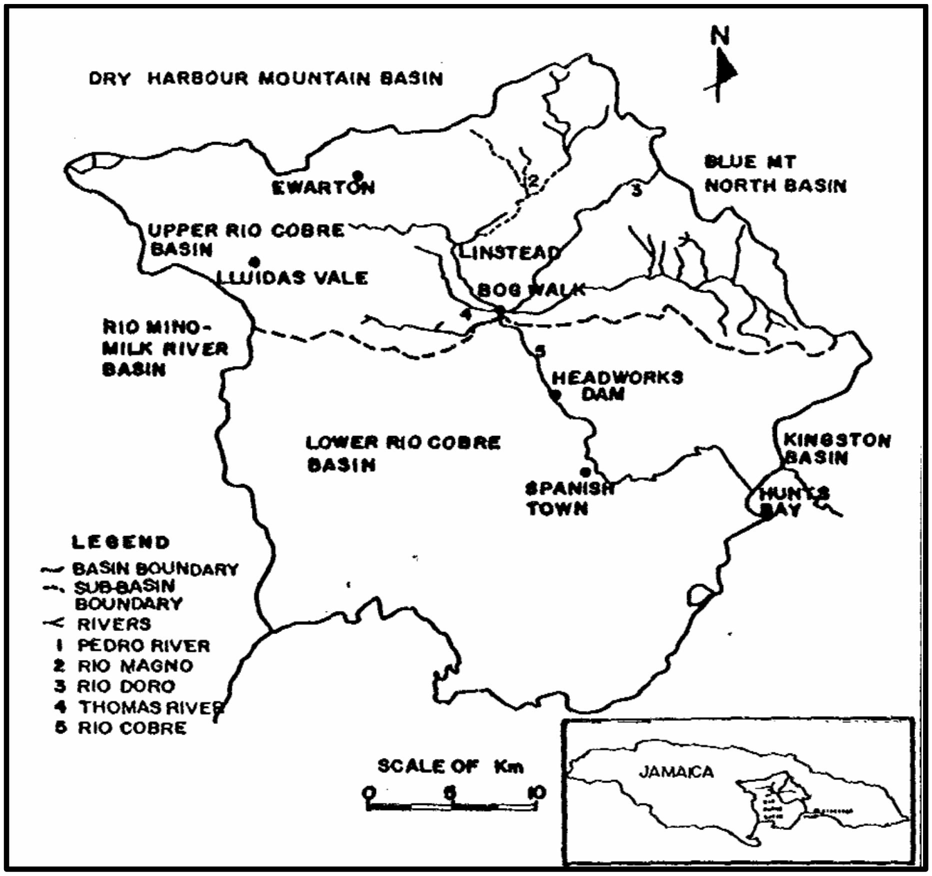


Figure 1.4 Map of Rio Cobre Basin

Source: Morgan (1995)

1.1.4 Institutional Framework

The Jamaican government comprises several ministries. The ministries of concern for this research, however, are those associated with the water and agricultural sectors, and the structure of these ministries is shown in figure 1.5. The Ministry with responsibility for the water sector is the Ministry of Water, Land, Environment and Climate Change (MWLECC). MWLECC has responsibility for policy formulation and implementation related to water, land, environment and climate change. Reporting to this ministry are several state agencies (see Figure 1.5), such as:

- The National Water Commission (NWC) – NWC is a statutory body having responsibility for the provision of potable water for domestic, commercial and sometimes industrial uses, as well as having responsibility for the collection and treatment of domestic wastewater.

- The Water Resources Authority (WRA) – WRA is responsible for the management, protection, and controlled allocation and use of Jamaica’s water resources.
- Rural Water Supply Limited (RWSL) – RWSL’s objectives are to improve the basic sanitary/health conditions by increasing the coverage of potable water and sanitation services in poor rural areas.
- The National Environmental Protection Agency (NEPA) – NEPA is an executive agency and is charged with promoting sustainable development by ensuring the protection of the environment and orderly development in Jamaica.

The agricultural sector falls under the Ministry of Agriculture and Fisheries (MoA&F). This ministry is responsible for the sustainable development of Jamaica’s agricultural sector. There are also several state agencies reporting to this ministry (see Figure 1.5). Those of concern for this research are:

- The National Irrigation Council (NIC) – NIC is the government agency charged with managing, operating and maintaining irrigation schemes within six districts located in key irrigation areas.
- The Sugar Industry Authority (SIA*)* – SIA is the regulatory body of the Jamaica sugar industry and has been vested with powers to regulate and monitor the industry including the functions of arbitration, planning, research and development.
- The Sugar Industry Research Institute (SIRI) – SIRI has been established under the auspices of the SIA, and its main functions are to research and develop methods to improve agriculture technology and efficiency as it relates to sugarcane production.

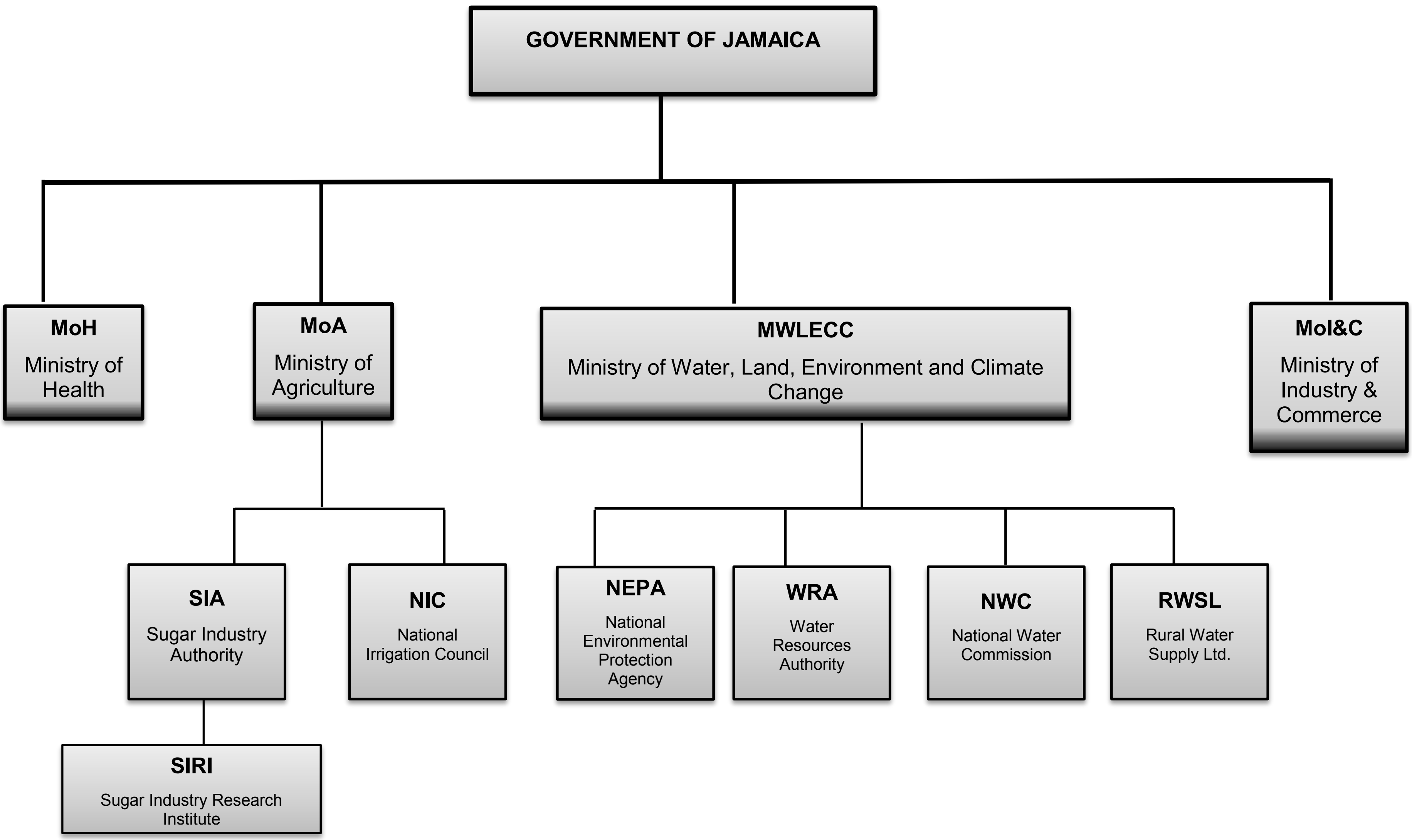


Figure 1.5 Government of Jamaica (GoJ) Structure of Relevant Ministries and Agencies

Source: Author (2015)

1.1.5 Regulatory Framework

There are several water providers within the Jamaican water sector which supply water for all its various uses; these are:

- The National Water Commission (NWC), which provides potable water for domestic, commercial and industrial uses.
- Private Water Operators, which also supply potable water for domestic uses to less than five percent of the population
- Rural Water Supply Limited (RWSL) – which constructs and operates potable water supply schemes for rural communities, and
- The National Irrigation Council (NIC) – which provides water to the agricultural sector for irrigation proposes.

These various water providers are not only governed by the Ministry of Water, Land, Environment and Climate Change but also by several other ministries and/or agencies, some are shown in Figure 1.6. Some of these are also shown in Figure 1.5, but Figure 1.6 concentrates on the regulatory framework for the water sector. Some of these ministries and agencies have already been mentioned, but their roles in relation to regulation are now highlighted. There is regulation in the form of economic regulation, abstraction licences, water quality standards and environmental regulation. The regulatory bodies within the water sector are:

- The Office of Utilities Regulation (OUR) – which provides economic regulation in the form of tariff setting and guaranteed standards of performance.
- The Ministry of Health (MoH) – which is responsible for setting and enforcing drinking water quality standards.
- The Water Resources Authority (WRA) - The functions of the WRA include the monitoring of surface water and groundwater quality as well as the allocation of water rights for various uses by issuing water abstraction licences.

The National Water Commission is the primary operator of wastewater treatment facilities, with a few private operators and one main regulator, as can be seen in Figure 1.7. Regulation for the wastewater sector is by:

- National Environmental Protection Agency (NEPA) – with the responsibility of issuing effluent discharge permits, setting and enforcing effluent discharge standards and setting the wastewater reuse standards for irrigation.

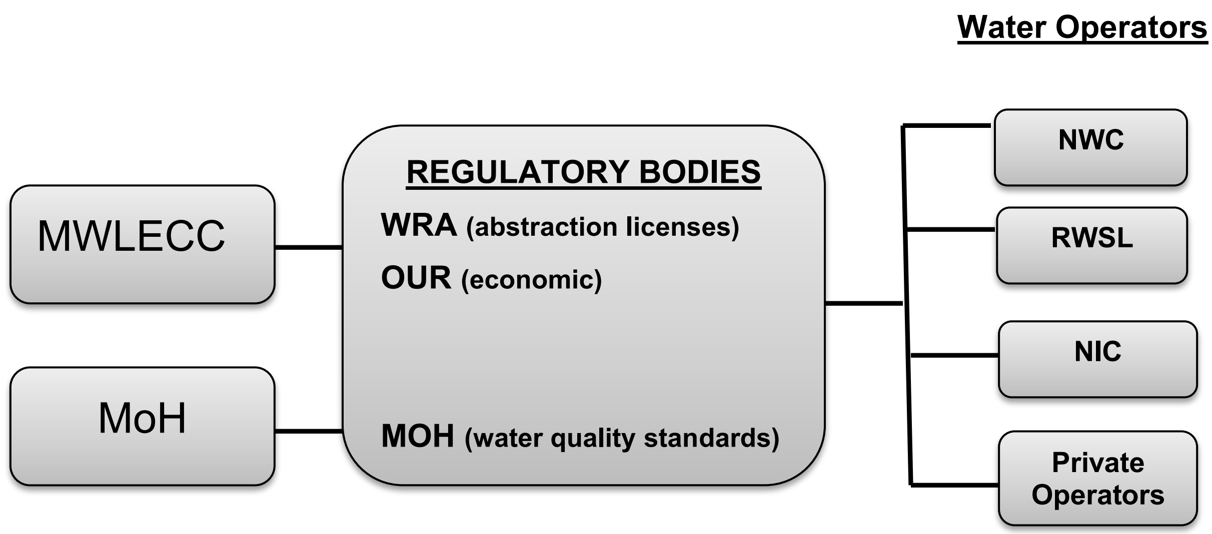


Figure 1.6 Diagram Illustrating the Regulatory Framework for the Water Sector

Source: Author (2014)

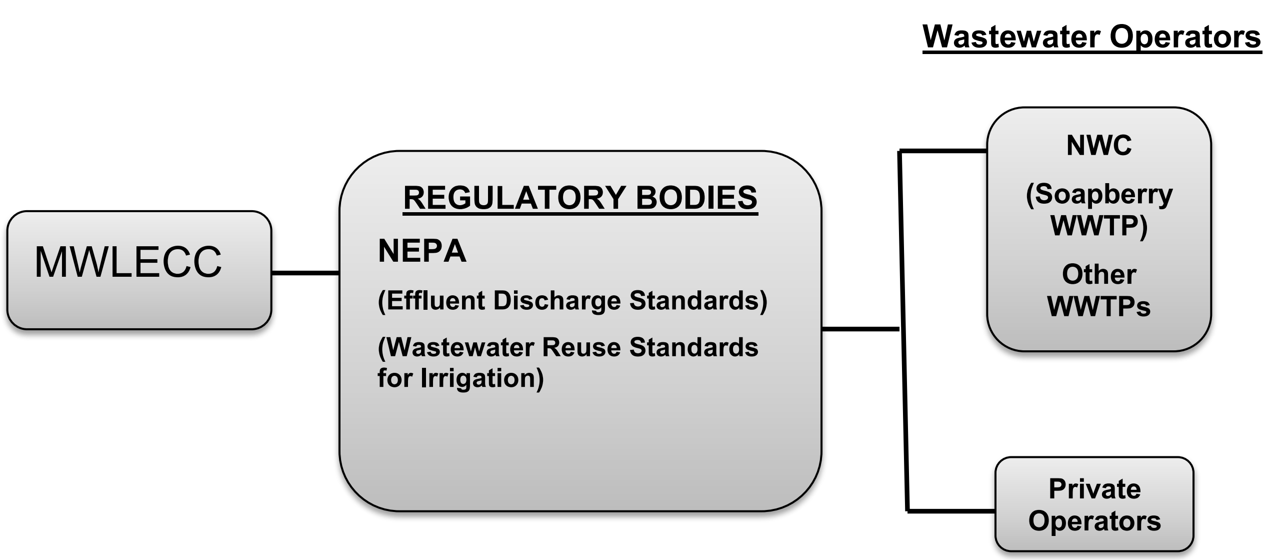


Figure 1.7 Diagram Illustrating the Regulatory Framework for the Wastewater Sector

Source: Author (2014)

1.2 Background to the Problem

Xaymaca – meaning 'land of wood and water' or 'land of springs' is the Arawak name given for Jamaica by its earliest inhabitants (JIS, no date). As the Arawak name suggests, Jamaica has abundant water resources. This is apparent as The Water Resources Authority, WRA (2014) has reported a reliable/safe yield for the island of 11,365 mega litres per day (MLD), while current water usage across all sectors amounts to only 1,727 MLD (WRA, 2014). This usage represents a mere fifteen percent of the available water resources. This available water resource is in terms of both surface water and groundwater reserves. Groundwater resources are of significant importance in Jamaica, and the country has a large dependence on this water source which supplies between 84% and 92% of water demand (WRA, 2012).

However, despite having vast quantities of freshwater resources and being completely surrounded by the Caribbean Sea, only 73% of the population is supplied via house connections (STATIN, 2011) - 91% of which is from the National Water Commission, NWC (primarliy intermittent supplies). The remaining 27% obtain water from standpipes, water trucks, rainwater catchment tanks, and direct access to rivers (STATIN, 2011).

Although Jamaica is currently not faced with issues of water stress or water scarcity, the water supply issues are nonetheless real and have been documented in the NWC Parish Plan document (NWC, 2011) and the Climate Change Risk Atlas for Jamaica (CARIBSAVE, 2012). These issues relate to current shortfalls in water supply and the location of water resources in relation to major population centres; agricultural water demand; and climate change risks. These are further explained below.

1.2.1 Potable Water Supply Shortfall

There is a current deficit in water supply for the island, amounting to 45 MLD, as well as projected future deficits in supply (136 MLD in 2030) if nothing is done (NWC, 2012). Similarly, on the basin level, the Rio Cobre Basin has a current deficit in supply of 22 MLD. This deficit in supply for the Rio Cobre basin is not only due to the size of existing infrastructure (pumping equipment, treatment capacity of plants and undersized distribution mains) but is as a result of the limited water resources of the basin. The Rio Cobre Basin, along with the Kingston and Rio Minho Basins, all have the largest population centres, with water demands that exceed available resources (WRA, 2014). Comparatively, across the various basins, the Rio Cobre Basin has by far the greatest water supply shortfall followed by the adjoining Rio Minho Basin (see Figure 1.8). This is due mainly to the rapidly increasing populations within these basins. St. Catherine is the second most populous parish on the island (after KSA) and its population has increased by as much as 7% between the 2011 and 2001 census period (compared to the national growth rate of 3% over the same period) (STATIN, 2011). This can be attributed to rapid urbanization - which only seems to be accelerating, as indicated by the number of subdivision applications for housing received for this area. This is of primary significance because the study area, i.e. the Rio Cobre basin, spans the parish of St. Catherine, and the water resources of the basin are scarce and finite.

There is therefore a deficit in water supply for the Rio Cobre Basin and for the island in general. However, there is only a deficit in the water resources for some basins, including the Rio Cobre basin, and not for the island on a whole. The distribution of water resources varies across the country's ten hydrological basins, where the north-eastern regions are more water secure, and the southern coastal plains suffer from low rainfall and frequent periods of droughts. Since insufficient volumes of freshwater resources is not a problem for Jamaica then it is expected that, although certain basins have insufficient supplies, inter-basin water transfers would be the solution to the current problems in water supply. However the costs to convey water from the northern side of the island to the "water restricted" south coast where the major urban centres are located would be astronomical. Figure 1.7 below shows the portions of water used and unused for each basin. Interestingly, as much as 78% of the water resources of the Rio Cobre Basin are currently being used. Although 22% of the water resources is currently unused, if 100% of the water resources were to be delivered there would still be a shortfall in supply based on current demands.

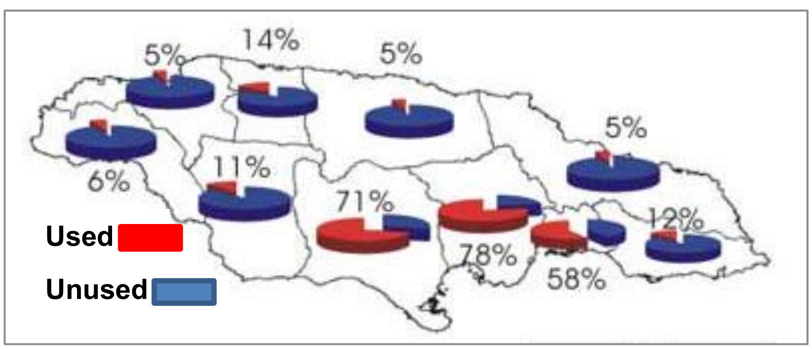


Figure 1.8 Map Showing Exploitable Water Used by Basin

Source: Water Resources Authority, WRA (2012)

1.2.2 Agricultural Water Demand

In terms of water use, the agricultural sector has the greatest water demand, accounting for 75% of the water consumed in the country, followed by 17% for domestic water, 7% for industrial and 1% for tourism (WRA, 2012). On the basin level, 70% of the water resources are used for agriculture, and half of this amount is used to irrigate sugarcane. The research therefore places emphasis on the sugarcane crop because of its prevalence (occupying the majority of the irrigable lands in the basin) and its water demand (using more than have of the agricultural water allotment for the basin).

Irrigation is important to the agricultural sector because rainfall distribution on the island is uneven. Several sugarcane plantations require only minimal irrigation because of their geographical locations, where there is ample rainfall throughout the year. However this is not the case for the sugarcane farmlands within the Rio Cobre Basin which are dependent on irrigation. The demand for irrigation water is greatest in the south, due to lower rainfall. Ironically, the parishes with the largest proportion (60%) of farming area are also located in the south: Westmoreland (44,000 ha), St. Elizabeth (30,000 ha), Clarendon (44,000 ha) and St. Catherine (38,000 ha) (MoA&F, 2014). (See Figure 1.2 for a map of Jamaica which shows the parishes).

Figure 1.9 Sugarcane being irrigated by flooding the furrows

Source: Handal (2015)

1.2.3. Climate Change Risks

“The island has been found to be vulnerable to climate change as both observed and modeled climate variables indicate some impact on water resource availability. Drought conditions frequently affect Jamaica, and drought has been a recurring national problem since 2010, particularly in the southern coastal plains, which also have the highest urban population. If temperatures increase and rainfall decreases, as observed climate data indicates, episodes of drought may become more severe. Coastal aquifers in the south have already experienced seawater intrusion, largely resulting from over-abstraction. Sea level rise is likely to make this issue more severe. Additionally, Jamaica has a history of flooding, and changes in climate may result in increased episodes of extreme weather events which can cause erosion of the topsoil and subsequent reduction in water quality of groundwater (CARIBSAVE, 2012)."

1.2.4 Conclusion

The two main abstractors of water in the Rio Cobre basin are NWC (for domestic water supplies) and NIC (for irrigation water), which have been granted rights to abstract specified volumes of water from the Rio Cobre River daily. In addition to providing water for domestic and agricultural purposes, the Rio Cobre River is also the receiving body for the effluent discharge stream from the Soapberry wastewater treatment plant. Consequently, there are three competing uses for the finite and limited resources of the Rio Cobre Basin and the Rio Cobre River in particular. Two of these uses are for abstraction, and the third is for discharge. These are: abstractions by NWC to supply its domestic customer base (which has limited water resources and a current supply deficit with an ever increasing population), abstractions by NIC for agricultural uses for which the prime crop is sugarcane and thirdly, for the discharge of treated effluent from Soapberry wastewater treatment plant. Figure 1.10, shows the various water use activities by NIC, NWC and Soapberry, and their relative positions along the Rio Cobre River.

These competing water uses of the limited and finite resources of the basin speak clearly of the need for integrated water resources management (IWRM) for the basin. One such IWRM approach is reusing the effluent from Soapberry for agricultural purposes and in particular, for sugarcane irrigation. This IWRM measure of directly reusing Soapberry's effluent for irrigation being investigated by this research is in keeping with the Island's policy directives. Both the Water Sector Policy (MWLECC, 2004) and the draft Water Sector Policy (MWLECC, 2015) make mention of exploring the potential for wastewater reuse for irrigation. Additionally, Jamaica's on-going National Development Plan – "Vision 2030 Jamaica" (PIOJ, 2010) has, as one if its goals, 'to ensure environmental sustainability and conservation of the country's national resources". The Vision 2030 document proposes to achieve this goal by: "hazard risk reduction and adaptation to climate change as well as sustainable urban and rural development". However, the greatest support for this research stems from The Climate Change Risk Atlas for Jamaica (CARIBSAVE, 2012) which recommends the following as one of its strategies for water management in Jamaica – i.e. "to assess the possibility of broad scale implementation of waste water recycling schemes and legislation especially in irrigation. "

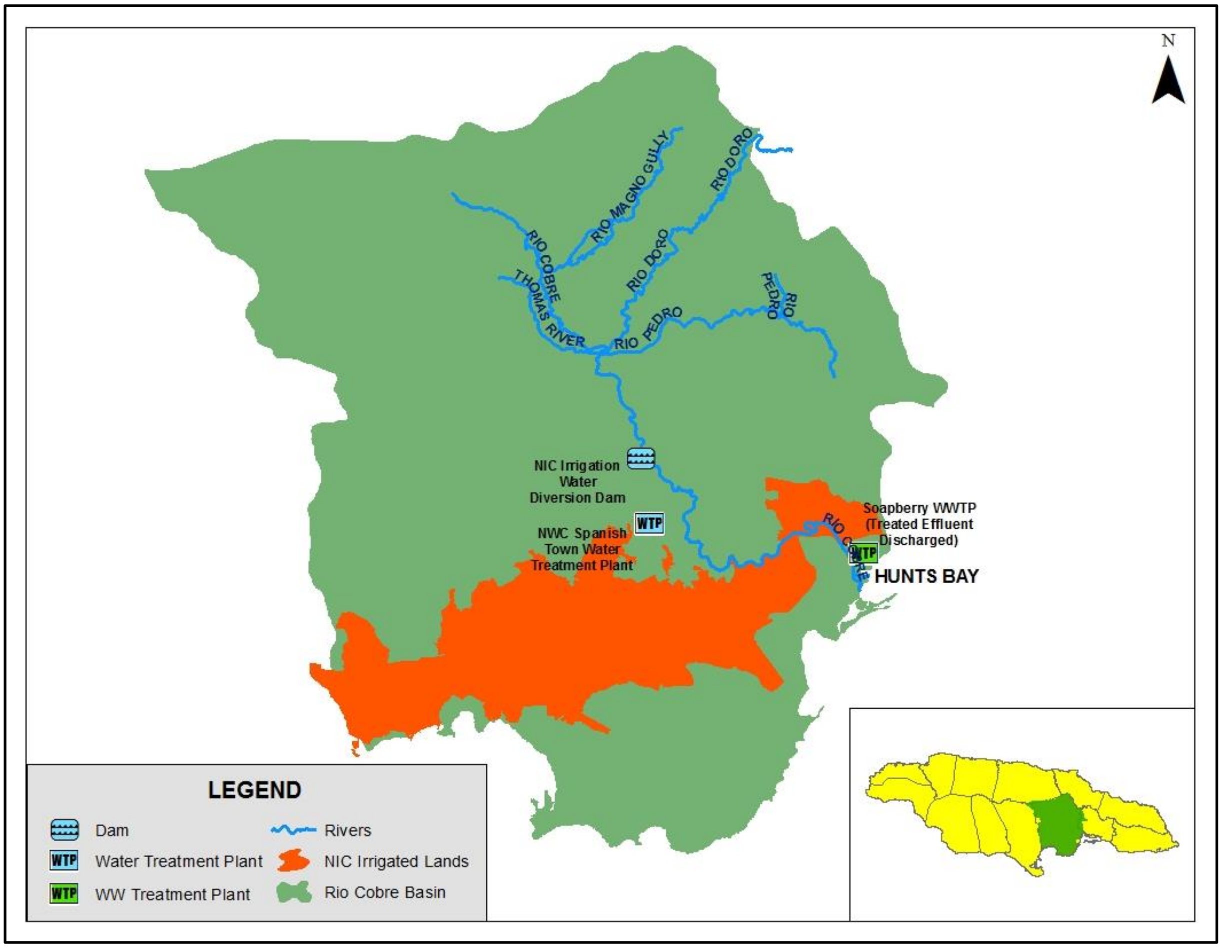


Figure 1.10: Map of Rio Cobre Basin showing the locations of its three Competing Uses

Source: Author (2015)

It is important to note, that the current utilization of the water from the Rio Cobre River for irrigation is not an indirect use of the treated effluent from Soapberry. This is because the NIC point of abstraction for irrigation is further upstream while Soapberry's treated effluent is discharged downstream – only a few kilometres before the mouth of the river, i.e. the point it reaches the Caribbean Sea

1.3 Problem Statement

The Rio Cobre River has three competing uses for its water resources, which have all been granted the required abstraction licenses or discharge permits. It serves as:

i. A raw water source for the National Water Commission's Spanish Town water treatment plant for potable uses (18 MLD),
ii. A source of irrigation water for over 7,042 hectares for customers of the National Irrigation Council (368 MLD), and
iii. A receiving body for the effluent discharge stream from Soapberry wastewater treatment plant (75 MLD).

However because of the supply shortfalls previously mentioned; the increasing population and hence increasing water demand; the occurrences of more severe and prolonged drought periods; and also the high costs associated with inter-basin water transfers, NWC is desirous of abstracting a further 91 MLD of water daily from the Rio Cobre River to both increase the output from Spanish Town Treatment plant located in St. Catherine and to supply an additional treatment plant that is planned, but yet to be constructed. It is important to note that this is a short term solution because the total water resource of the basin is just not adequate to meet the demands.

Markedly, this application by the NWC to the Water Resources Authority for increased abstractions was deferred pending a study of the Rio Cobre Basin to assess whether this increased abstraction can be safely and sustainably taken (WRA, 2014). Potable water uses are generally given high priority in regard to water allocation (Water Sector Policy, 2004). However, for Jamaica's stagnant economy the importance of irrigation water, especially for sugarcane irrigation (as 76% of all irrigated land is for sugarcane production) cannot be ignored. Furthermore, sugarcane production contributes significantly to GDP in terms of sugar and rum exports accounting for approximately 45% of the export earnings for all export crops and derived products (MoA&F, 2014). Additionally NIC is unwilling to yield its right to the above stated volume, as the Rio Cobre irrigation scheme is its most economical, as it is a gravity supply system unlike its other pumped systems.

Even if the study reveals that NWC can safely abstract the additional volume, the overall water resources of the basin are insufficient. As a result NWC will have no means of sustainably increasing its water supply to its customers in this area who desperately need the additional water, as the cost to channel water from Jamaica's north coast to the south cost would be astronomical. It is therefore paramount that the potential for Soapberry's effluent re-use is considered for the more efficient management of water resources. This greater efficiency in managing Jamaica's water resources by reusing wastewater for irrigation is supported by the Jamaica Water Sector Policy 2004, which states that this area should be further researched and considered.

There is therefore a gap in the knowledge within the Jamaican water sector as to how Soapberry's effluent may be reused for agriculture and therefore better manage the resources of the Rio Cobre basin. This research has therefore adopted a case study approach to assess whether the treated effluent from Soapberry (75,000m^3) could be used for sugarcane irrigation. This would greatly offset the volume of water required by NIC to be abstracted from the Rio Cobre River and therefore provide NWC with the leeway to abstract the additional 91 ML of freshwater required daily.

Nevertheless, for Soapberry's effluent to be used as irrigation water further treatment would be required. This is because Soapberry's effluent currently does not meet the Jamaican quality standards, for irrigation using effluent, as the level of thermotolerant coliforms is above the specified national limit. Furthermore, for effluent reuse for sugarcane irrigation to be viable, there must be acceptance of treated effluent as a water resource, especially among the agricultural sector, and it must not be economically unfavourable when compared to the current source.

It is therefore for these reasons the following research questions arise:

- How can Soapberry's treated effluent be used for irrigation?
- How much water can be provided from Soapberry?
- How much water is needed by the sugarcane farmers for irrigation?
- How much of the irrigation demand can be met by Soapberry on a monthly basis?
- Will the Farmers of the Rio Cobre basin accept treated effluent for irrigation water?
- What are the cost implications for reusing Soapberry's effluent for irrigation?

1.4 Research Aim and Objectives

The aim of the research is to assess whether the water resources of the Rio Cobre Basin in Jamaica can be managed more effectively, by exploring the reuse potential of Soapberry's treated effluent for sugarcane irrigation.

The research objectives are:

v. To establish whether Soapberry WWTP can meet national effluent reuse standards for irrigation and be safely used for sugarcane irrigation

vi. To determine the acceptance level of treated wastewater for irrigation among sugarcane farmers in the Rio Cobre Basin

vii. To compare the quantities of water available from Soapberry WWTP with the irrigation water demands.

viii. To economically evaluate the proposed irrigation source against the existing source

1.5 Project Scope

The research is focused on the treated effluent produced by Soapberry wastewater treatment plant and the potential for its direct re-use as irrigation water for the sugarcane crop only within the geographical location of the Rio Cobre Basin, St. Catherine, Jamaica. Although details are location specific, a similar approach may be applicable in other parishes of Jamaica (St. James) and possibly other Caribbean islands.

1.6 Report Structure

The issues associated with wastewater reuse are interdisciplinary (Mara and Cairncross, 1989), as such; the research required careful examination of the following areas: social, health, technical, economic, financial, environmental and institutional.

The report is comprised of five chapters. The review of relevant literature pertaining to effluent reuse for irrigation - in the context of sugarcane irrigation is presented in Chapter two. Where - issues such as potential benefits, health and environmental risks and agronomic considerations for sugarcane are discussed. Chapter three presents the methodology employed for the research; which includes a mix of both qualitative and quantitative data collection tools. These tools (document analysis, semi-structured interviews and literature review) are discussed in terms of their related credibility/validity/reliability. Chapter four presents the findings of the data collected. It includes an analysis and discussion of the suitability of reusing soapberry’s treated effluent for irrigation and the outcome of the social survey to determine farmers’ attitudes toward effluent reuse. Chapter five provides recommendations and conclusions based on the findings of the research in relation to the research aims.

2 LITERATURE REVIEW

2.1 Chapter Overview

The literature review provides an overview of the concepts relating to wastewater reuse for irrigation in the general sense, and from the perspective of reusing Soapberry's treated effluent to irrigate sugarcane. The issues associated with wastewater reuse are interdisciplinary (Mara and Cairncross, 1989), and as such, the following inter-related issues: social, health, technical, economic, financial, environmental and institutional - are highlighted in this chapter.

The Chapter begins by explaining the methodology adopted for the literature review (Section 2.2). The discussion is initiated by presenting global and local occurrences of wastewater reuse for irrigation (Section 2.3). A discussion on the advantages of effluent reuse for irrigation is presented in Section 2.4. While, the disadvantages of using treated effluent for irrigation by discussing the various health and environmental risks is presented in Section 2.5. The various protective measures that can be employed to reduce the risks from the hazards presented in the previous section are given in Section 2.6. The literature review continues by presenting a discussion on the microbiological quality considerations for wastewater to be used for irrigation, and a comparison on various effluent reuse standards for select countries (Section 2.7). Other important water quality concerns regarding wastewater reuse for irrigation is presented in Section 2.8.
The discussion then switches focus in Section 2.9 by presenting certain agronomic information for sugarcane. Social, institutional and economic considerations for the reuse of wastewater for irrigation are given in Sections 2.10, 2.11 and 2.12 respectively. The review ends with a summary of the main points discussed (Section 2.13).

2.2 Literature Review Methodology

The literature review process commenced by creating a mind map of the likely sources of information based on the research topic. This is shown in Table 2.1 below.

Table 2.1 Mind Map of Likely Sources of Information

Local University/College Libraries	University of The West Indies (UWI) Library College of Agriculture, Science and Education (CASE) Library
Government Ministries and Agencies	National Water Commission (NWC) Water Resources Authority (WRA) Ministry of Agriculture and Fisheries (MoA&F) Scientific Research Council (SRC) Sugar Industry Research Institute (SIRI) Jamaica Information Service (JIS)
Online Search Engines	Google Google Scholar
Loughborough University's Online Resources	Library Catalogue Plus WEDC Database Aqualine
NGOs	World Health organization (WHO) World Bank

The initial stage of the literature review was centred on justifying the research problem and developing the aims and objectives of the research, by identifying gaps and inconsistencies in current knowledge. The search strategies and justifications of the approach of this "pre-research" stage of the literature review are detailed in Table 2.2.

Table 2.2 Pre-Research Stage - Literature Search Strategies

Research Question/Area	Source of Information	Search Strategy	Justification of Approach
Is the problem identified for research actually a problem? And to what extent? (i.e. Potable water supply shortfall and limited water resources of Rio Cobre Basin)	Government Ministries and Agencies: NWC WRA NIC	Review of known NWC Documents and WRA website	Problem identification and quantification by determining the safe yield of the water resources of the Rio Cobre Basin and comparing it with the Basin's water demands (domestic, industrial and agricultural)
Is it worth investigating?		Interviews with senior NWC and WRA staff for their perspectives on research topic	To inform the problem background
Are there any benefits from the research?		Review of Jamaica's Water Sector Policy and Jamaica's National Development Plan to see if they are in support of research objective	

Once this stage was completed, the main literature review was guided by an attempt to achieve the aims and objectives of the research. The main intentions of the literature review were: to develop a deeper understanding of the issues relating to wastewater reuse for irrigation, to situate the research in context, and to study literature on relevant methodologies and data collection techniques required for the research. Additional research questions based on four main keywords (Jamaica, sugarcane, effluent reuse and irrigation) were generated - which the literature review sought to answer. The sources of information, search strategy and justification of approach used in obtaining the answers are given in Table 2.3 on the pages following.

Table 2.3 Literature Search Strategies

Concept	Research Question/Area	Source of Information	Search Strategy	Justification of Approach
Jamaica	How can the audience fully understand the context of the research?	JIS, NWC, MWLECC, MoA&F, EOJ, Acts and Regulations	JIS website provided background information on the country. The various ministry websites were browsed to obtain the role and functions of all the players in the water sector. The roles were verified by reviewing the Acts governing each agency.	To create a country profile with information pertinent to the topic To provide information on Jamaica's institutional arrangements and regulatory framework
Effluent Reuse	What are the global and local perspectives on wastewater reuse for irrigation?	University of the West Indies Library Catalogue	The key words and phrases entered into the search field were - "wastewater reuse + irrigation" and "wastewater + agriculture"	To obtain local and regional perspectives on wastewater reuse for agriculture To obtain printed books, so as to explore a variety of information sources. The following key sources of information were found - Shuval (1986), Pescod (1992) and Mara and Cairncross (1989)
Effluent Reuse & Irrigation	How can treated effluent be safely used for irrigation? What are the implications for irrigation water quality? What are the guidelines for effluent reuse for irrigation?	NGO Websites	WHO and FAO websites were visited to obtain wastewater reuse guidelines and irrigation water quality information for food safety	These are internationally acceptable guidelines and standards that have been adopted worldwide, and are therefore credible sources of information, which would be used to guide the research.
		Google Scholar Search	The keywords and phrases entered into the search field were – “Mara Blumenthal wastewater irrigation”	To obtain revisions of the WHO Guidelines. The WELL resources were found and downloaded

Table 2.3 Literature Search Strategies (cont'd)

Concept	Research Question/Area	Source of Information	Search Strategy	Justification of Approach
Effluent Reuse & Irrigation	(Cont'd)	Google Search	The key words and phrases entered into the search field were - "wastewater reuse + health risks", "effluent reuse + benefits", etc.	To obtain the advantages and disadvantages (including health and environmental risks) of effluent reuse for irrigation.
	What are the effluent reuse standards locally and in other countries?	EPA Website	Website was visited to download the U.S. Wastewater Reuse Guidelines	To compare the effluent reuse standards for irrigation in different countries
		Google Scholar Search	The keywords and phrases entered into the search field were – "wastewater reuse + irrigation"	To obtain irrigation water quality standards from around the world. Wastewater Reuse standards for Alberta Canada were found and downloaded
		NEPA	Request Jamaican Standards	For Data Analysis
Effluent Reuse & Irrigation & Sugarcane	What are the international policy implications of waste fed agriculture in the context of international trade of safe food products?	Dissertation Theses	Similar research was done in the area, So a copy of the Dissertation was requested for viewing	To see what work has been done in the field and current gaps in knowledge. To cross check/validate information collected and to update knowledge on the area. To find additional sources of information in references
		GLOBALGAP Formerly (UEROGAP)	Referred to GLOBALGAP by WHO Guidelines, and therefore searched the internet for information	To investigate the impacts on international trade for using treated effluent for irrigation To see what criteria must be met for GLOBALGAP certification and whether Farmers in the Rio Cobre Basin could be certified

Table 2.3 Literature Search Strategies (cont'd)

Concept	Research Question/Area	Source of Information	Search Strategy	Justification of Approach
Effluent Reuse & Irrigation & Sugarcane	Are there any examples/case studies of effluent reuse for sugarcane irrigation?	Library Catalogue Plus	The keywords and phrases entered into the search field were –"“wastewater + irrigation”. This produced 4,811 hits. The search results were then narrowed to show only the articles that had the full text available online. The titles were skimmed and the abstracts of relevant articles read. Two useful documents were found. “Wastewater” was then substituted for “treated effluent” and narrowed the search further to include sugarcane. Keywords searched – “treated effluent” + “irrigation” + “sugarcane”. This produced much less hits (246) which was much more manageable. Two useful documents were obtained for Brazil	Credible and reliable sources of information. The articles found were written by respected and knowledgeable persons in the field and the articles were all Peer reviewed. Library Catalogue Plus led the author to Science Direct (the search engine for Elsevier publishers) which had several relevant peer reviewed articles.
Irrigation & sugarcane	What is the water requirement (quantity and quality) for sugarcane?	Google/Google Scholar	The keywords and phrases entered into the search field were – “irrigation water quality standards”, sugarcane water requirement”	To obtain some agronomic information on sugarcane. A manual on sugarcane irrigation was found and downloaded.
Sugarcane & Jamaica & Irrigation	What are the requirements for the varieties of cane grown locally?	Sugar Industry Research Institute (SIRI)	Librarian searched database based on keywords given	To obtain information on the Jamaican Sugar Industry as well as agronomic information

2.3 Global and Local Perspectives on Wastewater Reuse for Irrigation

Wastewater reuse for irrigation is not a new practice and has been done for centuries in some Asian countries as well as in Scotland and England where raw and partially treated wastewater was directly applied to farm lands (Shuval, et al., 1986). Currently, treated wastewater is used extensively for irrigation in certain countries. For example 67%, 25% and 24% of the total effluent is used for irrigation through direct planning in Israel, India and South Africa respectively (Blumenthal, et al., 2000a). Likewise, case studies from around the world as reported in the EPA Guidelines (2012) reveal that as much as 90% of the available reclaimed water or treated effluent in Cyprus is used to irrigate citrus, olive trees and fodder crops. In Mexico City nearly 209 MLD of reclaimed water is used for irrigation of green areas, recharge of recreational lakes and agriculture.

This wide scale reuse of wastewater for agricultural purposes is mainly practiced in water and drought stressed countries, such as countries in the Middle East and North Africa (MENA), where both treated and untreated wastewater is applied to the land. It is also practiced in developed countries where there are adequate technologies to obtain good quality effluent for safe use in irrigation. For example, in the United States, reclaimed water or treated wastewater is used for irrigation and other purposes as a water conservation measure in several states, such as: Florida, California, Texas and Arizona (Haering, et al., 2009). It therefore appears that wastewater reuse is mainly practiced in instances where there is grave need and where the technological and institutional framework exists to produce effluent of acceptable quality (usually developed countries). Jamaica on the other hand does not fall into either of these categories - but certainly has the potential to benefit greatly from the many advantages of wastewater reuse for irrigation.

Jamaica has yet to substantially seize the advantages of wastewater reuse for irrigation, as current reuse practice is limited to the hotel industry where effluent from onsite treatment systems are used to irrigate golf courses and other green areas. There are also incidences of wastewater reuse for crop irrigation among a few of the players in the sugar industry. This reuse of wastewater in the sugar industry is minimal and involves mixing freshwater with the liquid outputs of the sugar process (treated liquid industrial wastes) and is done at site specific locations. Jamaica’s lack of momentum in the direction of effluent reuse for irrigation (despite the presence of institutional and legislative frameworks and the impending water crisis for the Rio Cobre Basin) gives greater impetus for further research into this area. The literature review is therefore aimed at exploring the potential of reusing treated domestic effluent from the island’s largest central wastewater treatment facility for sugarcane irrigation.

2.4 Benefits of Wastewater Reuse for Irrigation

There are several potential positive impacts to be gained from reusing treated effluent for irrigation. It is a reliable source of water that is available year round, and when used for irrigation, the nutrients are recycled thereby reducing the need for mineral fertilizers. Mara (2004), has reported and quantified the saving on nutrient recycling, where farmers in Mexico have saved US$135/ha/year on artificial fertilizers because of the valuable plant nutrients contained in wastewater. The reuse of wastewater for irrigation also has the advantage of increased crop yields. Asano (1998) as reported by Blumenthal et al. (2000b) comments on this positive impact and states that "the reuse of wastewater has been successful for the irrigation of a wide variety of crops, and increases in crop yields from 10-30 percent have been reported". Other positive impacts such as environmental improvements because of reductions in the amount of waste (treated or untreated) discharged into water courses, and the conservation of water resources by lowering the demand for freshwater abstraction are some of the benefits of wastewater reuse put forward by Khouri, Kalbermatten and Bartone, (1994, p. xi). These would benefit Jamaica if effluent from Soapberry were to be reused for irrigation, because as indicated by the WRA (2012) as much as 70% of the freshwater resources of the Rio Cobre Basin is currently used for agriculture, while there are deficits in the domestic water supply. This therefore suggests that if Soapberry's effluent were reused for irrigation, then the irrigation demand could be met (with nutrients provided), while making more of the freshwater resources available for domestic and industrial uses.

2.5 Health and Environmental Risks associated with Wastewater Reuse for Irrigation

Wastewater is not only a beneficial resource as discussed, but can also present a threat, with several possible negative environmental and health impacts (WHO, 2006a). These include: the creation of habitats for disease vectors (mosquitoes and flies), contamination of ground water, accumulation of toxic chemical pollutants in soil and crops (Khouri, Kalbermatten and Bartone, 1994) and human exposure to pathogens from excreta causing sickness. However, the WHO Guidelines (WHO, 2006a) indicate that these possible effects and their relevance depend on each specific situation and how the wastewater is used. Therefore the extent to which these risks are manifested is dependent on the quality of Soapberry's effluent, the irrigation techniques adopted and current prevalence rate of diseases in the Rio Cobre Basin.

2.5.1 Health Risks

The possible health risks associated with wastewater reuse in agriculture presented are based on a review of current literature, and in particular the WHO Guidelines for the safe use of wastewater in agriculture (WHO, 2006a) and Blumenthal et al., (2000a).

There are several pathways of transmission or exposure to pathogens and contaminants associated with the use of wastewater in agriculture (WHO, 2006a, p. 14). These are listed below:

- Human contact with wastewater (or contaminated crops) before, during or after irrigation (farmers, their families, vendors and local communities)
- Inhalation of wastewater aerosols (workers, local communities)
- Consumption of contaminated wastewater-irrigated products
- Consumption of drinking-water contaminated as a result of wastewater use activities (eg. Chemical or pathogen contamination of aquifers or surface waters)
- Consumption of animals or animal products that have been contaminated through exposure to wastewater
- Vector borne disease transmission resulting from the development and management of wastewater irrigation schemes and waste stabilization ponds

The use of untreated wastewater or polluted water in general, poses risks to human health since it may contain excreta-related pathogens (viruses, bacteria, protozoan and multicellular parasites), skin irritants and toxic chemicals like heavy metals, pesticides and pesticide residues (Drechsel, 2010). When wastewater is used in agriculture, pathogens and certain chemicals are the primary hazards to human health by exposure through different routes. In addition, contamination may be due to poor post-harvest handling that can also lead to cross-contamination of farm produce (Drechsel, 2010).

Examples of the hazards associated with wastewater reuse for agriculture (for developing countries) and the relative importance of each is given in Table 2.4.

Table 2.4 Examples of hazards associated with wastewater use in agriculture for developing countries

Hazard	Exposure route	Relative Importance
Excreta-related pathogens		
Bacteria (for example E. coli, Vibrio cholerae, Salmonella spp. Shigella spp.)	Contact; Consumption	Low–high
Helminths (parasitic worms)		
• Soil-transmitted (Ascaris, hookworms, Taenia spp.)	Contact; Consumption	Low–high
• Schistosoma spp.	Contact	Nil–high
Protozoa (Giardia intestinalis, Cryptosporidium, Entamoeba spp.)	Contact; Consumption	Low–medium
Viruses (for example hepatitis A virus, hepatitis E virus, adenovirus, rotavirus, norovirus)	Contact; Consumption	Low–high
Skin irritants and infections	Contact	Medium–high
Vector-borne pathogens (Filaria spp., Japanese encephalitis virus, Plasmodium spp.)	Vector contact	Nil–medium
Chemicals		
Heavy metals (for example arsenic, cadmium, lead, mercury)	Consumption	Generally low
Halogenated hydrocarbons (dioxins, furans, PCBs)	Consumption	Low
Pesticides (aldrin, DDT)	Contact; Consumption	Low

Source: Drechsel (2010) as adapted from WHO (2006a)

2.5.2 Environmental Risks

Groundwater is the most important of Jamaica's water resources, as 84% of the available water resource is in the form of groundwater (WRA, 2012). Therefore, to prevent jeopardizing the groundwater resources, it must be safeguarded from all potential contaminants. The WHO Guidelines (2006a, p.55) report that, "poor irrigation practices with untreated or partially treated wastewater, impact the quality and safety of groundwater in shallow aquifers and surface waters that may supply drinking water". Surface waters may also be at risk for excessive nutrient, primarily nitrogen and phosphorous which cause eutrophication. This creates environmental conditions that favour the growth of toxin producing cyanobacteria and algae. The resulting toxins can cause gastroenteritis, liver damage, nervous system impairment and skin irritation (WHO, 2006a). Another threat to water resources is organic chemicals. These are industrial solvents and the WHO Guidelines (2006a, p. 56) indicate that "these are expected to be removed or degraded during wastewater treatment". The U.S.EPA (1990) as reported by WHO Guidelines (WHO, 2006a) indicates that the frequency of detection for the majority of these organic chemicals was less than 10% and therefore may not need to be considered in wastewater use in agriculture.

2.6 Health Risk Barriers

Health hazards associated with the use of wastewater in agriculture are pathogens, certain chemicals, protozoa and viruses, all of which can pose threats to human health and life. The susceptible groups are the consumers of the crops irrigated with wastewater, the farmers and their families, and the local community. Fortunately however, there are risk management strategies to prevent exposure to these hazards, as documented in the WHO Guidelines for the safe use of wastewater in agriculture (WHO, 2006a, p. 17). This is done by constructing multiple barriers. These barriers or health protection measures are discussed in the sub sections below, and include: wastewater treatment, crop restriction, wastewater application techniques, exposure control methods and cessation of irrigation. Figure 2.5below shows examples of risk management strategies for wastewater use in agriculture to prevent exposures to pathogens and toxic chemicals by constructing multiple barriers. These barriers are explained further in subsequent sections.

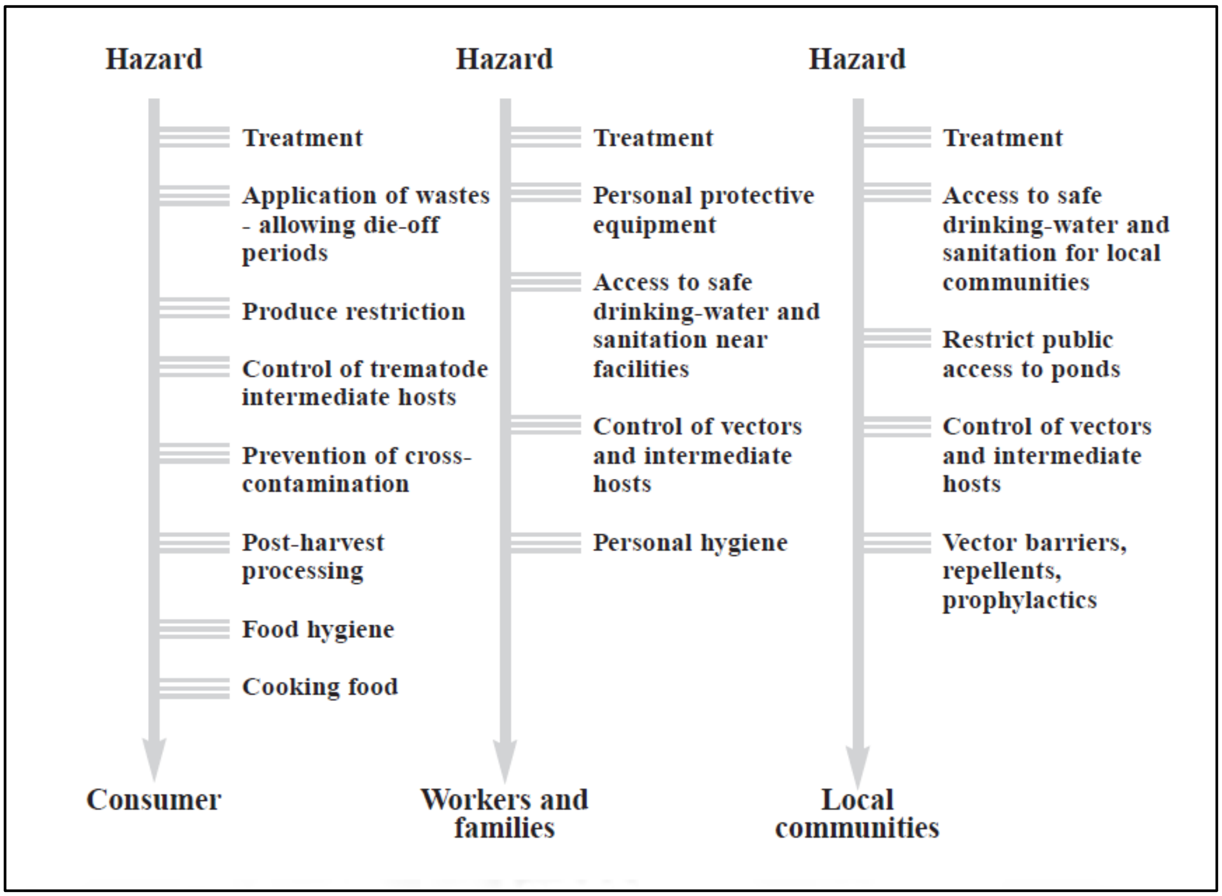


Figure 2.1 Examples of hazard barriers for wastewater use in agriculture

Source: WHO (2006a)

2.6.1 Wastewater Treatment

Wastewater treatment is done in order to remove pathogens and toxic chemicals to levels that do not exceed tolerable risks. It is important to note that when untreated wastewater is used to irrigate vegetables, the WHO Guidelines (WHO, 2006a, p.36) reports that it can lead to increased helminth infection (Mainly ascarsis lumbricoides infection), bacterial and viral infections and symptomatic bacteria". When compared to untreated wastewater, the reuse of treated wastewater for irrigation would reduce the health risks significantly. Mara (2004) confers with this by stating that irrigation with treated wastewater does not cause any excess prevalence of Ascaris infection among crop consumers.

With regard to toxic chemicals found in wastewater, the WHO Guidelines (WHO, 2006a, p.54) indicate that particular attention should be given to developing countries where industrial discharges and municipal wastewater are frequently mixed together. Although this is the case in Jamaica, it is mandated that all industrial wastes are pre-treated on site before discharging to the municipal sewers. Furthermore, evidence for direct health impacts from chemical exposures associated with the use of wastewater in agriculture is very limited. Although there have been a few incidences in Japan and China, but in such instances industrial waste (as opposed to domestic waste) was used for land application (WHO, 2006a, p. 54), and industrial waste is more likely to contain dangerous chemicals.

Wastewater Treatment at Soapberry WWTP - An overview of the treatment process at Soapberry is presented -the information was obtained from the Soapberry WWTP Design Report prepared by the National Water Commission, (NWC, 2007).

The treatment process consists of an oxidation lagoon system with downstream dissolved air floatation (DAF) and sand filtration. The existing system has two identical trains containing facultative lagoons followed by maturation ponds. Within each train, the incoming flow is split between two facultative lagoons. Each facultative lagoon flows into a second facultative lagoon. Flows from the two final facultative lagoons in each train are combined and flows through a series of two maturation lagoons. Spatial distribution of the ponds and the direction of wastewater flow are shown in Figure 2.7

Organic matter that reaches the lagoons is removed mostly by aerobic bacteria. The treated flow from one train of lagoons is returned to the headworks. Treated wastewater from the second series of lagoons is further treated by addition of a cationic polymer, as well as the flow-through mixing, flocculation, dissolved air flotation, and sand filtration units. The sludge and solids collected in the sand filters and DAF are returned to the headworks. The solids settle to the bottom and digest under anaerobic conditions. Figure 2.6 shows the current configuration of the treatment system at Soapberry WWTP.

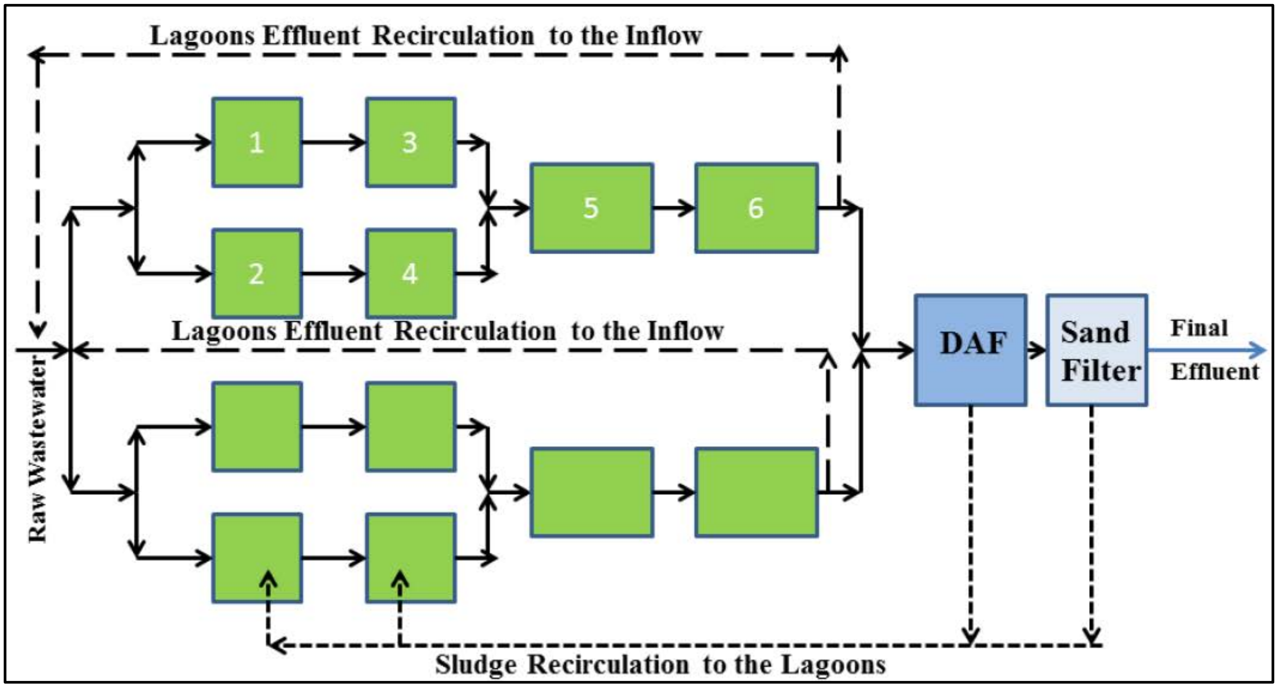


Figure 2.2 Treatment process at Soapberry
Source: NWC (2007)

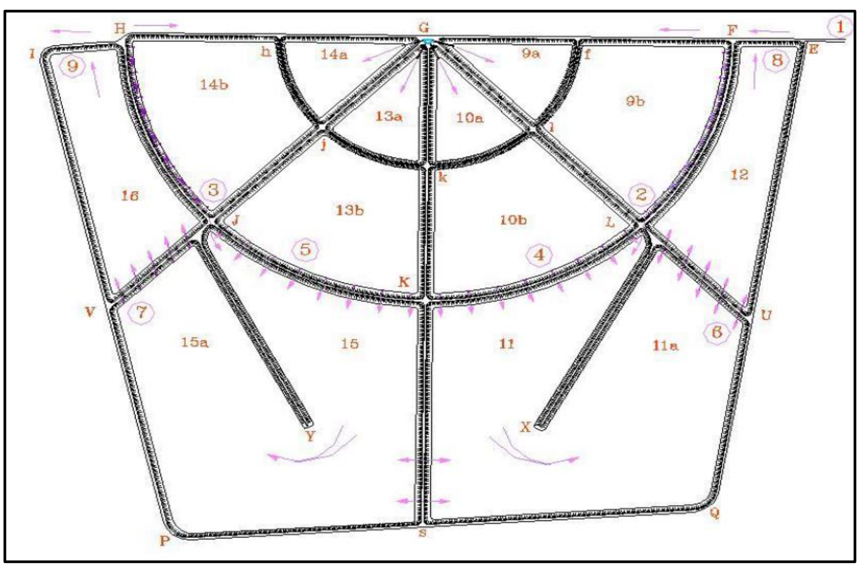


Figure 2.3 Plan of Soapberry WWTP Ponds and flow
Source: NWC (2007)

2.6.2 Crop Restriction

Restricted irrigation refers to the irrigation of all crops except salad crops and vegetable crops that are eaten raw or uncooked. Unrestricted irrigation includes the irrigation of salad crops and vegetables eaten raw or uncooked (Mara, 2004). As such, the crops cultivated will vary depending on the quality of the irrigation water, and measures implemented to protect the exposed groups. Crop restriction is often practiced in conjunction with wastewater treatment so that lower quality effluents can be used to irrigate non-vegetable crops (Blumenthal, 2000b). WHO (2006a, p. 27) reports that "the greatest health risks are associated with crops that are eaten raw or crops that grow close to the soil." Sugarcane that is cultivated in Rio Cobre Basin is not eaten raw, but is processed to make sugar, and sugarcane is reaped at a height of 8 to 9 metres. These factors increase the safety for consumption and can limit the extent of wastewater treatment required for the wastewater that will irrigate the sugarcane.

2.6.3 Human exposure control methods

Likely persons to be exposed to any health risks are: consumers of the crops, farm workers and their families, crop handlers and possibly nearby communities. The WHO Guidelines (WHO, 2006a) therefore recommend, limiting public access to irrigated fields, wearing protective clothing (e.g. footwear for farmers and gloves for crop handlers) and good personal hygiene practices among farmers (occupationally and in the home). Blumenthal (2000b) also indicates that adequate water should be provided in these reuse areas for consumption and hygiene (hand washing) to prevent consumption and use of wastewater.

The agricultural practices themselves (i.e. labour intensive vs. highly mechanized) may increase or decrease the contact with wastewater and therefore increase/reduce the associated health risks. Both mechanized and labour intensive farming practices are employed across the Rio Cobre Basin.

2.6.4 Wastewater application techniques

There are several types of irrigation systems used in sugarcane cultivation around the world. The methods used in Jamaica are furrow, drip, centre pivot and cannon. Centre pivot and cannon systems are over-hanging and irrigate by spraying. Among these, only centre pivot, furrow and drip irrigation techniques are used in the Rio Cobre Basin, and are shown in Figures 2.4 – 2.6.

Furrow Irrigation – "At the top end of a field, water is introduced to the furrows from open channels, a gated pipe or plastic fluming. The irrigation is stopped when the water reaches the bottom end of the field. In some situations the irrigation may be allowed to continue to allow more water to infiltrate into the soil. Run-off water is removed via tail drains" (Holden and McGuire, 2014, p. 22)

Figure 2.4 Sugarcane Irrigation by flowing Furrows
Source: Handal (2014)

Drip irrigation systems – "*allow small irrigations as frequently as daily (or even a number of times per day) to accurately supply crop needs. Advantages include flexibility with fertiliser application and use with automation. Water is delivered to the plant root zone via thin-walled tubing with regularly spaced emitters. The drip tube can be laid on the soil surface, but sub-surface systems are more common"*. (Holden and McGuire, 2014, p. 28)

Figure 2.5 Drip Irrigation System being installed
Source: Holden and McGuire (2014)

“Centre-pivot irrigators travel in a circle spraying water and can irrigate large areas (up to 1.6 km in diameter covering 200 ha). Most machines will cover 80 ha to 100 ha”. (Holden and McGuire, 2014, p.28)

Figure 2.6 Sugarcane being irrigated by centre-pivot system
Source: Holden and McGuire (2014)

The type of Irrigation technique can reduce the amount of human exposure to the wastewater. Drip irrigation reduces the exposure of workers and crop contamination and therefore provides the most heath protection, because the wastewater is applied directly to the crop. However, drip irrigation systems can only tolerate certain levels of total suspended solids (TSS) in the irrigation water, as excess TSS can clog the emitters. On the other hand, furrow irrigation can increase the risk of helminth infections in nearby communities, but is largely dependent on the basin itself and the initial prevalence (WHO, 2006a, p.32). Spray and sprinkler irrigation (including centre pivot) have the greatest potential to spread contamination onto crop surface and affect nearby communities (tiny droplets which may contain pathogens can be carried for considerable distances through air).

2.6.5 Cessation of irrigation

Cessation of irrigation is done days before harvest to improve crop quality by reducing bacteria numbers (i.e. allowing time for “bacteria die-off”) (WHO, 2006a, p. 78). The number of days is dependent on the crop type and effluent quality. However Vaz da Costas Vargas, et al. (1996) as reported by Blumenthal, et al. (2000b) recommends a period of cessation of irrigation before harvest of 1-2 weeks - which has resulted in improvements in the quality of the irrigated crop to levels seen in crops irrigated by fresh water. WHO guidelines, (WHO, 2006a) warns against the practicability in unregulated circumstances, as this is up to the discretion of farmers.

Interestingly, cessation of irrigation before harvesting is a normal requirement for sugarcane cultivation, and this practice is independent of the irrigation water quality. This is done to increase the sucrose content before harvest, and the “dying-off period” can last up to six weeks (SIRI, 2015). Since this is a crop requirement, issues of non-compliance with cessation of irrigation orders are negated, and the full benefits of pathogen die-off can be assured.

2.7 Effluent Reuse for Irrigation - Guidelines and Standards

2.7.1 Microbial Quality Guidelines

Guidelines for the microbiological quality of treated wastewater used for crop irrigation are provided by: the second and latest editions of the WHO Guidelines (WHO, 1989 and 2006a), the revision to (WHO, 1989) which was done by Blumenthal et al., (2000a) and the EPA Guidelines (EPA, 2012) developed by America. There are different approaches to establishing guidelines for the microbiological quality of treated wastewater used for irrigation. These are: the absence of faecal indicator organisms in the wastewater, the absence of measurable excess cases of enteric disease in the exposed population and a model generated estimated risk below a defined acceptable risk.

The Unites States of America has adopted a zero risk approach, which requires the absence of faecal indicator organisms in wastewater for unrestricted irrigation and a maximum allowable limit of 200MPN/100ml for restricted irrigation (EPA, 2012). On the other hand, the second edition of the WHO Guidelines (WHO, 1989) is based on epidemiological evidence, as well as Blumenthal et al., appraisal (2000a); however the appraisal is also supplemented by bacteriological studies of the transmission of pathogens, as well as a model-based quantitative risk assessment for selected pathogens. WHO Guidelines, second edition (WHO, 1989) and Blumenthal et al., (2000a) give critical levels of microbial contamination of irrigation water, while the latest version of the WHO Guidelines (WHO, 2006a) uses health based-targets. These microbiological Guidelines are given in Appendix A and B. Blumenthal et al., (2000a) revised microbiological guidelines for treated wastewater use in agriculture gives the following limits:

> ***Restricted Irrigation*** refers to the irrigation of all crops and vegetables which may be eaten uncooked.
>
> ***Unrestricted irrigation*** includes the irrigation of salad crops and vegetables eaten uncooked (Mara, 2004)

Unrestricted irrigation

- Thermotolerant Coliforms $\leq 10^3$/100ml

- Nematode Eggs ≤0.1/litre (however, this guideline limit can be increased to ≤1 egg/litre if conditions are hot and dry and surface irrigation is not used or if wastewater treatment is supplemented with anthelminthic chemotherapy campaigns in areas of wastewater reuse)

Restricted irrigation

- Thermotolerant Coliforms ≤10^5/100ml (spray or sprinkler irrigation) and ≤10^3/100ml (flood or furrow irrigation)
- Nematode Eggs ≤1 (flood or furrow and no children under 15 years) and ≤ 0.1 (any irrigation type, and includes children under 15 years)

2.7.2 Reliability of Guidelines

The limits proposed by the WHO, have been controversial and widely debated. Blumenthal et al., (2000b) cites Shelef (1991) as criticizing the WHO guideline (WHO, 1989) for using "partial epidemiological studies in developing countries, ignoring the acquired immunity of the population involved and ignoring the health risk assessment methodology used as a foundation for developing drinking water quality standards". However based on epidemiological studies and bacteriological evidence, the stated limits are safe for human and crop health (Mara, 2004, Blumenthal et al., 2000a and 2000b).

2.7.3 Jamaican Effluent Reuse Standards for Irrigation

The Jamaican standard is not based on WHO Guidelines (WHO, 1989 & 2006a), but is instead influenced by American standards, especially the California standards. The maximum allowable limit for thermotolerant coliforms is 12 MPN/100ml, while no standard is given for helminths. The Jamaican standard also, does not have specifications for restricted and unrestricted irrigation.

Table 2.5 Jamaican Effluent Reuse Standard for Irrigation

Parameter	Standard Limit
Total Suspended Solids (TSS)	15 mg/L
Biochemical Oxygen Demand (BOD)	15 mg/L
Chemical Oxygen Demand (COD)	<100 mg/L
Thermotolerant Coliform	12 MPN/100mL
Oil and Grease	10 mg/L
Residual Chlorine	>0.5 mg/L

2.7.4 Comparison of Effluent Reuse for Irrigation Standards

Some countries (e.g. France and Mexico) have based their effluent reuse standards for irrigation, on the second edition of the WHO Guidelines (WHO, 1989). While the different states within America, have used the EPA Guidelines (to varying degrees) as the basis for their standards. The maximum allowable limits for each state vary. “For unrestricted irrigation of food crops these range from 10-1000 thermotolerant coliform bacteria/100ml for surface irrigation to 2.2-200 thermotolerant coliform bacteria/100ml for spray irrigation” (Blumenthal et al., 2000b).

The state of California has some of the strictest standards, and stipulates a minimum bacterial (indicator) concentration detectable by routine monitoring of 2.2 total coliform bacteria/100ml for irrigation of food crops (to be achieved through secondary treatment followed by filtration and disinfection) and 23 total coliform bacteria/100ml for irrigation of pasture and landscaped areas (through secondary treatment and disinfection) (Blumenthal et al., 2000b). Like Jamaica, standards in several countries (e.g. Israel and Oman), have been influenced by American standards. A comparison of the standards for wastewater reuse for agriculture in a few countries and/or states is presented in Table 2.6 below. A discussion of these and other standards follow.

Table 2.6 Wastewater Reuse Standards for Irrigation - Select Countries

	Parameter										
Country	BOD (mg/L)	COD (mg/L)	Thermotolerant Coliform (MPN/100mL)	Total Suspended Solids (mg/L)	Residual Chlorine (mg/L)	Oil & Grease	pH	Helminth Eggs (egg/L)	TDS (mg/L)	SAR	EC
Jordan (Restricted)	300	100	100	50		8	6.0-8.0	<1	1500	9	
Kuwait	20	100	400	15		5	6.5-8.5	<1	1500		
Oman (Unrestricted)	15	150	200	15		0.5	6.0-9.0		1500	10	
Oman (Restricted)	20	200	1000	30		0.5	6.0-9.0		2000	10	
Alberta, Canada (Unrestricted)	<100	<150	<200	<100			6.5-8.6			4-9	1.0-2.5
Alberta, Canada (Restricted)	<100	<150	<200	<100			6.5-8.5			<4	<1.0
Virginia, U.S.A. (Unrestricted)	<10		49		1		6.9-9.0				
Virginia, U.S.A (Restricted)	<30		800	<30	1		6.0-9.0				
Florida (Unrestricted)	<20 avg <60 max		<25	5	>1						
Florida (Restricted)	<20 avg <60 max		<200 avg <800 max	<20 avg <60 max	>0.5						
Washington D.C (Unrestricted)	30		<2.2 avg <23 max	30	>1						
Washington D.C. (Restricted)	30		<23 avg <240 max	30	>1						
California, U.S.A			<2.2								
Jamaica	15	100	12	15	>0.5	10					
Mexico (Unrestricted)			1000_m-2000_d					<1			
Mexico (Restricted)			1000_m-2000_d					<5			

The NEPA standards were far more stringent for most parameters (except some American States) when compared with Jordan, Kuwait, Oman and Alberta Canada standards.

Biological Oxygen Demand, BOD – the acceptable BOD levels for the Alberta, Canada standards is as high as 100mg/L (as compared with 15mg/L for Jamaica). In comparison with the U.S. states of Florida and Washington D.C., which are generally strict, The Jamaicans standards, were even still more stringent. The accepted BOD level for both states is 30 mg/L while Jamaica is 15 mg/L.

Total Suspended Solids (TSS) - total suspended solids are as high as 100 mg/L for the Alberta, Canada standards as compared with 15 mg/L for Jamaica, Kuwait and Oman. However, TSS is only listed as a parameter for wastewater quality, with reference to the use of irrigation systems and to prevent the clogging of such systems (Khouri, Kalbermatten and Bartone, 1994, p. 39).

Thermotolerant Coliforms -The thermotolerant coliform limit for Florida was as high as 200/100ml (average) and an allowable maximum of 800/100ml for restricted irrigation. Washington's standard is more stringent permitting only 23/100ml of thermotolerant coliform – which is still high in comparison to Jamaica's standard of 12/100ml. Mexico's standard limit is 1000MPN/100ml and based on epidemiological evidence, does not pose serious risks to health (Blumenthal et al., 2000b).

Free Chlorine - Free chlorine is necessary for disinfection, but can damage plants at high concentrations. Khouri, Kalbermatten and Bartone, (1994, p. 40) also state that excessive amounts of free available chlorine (>0.05 mg/L Cl_2) may cause leaf tip burn and damage some sensitive crops, if chlorine is used for the disinfection of wastewaters. However, the minimum requirement for the NEPA standard (>0.5 mg/L) far outweighs this standard and is therefore possibly a threat.

Other Parameters not Included in Jamaican Standard - A comparison of the monitored parameters showed that the use of wastewater for irrigation application, in Alberta, Jordan, Kuwait and Oman involved the evaluation of additional water quality parameters. These were electrical conductivity (EC) and sodium adsorption ratio (SAR). Greater importance was even placed on these parameters not included in the Jamaican standard by FAO (Ayers and Westcot, 1985)

Moreover, U.S., EPA (2012) and FAO (Ayers and Westcot, 1985) state that salinity, or salt concentration, is probably the most important consideration in determining the suitability of wastewater for agricultural re-use. The importance of these parameters is further highlighted as research has shown that sugarcane is moderately sensitive to salinity (Maas, 1984) as reported by Khouri, Kalbermatten and Bartone, (1994, p.36)**.** Additionally specific ions such as boron, sodium and chloride may be toxic to crops. These ions from soil or water accumulate in sensitive crops to concentrations high enough to cause crop damage or reduce yields. These are discussed further in the next section.

2.8 Water Quality Related Problems in Irrigated Agriculture

The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate and toxicity. Guidelines for evaluation of water quality for irrigation are given in Table 2.6 below. They emphasize the long-term influence of water quality on crop production, soil conditions and farm management.

Table 2.7 Guidelines for interpretations of Water Quality for Irrigation

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

Source: Ayers and Westcot, 1985

2.8.1 Salinity

Water salinity is the sum of all elemental ions (e.g., sodium, calcium, chloride, boron, sulphate and nitrate). Salinity is determined by measuring the electrical conductivity (EC) and/or the total dissolved solids (TDS) in the water. High salt concentrations reduce water uptake in plants by lowering the osmotic potential of the soil. The use of high TDS water for irrigation will tend to increase the salinity of the groundwater if not properly managed. The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which salts are removed by leaching (Haering, et al., 2009). Increasing salinity levels decrease sugarcane yields, and care must be taken to prevent salt accumulation in the soil profile (Holden & McGuire, 2014)

According to FAO (Ayers and Westcot, 1985), a salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. Yield reductions occur when the salts accumulate in the root zone so that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time. The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage. If salts become excessive, losses in yield will result. To prevent yield loss, salts in the soil must be controlled at a concentration below that which might affect yield". Appendix C gives the yield potential for sugarcane and other crops grown in the Rio Cobre Basin based on their water and soil EC, as reported by FAO (Ayers and Westcot, 1985).

Leaching - "Under irrigated agriculture, a certain amount of excess irrigation water is required to percolate through the root zone so as to remove the salts which have accumulated as a result of evapotranspiration from the original irrigation water. This process of displacing the salts from the root zone is called leaching and that portion of the irrigation water which mobilizes the excess of salts is called the leaching fraction, LF" (Ayers and Westcot, 1985). Salinity control by effective leaching of the root zone becomes more important as irrigation water becomes more saline.

2.8.2 Sodium Absorption Ratio, SAR

Irrigation water with a high concentration of sodium ions may cause dispersion of soil aggregates and sealing of soil pores. Dispersion of soils results in reduced infiltration rates of water and air into the soil. When dried, dispersed soil forms crusts which are hard to till and interfere with germination and seedling emergence (Ayers and Westcot, 1985). The specific concentration of sodium that is considered to be toxic will vary with plant species and the type of irrigation system.

The most reliable index of the sodium hazard of irrigation water is the sodium adsorption ration, SAR.

2.8.3 Specific Ion Toxicity

Toxicity normally results in impaired growth, reduced yield, changes in the morphology of the plant and even its death. The degree of damage depends on the crop, its stage of growth, the concentration of the toxic ion, climate and soil conditions (Ayers and Westcot, 1985). The most common phytotoxic ions that may be present in municipal sewage and treated effluents in concentrations such as to cause toxicity are: boron (B), chloride (Cl) and sodium (Na) (Haering, et al., 2009). Holden and McGuire (2014, p.10) state that toxicity is rarely a problem with sugarcane.

2.9 Sugarcane Agronomic Considerations

Unless otherwise stated, the information presented in this section is obtained from the Sugar Industry Research Institute, (SIRI, 2015), and is based on sugarcane grown in Jamaica.

Sugarcane is defined as "SACCHARUM OFFICINARUM, a perennial tall growing, semitropical to subtropical plant of the grass family, with a sweet juice containing sucrose. Figure 2.7 below shows a field of growing sugarcane. Sugarcane requires eight (8) to twenty-four (24) months to reach maturity and sometimes blooms, sending out silky white flowers, known as cane arrows. Sugarcane can grow over 20 feet high but is usually reaped at a height of 8 to 9 feet. There is a hard rind or skin on the outside. The inside is a soft pitch which contains the juice in which the sugars re dissolved. Actual growth takes place in the leafy green top of the cane while the skin holds the sucrose" (MoA&F, 2014).

Figure 2.7 Sugarcane rows in Jamaica

Source: Wn.com (2011)

Sugarcane is generally not replanted every time it is harvested, but is allowed to regrow and produce another crop called a ratoon or stubble crop. The yield declines after a number of ratoons and at some point the cane has to be ploughed out and replanted.

As previously mentioned the length if the growing season for sugarcane varies from eight months (e.g. Louisiana) to nearly two years (e.g. Hawaii) (Rein, 2007). In Jamaica, the growing period is twelve months, and therefore the crop is harvest once annually. Sugarcane can be harvested green or burnt. In fact more than 50% of all sugarcane around the world is burnt prior to harvesting (Rein, 2007, p.61). The practice of burning cane is seen as an effective way to maintain high manual cutter outputs. However, there are many disadvantages associated with burning sugarcane, such as: atmospheric pollution and soil and water losses.

2.9.1 Nutrition

As with other crops, sugarcane requires sunlight, moisture and nutrients. The optimum temperature for growth and nutrient absorption is 26^{o}C, as sugarcane thrives best and produces more sugar in hot, sunny locations. “The nutrients required in relatively large amounts are referred to as major or macro elements and those required in much smaller quantities are referred to as minor or trace elements” (SIRI, 2015). The major elements are: carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, sulphur, calcium and magnesium. The trace elements are iron, manganese, boron, molybdenum, copper, zinc, chloride and cobalt. Carbon, hydrogen and oxygen are of little concern, as the plant obtains these quite easily from the atmosphere. Similarly, the trace elements are also adequately supplied for by the soil (SIR, 2015). However, of primary importance are: nitrogen, phosphorous and potassium, as they are most likely to be deficient. Table 2.8 summarizes the roles of these essential nutrients and the quantities required per hectare for plant and ratoon cane. A deficiency or lack of any of these elements will normally result in retarded growth.

Table 2.8 Sugarcane Essential Nutrients

Nutrients[1]	Role	Required Quantity
Nitrogen	A constituent of amino acids, proteins and vitamins Stimulates rapid vegetative growth resulting in increased yields Promote tillering and increases the rate of leaf formation as well as the size and chlorophyll content of leaves. Tillering or underground branching is a general characteristic of grasses. In cane, it provides the plant with a large number of stalks necessary for good yields.	Plant 80-115 kg/ha Ratoon 80-136 kg/ha
Phosphorous[2]	Promotes early root formation and vigorous growth May hasten maturity Positive effect on the rate of tillering	Plant 70-103 kg/ha Ratoon 0-61 kg/ha
Potassium	Takes part in nearly all cellular activity Plays a role in carbon assimilation in the transformation and translocation of sugars and in protein and starch formation	Plant 80-115 kg/ha Ratoon 80-136 kg/ha

Source: SIRI (2015)

Note:

1. Where expected yields are low as in low rainfall areas, inadequate irrigation frequencies and in general less than adequate cultivation practices, the lower end of the fertiliser scale usually applies, except for phosphate
2. Zero phosphate in ratoon cane applies as a result of high reserves of phosphate in soil types such as loams and sandy loam. Phosphate applied to planted cane usually suffices for more than one crop as it is less readily leached from soils.

Varying amounts of these nutrients are removed in the crop when harvested and must be replaced periodically in order to maintain satisfactory growth levels. This is normally accomplished by the addition of fertilizers.

2.9.2 Water Requirements

Sugarcane requires substantial irrigation water to achieve maximum productivity - with the water requirements varying with the plant growth stage. “The optimum irrigation frequency and amount of water will vary depending on the soil type and the crop growth stage. Different soil types store different amounts of Readily Available Water (RAW) – the water that plants can easily access. Crops that are actively growing will require more moisture than those that have been recently planted or are nearing maturity”. (Holden and McGuire, 2014, p. 33)

With suitable conditions of adequate temperature and sunlight, cane grows in direct proportion to the amount of water available (Holden and McGuire, 2014). Sugarcane’s response to irrigation is both seasonally and spatially variable due to climatic differences from year to year and between districts within the Jamaican sugar industry (SIRI, 2015). In Jamaica, the average annual crop water requirement of sugar cane is 1500 to 2500 mm. The southern plains of Clarendon and St, Catherine (Rio Cobre Basin occupies all of St. Catherine parish) generally receive less than 1000mm of rainfall per annum and can only grow cane economically with the aid of irrigation (SIR, 2015).

2.10 Social Issues of Wastewater Reuse

Sociocultural aspects of wastewater reuse for irrigation tend to focus on cultural and religious beliefs, public perception and human behavioural patterns (especially hygiene).

With regard to Jamaican culture, the current attitudes towards treated wastewater reuse for irrigation is definitively unknown, as social studies have not been conducted on this subject. However, in the author's experience, the general perception among the Jamaican populace is indifference bordering partial-acceptance. Religious beliefs are not expected to alter the view of wastewater reuse for irrigation, as the population is predominantly Christian Protestant (more than 90%), and there are no positions against its use for this religion. Social acceptance and public perception are expected to be the driving factors for the Jamaican context. The WHO Guideline (WHO, 2006a) indicates that the social acceptance of treated effluent as a source for irrigation water is subjective and is dependent on the specific user group. This suggests that user acceptability information would have to be obtained from the Rio Cobre Basin study area itself. (WHO, 2006a) has also suggested early stakeholder involvement as critical for effluent reuse projects. Acceptance level for wastewater reuse for irrigation is varied from total acceptance on one end of the scale to total rejection on the other.

Human behavioural patterns is equally important and is described as a key determining factor in the transmission of excreta related diseases by the WHO Guidelines (WHO, 2006a). This includes hygiene practices of persons who will come in contact with the treated effluent and the use of protective clothing and the wearing of shoes by farmers. The WHO Guidelines also state that the "social feasibility of changing certain behavioural patterns in order to introduce wastewater schemes must be assessed on an individual project basis". Education and training are therefore essential for the implementation of a successful and safe reuse scheme. This is emphasised by the lessons learnt from the use of treated wastewater for irrigation in Tunisia (Shetty, 2004, p.170) which showed that farmers in Middle East and North Africa (MENA) region did not possess the necessary training to use wastewater for agriculture in a safe and hygienic manner. This therefore suggests that even if there is acceptance among farmers in the Rio Cobre basin, training and a vigorous and vibrant health and safety campaign will be needed to ensure its safe use. Furthermore regular monitoring and evaluation are required to ensure health and protection measures are implemented effectively.

2.11 Institutional Issues for Wastewater Reuse

Mara and Cairncross (1989) as reported by (Khouri, Kalbermatten and Bartone, 1994) states that institutional capacity and enforcement capabilities must be increased in most developing countries if wastewater reuse projects are to be successful. This includes regular monitoring and evaluation of crop quality, wastewater quality and disease surveillance.

2.12 Economic and Financial Considerations

Economic and financial factors are crucial for encouraging the safe use of wastewater. Economic analysis seeks to establish the economic feasibility of a project and enables comparisons between different options, while financial planning, looks at how the project will be paid for, by determining the sources of revenue (WHO, 2006a).

2.13 Chapter Summary

Chapter two presented a summary of the past and current literature on matters relating to wastewater reuse for irrigation. The various health risks of pathogens and their relative importance and exposure routes are presented, as well as the possible threats to the environment – primarily ground water resources. For the potential benefits of wastewater reuse (increased freshwater resources etc.) to be realized, the various risks associated with its reuse must be minimised. Protective measures such as wastewater treatment, cessation of irrigation and human exposure control; are some of the measures discussed. An overview of the tertiary treatment process at Soapberry is given and particular attention is given to certain constituents of wastewater (Salinity, pH etc.) in relation to crop and soil health is discussed. The WHO guidelines (1989 and 2006) are also discussed, as well as the effluent reuse standards for Jamaica and other countries (e.g. Mexico and Kuwait). Sugarcane agronomics was discussed, and information presented on plant physiology. After vigorous discussion of the technical, health and environmental aspects of effluent reuse, the chapter ended with brief discussions on social, institutional and economical and financial aspects.

The next chapter presents the methodology used for the research.

3 METHODOLOGY

3.1 Chapter Overview

The chapter describes the methods and procedures used for the data collection tools chosen, as well as justifications for the choice of these data collection tools, and assessments of the credibility and reliability of the data sources. The methods used to analyse the data collected are also mentioned in this chapter. Analytical methods include the use of: graphs and charts, statistical analysis and thematic coding.

3.2 Methodical Approach

In developing a methodology to achieve the research objective of assessing the potential of reusing Soapberry WWTP's treated effluent for sugarcane irrigation – a conceptual framework (Table 3.1) was developed. This framework consists of the four research objectives, their related key concepts, research questions developed in order to meet these objectives and the measurement indicators used in answering these questions.

The indicators proposed in response to the research questions require both qualitative and quantitative data collection techniques, to generate the relevant data. The data collection methods used were: document analysis, semi-structured interviews and literature review. The approach taken is summarized in Table 3.2, which shows the data collection methods and documents utilized, as well as the related research objective.

A case study approach was adopted for this research, as Denscombe (2010, p.59) states that case studies focus on one or a few instances of a particular phenomenon with a view of providing in depth understanding of its relationships, experience and processes. This is therefore appropriate for the research and will aid in achieving the research aim and objectives. Moreover, several researches conducted in this field also utilized a similar approach. For example, Peters (2015) and Abdulla & Ouki (2015) used a case study approach to assess the potential of reusing wastewater for irrigation in the Eastern Caribbean and Libya respectively.

Table 3.5 Conceptual Framework

Research Objective	Key Concepts	Research Questions	Indicators
(i) To establish whether Soapberry WWTP can meet national effluent reuse standards for irrigation and be safely used for sugarcane irrigation	Effluent Quality (Environmental)	What is the current treatment performance of Soapberry WWTP? Does the effluent discharged from Soapberry WWTP meet the national water quality standards for irrigation using effluent? If not, What parameter(s) exceed(s) the national water quality standards for irrigation using effluent? How can Soapberry WWTP meet the national water quality standards for irrigation using effluent, and what are the risks to health and crop?	Effluent Quality Data Effluent Reuse Standards for Irrigation Effluent Quality Data Technical Information (Journal Articles)
(ii) To determine the acceptance level of treated wastewater for irrigation among farmers in the Rio Cobre Basin	User Acceptability (Social)	What are the attitudes/perceptions among sugarcane farmers in the Rio Cobre Basin towards the use of treated effluent (specifically from Soapberry WWTP) for irrigation? Are they willing to use this as a possible source of irrigation water?	Attitudes, Perception, Opinions and Feelings among farmers (Semi-structured interviews)
(iv) To compare the quantities of water available from Soapberry WWTP with the irrigation water demands	Technical and Agronomic Considerations	What is the irrigation water demand among sugarcane farmers in the Rio Cobre Basin? What quantity of treated effluent is discharged from Soapberry WWTP daily/monthly/seasonally?	Crop Water Requirement Data Current water consumption and usage pattern among farmers Effluent Discharge Volumes
(iii) To economically evaluate the proposed irrigation source against the existing source	Cost Effectiveness (Economic)	How does the proposed effluent re-use scheme compare (cost-wise) with the existing irrigation source/supply?	Life Cycle Cost for treated effluent reuse for irrigation scheme Tariffs for Existing Irrigation Supply and Proposed treated effluent reuse irrigation scheme

Table 3.6 Data Collection Methods and Documents Utilized

Research Objective	Indicators	Data Collection Method	Documents Required
(i) To establish whether Soapberry WWTP can meet national effluent reuse standards for irrigation and be safely used for sugarcane irrigation	Effluent Quality Data Effluent Reuse Standards for Irrigation Technical Information	Document Analysis Document Analysis Literature Review	Soapberry WWTP Operational Reports National Effluent Reuse Standards for Irrigation Journal Articles, Texts, Internet
(ii) To determine the acceptance level of treated wastewater for irrigation among farmers in the Rio Cobre Basin	Attitudes, Perception, Opinions and Feelings among farmers	Semi-structured Interviews with Key Informants	Outcome from semi-structured interviews conducted with sugarcane farmers
(iv) To compare the quantities of water available from Soapberry WWTP with the irrigation water demands	Crop Water Requirement Data Current water consumption and usage pattern among farmers Effluent Discharge Volumes	Literature Review Semi-structured Interviews with key informants Document Analysis	Agricultural Texts Outcome from semi-structured interviews conducted with sugarcane farmers Soapberry WWTP Operational Reports
(iii) To economically evaluate the proposed irrigation source against the existing source	Life Cycle Cost for treated effluent reuse for irrigation scheme Tariffs for Existing Irrigation Supply and Proposed treated effluent reuse irrigation scheme	Document Analysis Literature Review	BQ: Infrastructure Development Costs Operation and Maintenance Costs National Irrigation Commission Tariff Structure

3.3 Data Collection

3.3.1 Document Analysis

"Documents can be treated as a source of data in their own right – in effect an alternative to questionnaires, interviews and observation" (Denscombe, 2010, p. 216). Document analysis was used to collect the data necessary for addressing three of the four research objectives (see Table 3.2). This method was especially useful because of its cost effectiveness in obtaining data. A similar approach was also taken, by other researches investigating wastewater reuse potentials for irrigation in other countries. Peters (2015) and Abdulla & Ouki (2015) also utilized desk studies/document analyses as part of their methodologies. The documents analysed were: Soapberry WWTP monthly operational reports (for the years 2010-2015), National effluent reuse standards for irrigation, National Irrigation Commission (NIC) Tariff structure, and bills of quantities for infrastructure development projects. These are discussed below, and additional information about them is provided:

Soapberry WWTP monthly operational reports (2010-2015) – these documents provided data on the treated effluent quality from Soapberry and the volume of wastewater discharged. This information is required to determine the volume of effluent available for irrigation on a monthly basis, as well as the quality of the effluent and its suitability for irrigation. The access to these documents was relatively easy and was obtained by officially requesting the reports from the operators of Soapberry WWTP. Documentary research yielded years of data which would not be otherwise obtainable. This data source also provided the advantage of data permanence, which as described by Denscombe (2010, p. 232) is a source of data which is open to public scrutiny and is available in a form that can be by checked others.

The validity and reliability of the effluent quality data was assessed based on the laboratory methods and procedures used for testing each quality parameter. There is also an increased sense in the credibility of the data obtained because effluent quality testing was not conducted by the operators of Soapberry, but by an independent privately operated laboratory – and therefore expected to be free of biases. The test procedures followed are internationally recognized and accepted; these are either the HACH Method (HACH, 2005) or the Standard Method (APHA, AWWA, WEF, 2012). Furthermore, some of these testing procedures for the laboratory are ISO/IEC 17025 accredited. The methods used in testing each parameter are described in Table 3.3 below. The testing laboratory also provided a certificate of quality with the effluent quality data. This showed the internal quality control methods used by the laboratory to verify the accuracy and the precision of the laboratory results. For example, negative control samples were used for validation of coliform analysis and pH meters were calibrated daily. The quality control measures used to validate the Phosphate, Nitrogen and Chemical Oxygen Demand results were:

- Reagent/Method blank – Which is useful in determining certain types of constant errors in the analysis. The results from a blank determination reveal errors due to interfering contaminants from the reagent and vessels employed in the analysis.

- Duplicate Analysis – This measures the precision of the analytical process. Duplicate analysis usually involves a replicate sample.

- Per-cent Recovery – determines bad reagents, interferences and faulty instruments. It also checks for accuracy of the test results. This is done by adding a small amount of a substance of known concentration to the sample and then analysing the sample. Per-cent Recovery is therefore, the amount of substance collected / amount of substance expected to be collected, as a per-cent.

- Standard Reference Materials - Detects bias in an analytical method and checks the accuracy of the analysis. It a solution made of known composition and concentration.

Table 3.7 Effluent quality parameters measured and methods used for testing

PARAMETERS	TEST METHOD	NOTES ON METHOD
Biological Oxygen Demand (mg 0_2/L)	H-8043	Dilution Method
Total Suspended Solids**	SM-2540D	Total Suspended Solids Dried at 103-105◦C
Total Nitrogen	SM-4500-C	Persulfate Method
Phosphate as Phosphorous (mg PO_4^{3-} - P/L)**	H-8048	PhosVer 3 (Ascorbic Acid Method)
Chemical Oxygen Demand (mg O_2/L)**	H-8000	Reactor Digestion Method
pH**	DR	pH/ISE Electrode
Faecal Coliform (MPN/1000 ml)**	SM-9221	Multiple Fermentation Technique for Members of the Coliform Group

**Indicates parameters with ISO/IEC 17025 accreditation

KEY: H – HACH Method; SM – Standard Method; DR – Direct Reading

Further validation of the effluent quality data presented in the reports by means of independent testing was not possible because of financial constraints. Furthermore, even if this was possible, only a year's worth of data would be obtainable because of the time available for this research. On the other hand, the homogeneity of the data presented in the reports was checked by triangulation. That is, the data provided by the operators of Soapberry (copies of quality certificates) and forwarded to the researcher was checked against the data the operators of Soapberry would have sent to The National Environment and Planning Agency (NEPA) as a stipulation of the effluent discharge licence. This is important as conflicting data could have been presented in both circumstances, because the purpose for which the data was created may not have been specific for the aim of the research (Denscombe, 2010, p.233). The data used for cross-checking was obtained from NEPA by utilizing the Access to Information Act in order to obtain information from public agencies. Both sets of data were compared for consistency, so as to improve the reliability of the findings. Any discrepancies identified were reported to the operators of Soapberry for validation.

Jamaican Effluent Reuse Standards for Irrigation – This document was obtained from NEPA, the agency responsible for developing the standard and monitoring compliance with it. This is an official legal document and the contents are therefore factual. As a result, this source has no issues of reliability, credibility or validity with which to contend.

National Irrigation Commission (NIC) Tariff Structure – The tariff structure was obtained from the NIC. This information was required to compare the existing cost for irrigation water economically against the proposed effluent reuse scheme. This is authentic, factual information, and is therefore valid and credible.

Bills of quantities for infrastructure development projects – These documents provided a basis for comparison to project and estimate the costs involved in developing a treated effluent re-use scheme. Bills of quantities which have similar activities to those required for this research were obtained from NWC by an official request for the data. The costs which were not current were forecasted based on the current rate of inflation and exchange rate. The material prices were corroborated by price quotations directly from the suppliers. The data obtained by this means is both credible and reliable, as this is the industry cost for actual works completed from the only water utility in the country.

3.3.2 Semi-structured Interviews

Some of the data required for this research could only be obtained from the sugar cane farmers of the Rio Cobre basin directly. This Information included their attitudes towards reusing treated effluent for irrigation as well their farming practices. Fisher and Reed (2012, p.2.10) highlight the suitability of using qualitative research when dealing with one community or population group – such as the sugarcane farmers of the Rio Cobre Basin. In addition, qualitative research is used when investigating human behavior, as it is aimed at providing a holistic understanding of complex realities and it provides answers to the question: Why? (Fisher and Reed 2012, p.2.10)

Denscombe (2010, p. 173) recommends the use of interviews when insights into peoples' opinions, feelings, emotions and experiences are required. The Who Guidelines (WHO, 2006a) also recommend social surveys to determine public perception on using wastewater for irrigation. Additionally, research done by Abdulla & Ouki (2015) used interviews to solicit information from farmers, in their research aimed at assessing the reuse potential of treated effluent for irrigation in Tobruk, Libya. Interviews are therefore suited for collecting information on the farmers' attitudes towards effluent reuse. On the other hand, the type of data on farming practices required are quantitative in nature (see Table 3.4, Questions 1-6), but can also be obtained through interviews. Based on the types of data to be obtained from the farmers, the data collection tool chosen was semi-structured interviews. Semi-structured interviews will allow for information on both farming practices and farmers' opinions to be collected in one exercise. This method was chosen because of its feasibility in terms of gaining direct access to the prospective interviewees, and because the semi-structured interviews are viable in terms of cost and time (Denscombe, 2010, p.174).

Conversely, this information could have been collected using other suitable data collection tools such as questionnaires and focus group discussions. Questionnaires, although capable of capturing the majority of the questions asked in the semi-structured interview, would not allow for data on attitudes and perceptions to be collected. On the other hand, focus group sessions are ideal for collecting this type of data; however, because of conflicting schedules, there was difficulty in coordinating a date/time/venue suitable for all the participants. As a result, semi-structured interviews were chosen instead.

Selection of Key Informants – The research population is thirty-four (34) sugarcane farmers in the Rio Cobre Basin, Jamaica (NIC, 2014). A non-probabilistic approach to sampling was adopted because the researcher did not have sufficient information about the population to undertake probabilistic sampling. Denscombe (2010, p.25) recommends non-probabilistic approaches to sampling in such instances, and also because of the difficulty in contacting a sample selected through conventional probabilistic sampling techniques. Noteworthy, however, is the fact that non-probabilistic sampling can still retain the aim of generating a representative sample (Denscombe, 2010, p.25). Since the farmers were not known to the researcher, contact was made with this selected group through the sugarcane field workers assigned to the parish of St. Catherine and employed by the Sugar Industry Research Institute, SIRI. These field workers are familiar with the farmers as they provide technical support and conduct regular farm visits.

Purposive sampling was done for this population group. Denscombe (2010, p. 34) states that:

> *“Purposive sampling operates on the principle that we can get the best information through focusing on a relatively small number of instances deliberately selected on the basis of their known attributes.”* Denscombe (2010, p. 34)

Therefore, only “hand-picked” sugarcane farmers were targeted, based on their; proximity to Soapberry WWTP and farm size (i.e. to include small, medium and large farmers). This ensured that a wide cross-section of farmers were included in the sample and Denscombe (2010, p. 35) states that “purposive sampling, is to a degree emulating a representative sample, when used in this way” Denscombe (2010, p. 35).

An exploratory sample within this population was chosen. Denscombe (2010, p. 25) indicates that an exploratory sample is used as way of probing relatively unexplored topics, and that the point of the sample is to provide the researcher with a means of generating insights and information. It is therefore not always necessary to select people for the sample in terms of getting an accurate cross-section of the population. Interviews were therefore conducted with the six (6) “hand-picked” farmers – i.e. a sample size of 18% from the 34 sugarcane farmers in the Rio Cobre Basin. It should be noted that the data obtained are both representative of the population for the reasons previously mentioned, and also useful in achieving the research objective of perceptions on wastewater reuse, because the six (6) farmers interviewed cultivate over 60% of the irrigable sugar lands in the study area.

Conducting the Interviews – All eight (8) interviews were conducted by the researcher (in February 2016), and the meeting date, time and venue was pre-arranged and conducted at the farmers’ convenience. The interviews were conducted in-situ (i.e. on the farmers’ properties). At the start of each interview, consent to participate in the interview was sought, and each interviewee was informed that they could withdraw from the process at any time. It was clearly communicated that the interviews were being conducted to aid in the fulfillment of an academic qualification. The interviews were not recorded, as it was believed that this would have made the farmers uncomfortable. Instead filed notes were taken of the discussion, and periodic checks were made by the researcher/interviewer during each interview to ensure that the correct understanding was derived from the informants' comments. This was done by summarizing the interviewees' opinions, reflecting the opinions back to the interviewee, for confirmation by them.

In relation to the interviewer, guidance by Denscombe (2010, p. 180) was followed, and the researcher made every effort to remain neutral and impartial on the statements made and opinions expressed during the interview. Efforts were also made to reduce interviewer effect, by carefully selecting the attire to be worn and by having the field worker sit in on the interviews, since the farmers are familiar with the SIRI field worker.

Interview Questions and Structure - Table 3.4 shows the list of questions for discussion, which incorporated both closed and open-ended questions. A flexible approach was taken to the order in which the questions were administered, and the respondents were given the freedom to develop ideas and speak widely around the subject, while balancing the need to focus the interview on matters directly relevant to the research (Denscombe, 2010, p. 175). Table 3.4 also gives the reasons for including each question in the interview.

Table 3.8 Semi-structured Interview Questions

INTERVIEW QUESTIONS	REASONS FOR ASKING QUESTION
1. Do you cultivate sugarcane?	To confirm that the targeted farmers actually cultivate sugarcane.
2. What is the size/area of your sugarcane farmland? a) Where are your sugarcane farmlands located?	To determine the potential water and fertilizer requirement Location of the farmland is useful in developing the effluent reuse scheme - in terms of required infrastructure and the locations of interested/non-interested farmers in the scheme
3. What time of year is the sugarcane crop typically planted? a) How is the sugarcane planted?	Since the quantity of water required throughout the crop life varies, the answers to the question will help in determining the monthly/seasonal crop water requirement. Depending on whether the sugarcane is planted or rationed, the water and fertilizer requirement varies.
4. Do you irrigate the sugarcane? a) Where do you get the water used to irrigate the sugarcane? b) How much do you pay for the water used to irrigate the sugarcane? c) How often do you irrigate the sugarcane crop? d) How much water do you use each time that you irrigate the sugarcane? e) How is the irrigation water applied to the land? f) How much irrigation water do you apply throughout the life of the crop?	To confirm that irrigation water is indeed needed by sugarcane farmers in this area. To find out where irrigation water is obtained and the cost. (Cost given here is required for triangulation with NIC Tariff) To determine irrigation habits and frequency. This information will also assist in determining the crop monthly/seasonal water requirement to see how much of the farmers' water requirement can be met on a monthly basis. How the irrigation water is applied (drip/flood) will indicate whether treated effluent can be applied since drip systems will require water with substantially less suspended solids than flood irrigation. Also, when using treated effluent - drip, spray and flood Irrigation have different associated health risks
5. Do you apply fertilizers to your sugarcane crop? a) What type of fertilizer do you use? b) How much fertilizer do you use? c) What fertilizer application rate do you use?	To determine the effect of using nutrient rich treated effluent and the resulting fertilizer requirement. The savings from the likelihood of using less fertilizer can also be computed. Fertilizer quantities stated will be used to triangulate data obtained from research on sugarcane fertilizer requirements

Table Continues

Table Cont'd

INTERVIEW QUESTIONS	REASONS FOR ASKING QUESTION
6. How often is the sugarcane crop harvested annually? a) Is the sugarcane harvested green or burnt? b) Is the sugarcane mechanically or manually harvested?	To determine the crop life and hence monthly/seasonal water requirement. Information on harvesting methods will also assist in determining health risks based on whether farming is labour intensive or highly mechanized
7. Are you aware of the Soapberry Wastewater Treatment Plant?	To find out if farmers are aware of wastewater treatment plants and their function and process. This question was also asked to see if farmers understood the concept of treated wastewater
8. Would you be willing to use treated wastewater to irrigate your sugarcane farm? a) What are your reasons for being willing, or not being willing, to use treated wastewater to irrigate your sugarcane farm? b) Do you have any concerns about using treated wastewater to irrigate your sugarcane farm?	To determine farmers' attitudes/perceptions towards using treated wastewater for irrigation.
9. Compared to the current costs incurred for irrigation water would you be willing to pay the same amount, more or less for treated wastewater? a) What are your reasons for how much you would be prepared to pay for treated wastewater used for irrigation?	To determine whether farmers are willing to pay for treated wastewater

To increase confidence in the data obtained from the semi-structured interviews, the validity of the interview data was checked in the following ways as described by Denscombe (2010, p. 189):

- The plausibility of the data collected was checked and corroborated with other sources of information on the topic (for example, data on quantities of fertilizer used and crop water requirements obtained from the interviews were checked with agronomic facts from literature.
- For triangulation some questions were repeated at different points of the interview to establish whether a similar response was given. Additionally, after the interview was completed, the transcripts of the interviews were sent to the persons interviewed for corroboration.

3.3.3 Literature Review

Data for this research was also obtained from review of literature. Sugarcane crop information and methods to improve the treatment capabilities of Soapberry were the main areas of focus for the data collection exercise.

Agricultural texts were obtained from internet searches and books borrowed from the Sugar Industry Research Institute (SIRI) Library. The texts provided general information on the sugarcane plant, plant physiology, irrigation water quality, and irrigation water and fertilizer requirements.

Literature Research on ways to reduce numbers of thermotolerant coliforms was done through internet searches, journal articles and texts. This information is needed to improve the treatment performance of Soapberry, and provide or identify potential options for Soapberry to meet the irrigation water quality standard for thermotolerant coliforms.

These sources are credible; as the authors of the publications cited not only have the qualifications required but are respected by their peers. The data presented in each text was triangulated against the data presented in other texts, so as to ensure the validity of the data obtained.

3.3.4 Engineering Design

The methodology also required some technical engineering work for the fulfilment of the research objectives. This included: a storage analysis (for treated wastewater), plan and preliminary design of the conveyance network for the effluent reuse scheme and field checks to obtain irrigation (drip) specifications. These actions and their justifications are summarized below.

ACTION	JUSTIFICATION
Do Storage Analysis	To determine the storage requirements. This will have a cost and will impact the economic considerations
Plan and Design Conveyance Network	To determine the project feasibility and the associated costs
Check/Obtain specifications for drip irrigation systems	To determine whether they are prone to clogging, based on effluent quality (TSS content of the effluent)

3.4 Data Analysis

3.4.1 Semi-structured Interviews

The semi-structured interviews yielded both quantitative and qualitative data. The qualitative data obtained (primarily from questions 7-9) was analysed based on Grounded theory, using simple thematic coding. Fisher and Reed (2012, p. 7.5) and Denscombe (2010, p.284) recommend thematic data coding in analyzing qualitative data, and specifically for data generated by open ended interview questions. Coding is described as '*the process of examining data for themes, categories and keywords, whereby identified blocks of text are marked with a code*" (Fisher and Reed, 2010, p. 7.5). After transcribing the interviews, key themes and concepts were identified from each interview transcript in order to facilitate: making comparisons between respondents, identifying commonalities and avoiding basing findings on one interview. The themes were based on pre-prepared guiding issues suggested by the research objectives, as well as other themes developed during reading. After coding, the data were analysed quantitatively, i.e. counting to indicate the relative frequency of certain types of responses. The coded data were also qualitatively analysed by interpreting and relating the themes to the research questions and literature.

The quantitative data obtained from the respondents (questions 1-6) were collated and used to create charts, graphs and tables to enable visual recognition of patterns and trends, as well as to relate and compare the data to data obtained from the literature, so as to provide needed inputs for the engineering design (e.g., crop water requirements).

3.4.2 Document Analysis

Soapberry WWTP monthly operational reports were analysed by first tabulating the effluent quality data (for the period January 2010- June 2015), wherein four (4) quality tests were reported for each month for the following parameters: pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), phosphates (PO_4 – P), total nitrogen and thermotolerant coliforms. From the four (4) readings given each month for each parameter – the mean, maximum and minimum values were determined using Microsoft Excel. The arithmetic mean was calculated for all reported parameters except thermotolerant coliforms, for which the geometric mean was instead calculated. The data for each parameter was compared with the Jamaican standard for effluent reuse for irrigation. The compliance rate was also determined for each parameter, and comparison of the mean values with compliance requirements were represented graphically.

3.4.3 Literature Review

The books and articles found were analysed based on certain selection criteria, such as: relevance, date of publication, accessibility and qualifications of the authors.

3.4.4 Engineering Design

The analysis of the data to be used in the preliminary engineering design of the effluent reuse scheme was done using:

- Geographical Information Systems (GIS) – to obtain elevations and distances
- Manning's Equation – for pipe sizing
- Storage Analysis – to determine storage requirements

3.5 Chapter Summary

The prospect of reusing the treated effluent from Soapberry wastewater treatment plant for sugarcane irrigation depends on environmental, technical, social and economic considerations. As a result, the research methodology developed included varying data collection tools. These were: document analysis, semi-structured interviews and literature review. The methods selected to analyse the data obtained from these tools were: thematic coding, statistical analysis, charts and graphs. The subsequent chapter details and presents the findings of the data collected.

4 DATA ANALYSIS AND DISCUSSION

4.1 Chapter Overview

This chapter presents the analysis and discussion of the data collected from the data collection methods employed (i.e. document analyses, semi-structured interviews and literature review). The discussions in this chapter are structured around answering the four (4) research aim and objectives.

Sections 4.2-4.6 sought to answer the research aim of establishing whether Soapberry WWTP's effluent can meet national effluent reuse standards for irrigation and be safely used for sugarcane irrigation by:

- Providing a comparison of Soapberry's treated effluent quality with the Jamaican effluent reuse standard for irrigation, and describing ways in which the treatment process can be altered to meet the Jamaican standard for parameters exceeding the standard limit.
- Discussing mitigation measures to protect against the potential health risks of using Soapberry's treated effluent for sugarcane irrigation.
- Critically discussing key irrigation water quality issues for crop health as a result of using wastewater for irrigation.

In Section 4.7, the social aspects of wastewater reuse for irrigation are discussed based on the data obtained from the semi-structured interviews (Questions 7-9). This data has been qualitatively analysed and discussed to reveal the attitudes and perceptions of sugarcane farmers regarding reusing Soapberry's treated effluent for irrigation.

Section 4.8 provides an assessment and comparison of the treated wastewater quantities available for irrigation from Soapberry WWTP and the irrigation water demand of the sugarcane farmlands in the Rio Cobre Basin.

Sections 4.9-4.10 provide an economic evaluation of the proposed irrigation source against the existing source, by:

- Presenting the preliminary engineering design and costing for the irrigation scheme using treated effluent
- Comparing the existing NIC tariff with the proposed tariff

The chapter then concludes by summarizing the work presented in this chapter (section 4.11).

4.2 Comparison of Soapberry's Effluent Quality and The Jamaican Effluent Reuse Standard for Irrigation

As presented in the literature review, the Jamaican effluent reuse standard for irrigation does not make specifications for restricted or unrestricted irrigation. There is one standard, which has stipulations for the following parameters: oil and grease, total suspended solids, residual chlorine, biochemical chemical demand, chemical oxygen demand and thermotolerant coliforms.

For a quick snapshot of the treated effluent quality compared to the Jamaican effluent reuse standards, Table 4.1 below is given. Table 4.1 shows the mean, minimum and maximum values of all the results obtained for each parameter, over the period January 2010 – June 2015 (BOD, COD, TSS and thermotolerant coliform) and September 2013 – April 2014 (Oil and Grease). Please note that a residual chlorine value of zero is given because the treatment process at Soapberry does not involve disinfection, and chlorine is not added to the final treated effluent. The table also shows the Jamaican effluent reuse standard for irrigation, for easy comparison.

Table 4.1 Comparison of Soapberry's Treated Effluent Quality with the Jamaican Effluent Reuse Standard

	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Thermotolerant Coliform (MPN/100ml)	Oil and Grease (mg/L)	Residual Chlorine (mg/L)
Jamaican Standard	**<15**	**<100**	**<15**	**<12**	**<10**	**>0.5**
Mean	14.9	55.1	16.8	946	3	0
Minimum	0.4	3.0	2.0	16	1	0
Maximum	134.0	313.0	153.0	2400	4	0

The information outlined in the above table, reveals the following about the treated effluent from Soapberry:

- It does not meet the limit for thermotolerant coliform, in fact even the minimum reported value over the five and half year period exceeds the limit given in the standards.
- BOD, COD and TSS show some level of compliance with the standard.
- Oil and Grease is 100% compliant with the limit.
- The treated effluent does not have residual chlorine

For a more comprehensive and holistic view, the monthly means for the parameters (BOD, COD, TSS and thermotolerant coliform) for the period January 2010 to June 2015 (except May 2010 for which no sampling and testing was conducted) were plotted as time series graphs and juxtaposed against the Jamaican effluent reuse standard for irrigation (Figures 4.1, 4.2, 4.3 and 4.4). This was done to visually show the compliance and non-compliance of the various parameters over time. A discussion on these parameters and the line graphs drawn, are in the following subsections. For the monthly mean, minimum and maximum values for each parameter over the five and half year period please see Appendix D.

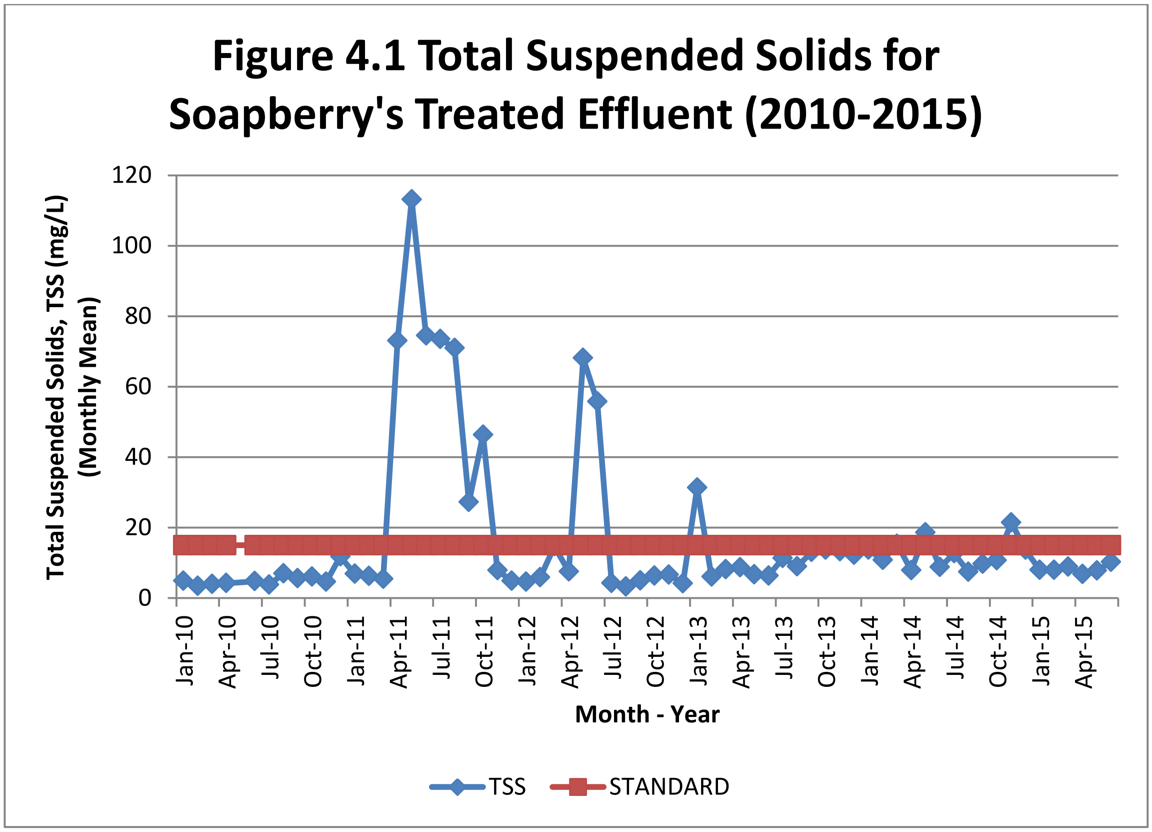
Graphs were not done for oil and grease and residual chlorine, since the effluent is not chlorinated and as a result, the residual chlorine values are nil. With regard to oil and grease, it is in compliance for all instances, in fact, the maximum reported (4mg/L) value for the eight month period reviewed, is less than half the standard limit (10 mg/L) – as such, it was not necessary to provide further analysis, as this parameter safely meets the Jamaican effluent reuse standard for irrigation.

4.2.1 Total Suspended Solids (TSS)

The mean value for TSS for the period under review is 16.8 mg/L, which is above the standard limit of 15 mg/L, as given in table 4.1. The minimum and maximum reported values for the period were 2 mg/L and 153 mg/L respectively. On the other hand, the treated effluent from Soapberry WWTP was found to be in compliance for TSS 80% of the time, for the monthly means between the period January 2010 to June 2015 (i.e. 52 out of a total of 65 samples – no sampling and testing was conducted for May 2010). These incidences of non-compliance (as shown by the points above the standard line in Figure 4.1) were investigated and it revealed that there were power outages and/or lack of cationic polymer, which is required for the removal of suspended solids which include algae.

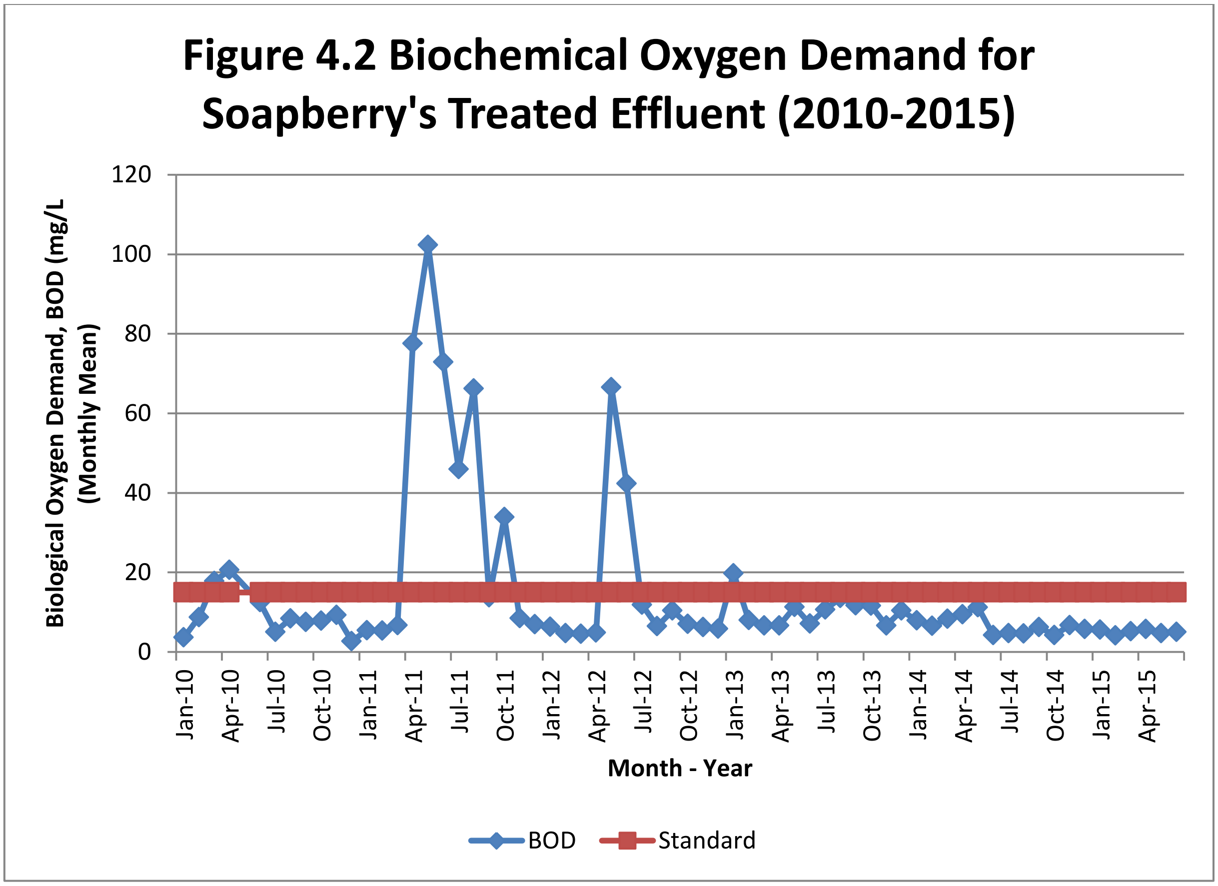
The causes for non-compliance for TSS are based on operation and maintenance blunders and can be remedied by equipping the plant with generators and ensuring a steady supply of polymers. Soapberry WWTP can therefore produce treated effluent to meet the Jamaican standard for TSS at all times – provided that these operational challenges are surmounted.

Nevertheless, it must be noted, that the Jamaican standard is excessively stringent for TSS when compared with the standards for Alberta Canada and Virginia, U.S.A. which have maximum allowable limits of 100 mg/L and 30 mg/L respectively. Furthermore Harivandi (1999), Landschoot (2007) and Lazarova, et al. (2004) as reported by Haering et al., (2009) state that TSS is only of concern for drip irrigation systems since the particles may clog the emitters, and that TSS levels less than 50-100 mg/L are generally safe for drip irrigation. Moreover drip irrigation is not prevalent among the sugarcane famers of the Rio Cobre Basin (only two of the six farmers interviewed have drip irrigation systems). Besides, the WHO guideline (WHO, 2006a) does not have TSS as a monitored parameter and is only concerned with the level of thermotolerant coliforms and the number of helminth eggs. Soapberry's treated effluent can therefore be used for irrigation and to irrigate sugarcane in particular – based on the level of TSS present in the treated effluent, as it is within the Jamaican standard limit and deemed not pose a threat to human health or crop.



4.2.2 Biochemical Oxygen Demand (BOD)

The mean value for BOD for the five and a half year period is 14.9 mg/L as given in table 4.1.This is just below the standard limit of 15 mg/L. However, minimum and maximum recorded values over that time were 0.4 mg/L and 134 mg/L (i.e. almost nine times the limit) respectively. The monthly mean values for BOD was found to be in compliance 83% of the time, for all samples taken between the period January 2010 to June 2015 (i.e. 54 out of a total of 65 samples – no sampling and testing was conducted for May 2010). Figure 4.2 shows the trend in BOD over the period and highlights the instances for which the BOD was above the Jamaican standard limit for irrigation use.



There is a known correlation between TSS removal and BOD reduction for wastewater pond treatment systems as the presence of algae contribute to increases in both suspended solids and BOD (Mara, 2004). This is evident for the data obtained, and can be seen in Figures 4.1 and 4.2, as there are simultaneous peaks and falls in both parameters. As explained before, these incidences of non-compliance were investigated and it revealed that there were power outages and/or lack of cationic polymer, which is required for the removal of suspended solids (including algae), and by extension BOD reduction, since algae contribute to BOD and microbes can attach themselves to other particles in wastewater (Mara, 2004).

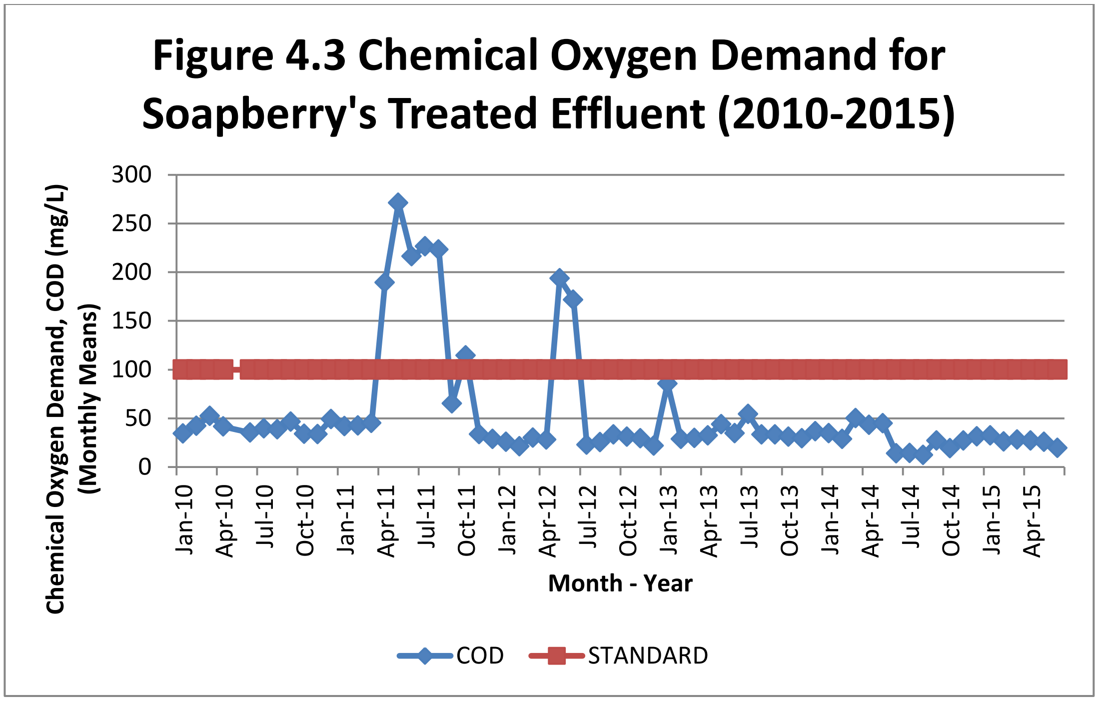
Since the causes for non-compliance for BOD are based on operation and maintenance problems and not deficiencies in the treatment process itself, it can be argued that Soapberry WWTP can produce treated effluent to meet the Jamaican standard for BOD at all times – once general operation and maintenance issues are addressed. Furthermore, a comparison of other wastewater reuse standards for irrigation (Table 2.6) showed that, the Jamaican standard was relatively strict for this parameter. Only a few countries/territories (Oman and Virginia, U.S.A.) equalled or came close the Jamaican standard limit of 15 mg/L – but this was for unrestricted use, i.e. crops that will be eaten uncooked. Again, the WHO guideline (WHO, 2006a) does not list BOD as a monitored parameter and is only concerned with the level of thermotolerant coliforms and the number of helminth eggs. This lack of significance for BOD as a quality criterion for wastewater reuse for irrigation is supported by Blumenthal et al., (2000b), which states:

> "*When wastewater is treated with the intention of using the effluent for agricultural irrigation and not disposal in receiving waters, the important quality criteria are those relevant to human health rather than environmental criteria and those related to the health of the fish in receiving waters. Therefore, faecal coliform removal and nematode egg removal are more important than BOD removal".*

Soapberry's treated effluent can therefore be used for irrigation and to irrigate sugarcane in particular – based on the BOD level of the treated effluent, as it can consistently comply with the Jamaican standard and deemed not pose a threat to human health or crop.

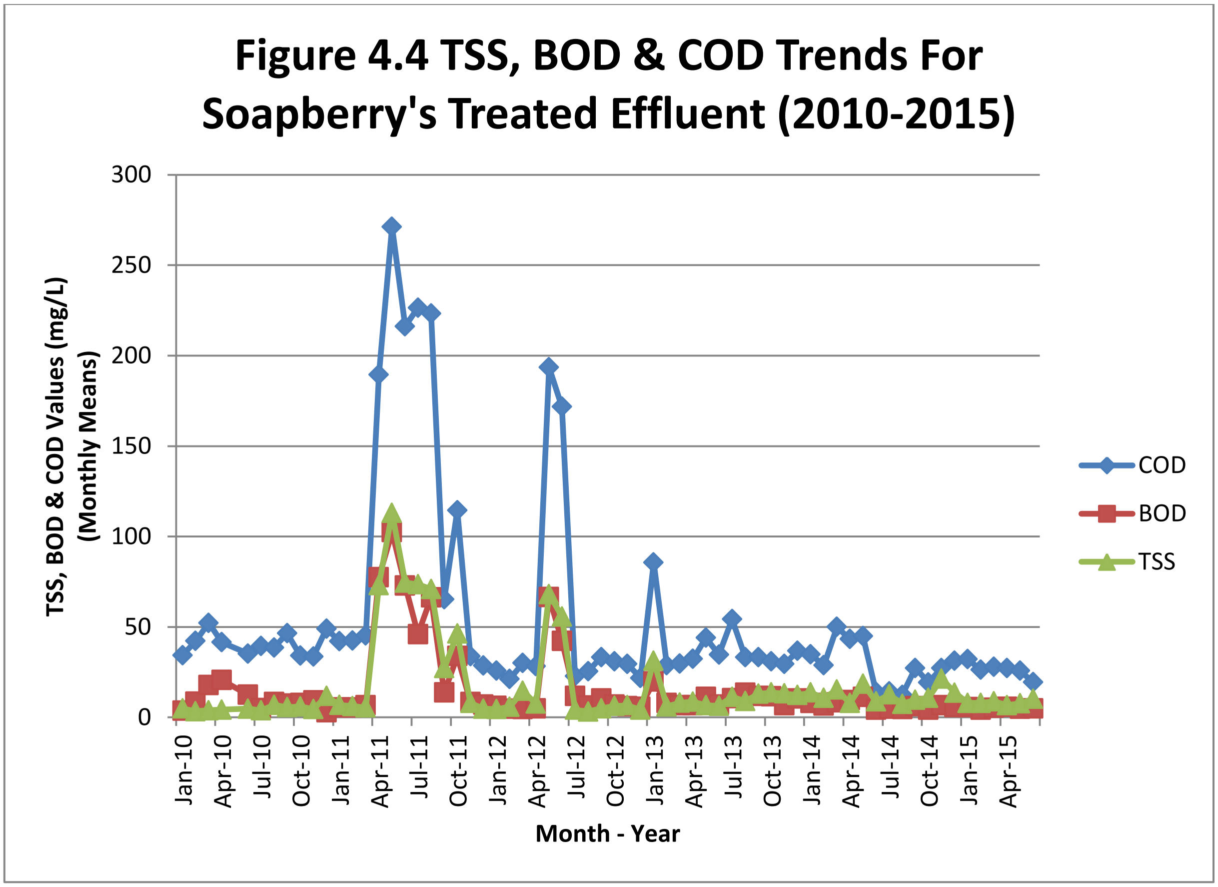
4.2.3 Chemical Oxygen Demand

The mean chemical oxygen demand for Soapberry's effluent for the period is 55.1 mg/L, which is far below the Jamaican standard limit of 100 mg/L. Although the mean value for COD is only 55.1 mg/L and the minimum reported value is 3 mg/L, there are incidences for which the COD values exceed the irrigation standard limit (non-compliance rate of 12%). In fact the maximum reported value over the five and a half year period for COD is 313 mg/L. Figure 4.3 shows the trend in COD for the treated effluent over the period as compared with the Jamaican standard.



Notable, is the fact that the incidences of non-compliance for COD also correlate with the incidences of non-compliance for BOD and TSS (see Figure 4.4). Figure 4.4 shows a combined plot for BOD, TSS and COD and shows the trend over the period. The graph illustrates the relationship between the parameters, and speaks to the effect which the lack of cationic polymer and power outages at Soapberry had on the quality of the treated effluent produced.

As was the case for BOD and TSS, it can be argued that Soapberry WWTP can produce treated effluent to consistently meet the Jamaican standard for COD – once general operation and maintenance issues are corrected.



4.2.4 Thermotolerant Coliforms

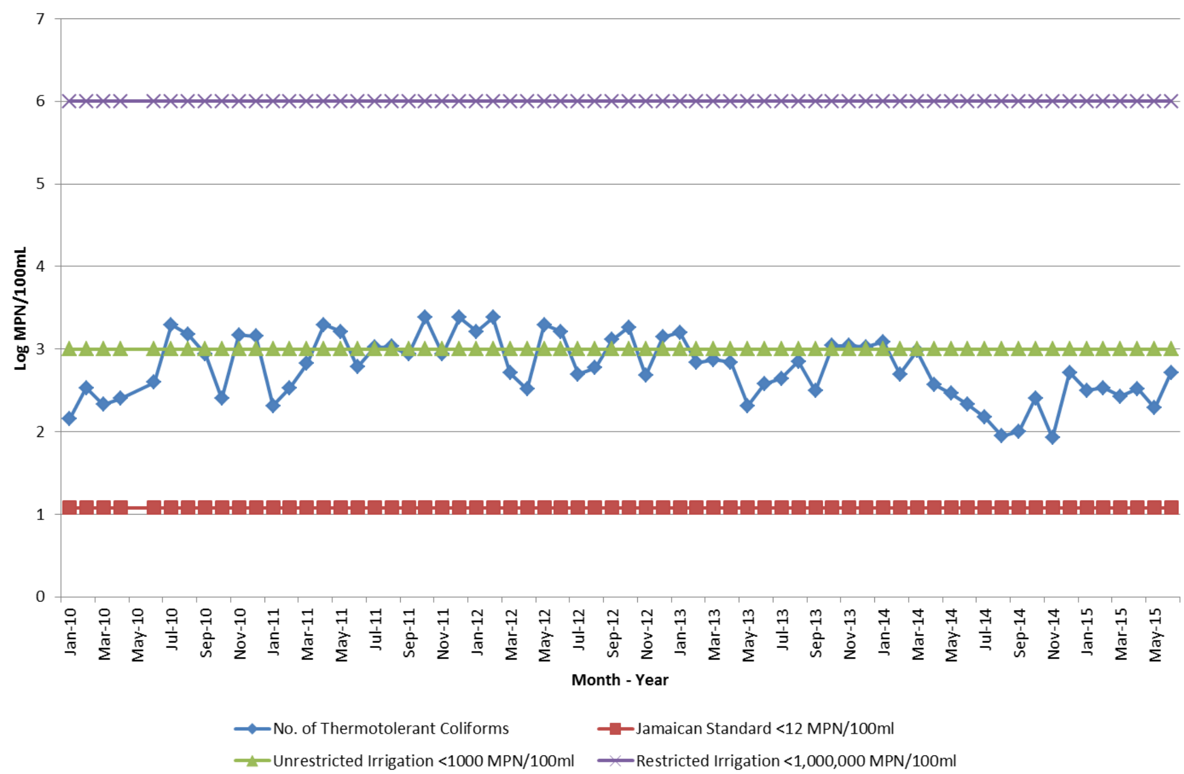
The treated effluent from Soapberry WWTP failed to meet the thermotolerant coliform requirement for all observed instances, based on the Jamaican irrigation water quality standards using treated wastewater. The mean number of thermotolerant coliforms is 946 MPN/100mL, which is almost eighty times higher than the maximum allowable limit of 12 MPN/100mL. Even the minimum reported number of thermotolerant coliforms of 16 MPN/100mL is higher than the standard limit. The standard deviation and variance for the data set are 644 and 414,493 respectively, indicating that there a wide fluctuations in the number of thermotolerant coliforms in the treated effluent.

In order to meet the Jamaican standard the number of thermotolerant coliforms in the treated effluent must be drastically reduced. Options for reducing the thermotolerant coliform levels include: additional maturation ponds, chlorination or Ultraviolet (UV) disinfection (Smith, 2011). In any event some form of chlorination must be done to obtain the residual chlorine level stated. Interestingly, Soapberry's design limit for the number of thermotolerant coliforms in the influent and treated effluent was 250 and 38 MPN/100m respectively, however due to the exceptionally high influent loads (BOD in the range of 400 mg/l) the plant is not performing as it should. There is frequent illegal dumping of abattoir wastes into manholes, which has contributed to high influent thermotolerant coliform numbers.

On the other hand, the requirement for thermotolerant coliform for irrigation water based on the Jamaican standard is exceptionally demanding. The Jamaican limit is higher than all the countries/territories reported in Table 2.6. For example Kuwait has a standard limit of 400 MPN/100mL and Oman has a standard limit of 200 MPN/100mL and 1000 MPN/100ml for unrestricted and restricted irrigation respectively. Only some U.S. states such as Florida, California and Washington D.C., have such strict microbial limits. For example, California has a standard limit for thermotolerant coliforms of 2.2 MPN/100mL, which has been argued to be excessively demanding by Mara (2004) and Blumenthal et al., (2000a) is in the same range as the Jamaican limit. Furthermore, Blumenthal et al (2000a) has recommended a maximum allowable concentration of 1000 MPN/100mL (for unrestricted irrigation) based on epidemiological research. Mara (2004, p. 238) supports this value and even provides several cases for its acceptance. When compared to this limit, the treated effluent from Soapberry is partially compliant for the guideline value, and indicates that modifications will still be required for Soapberry to meet this value. However, the amount that would be expended to meet 1000 MPN/100mL is far less than that of reaching the Jamaican standard limit of 12 MPN/100mL. It could be further argued that the maximum allowable number of thermotolerant coliforms of 10^5 MPN/100 ml put forward by Blumenthal et al., (2000a) for restricted irrigation is applicable in the researched scenario. This is because sugarcane will not be eaten raw and will be used to make sugar and therefore undergoes intense washing and heating processes that destroy pathogens. Restricted irrigation safeguards the crop consumers, while putting farm workers at risk. However, the anticipated risk is reduced because sugarcane fields are dense and not normally traversed, hence limiting the contact with the wastewater. Furthermore, the fields are often set ablaze right before harvesting (five of the six farmers interviewed reaps their cane burnt). This aids pathogen removal, thereby protecting the farm workers, who will reap the crop. Additional protective measures were discussed in section 2.6.

Figure 4.5 shows the trends in thermotolerant coliform numbers over the period reviewed as compared with the Jamaican Standard (12 MPN/100mL) and Blumenthal et al., (2000a) suggested limits of 1000 MPN/100mL and 10^5 MPN/100ml for unrestricted and restricted irrigation respectively. As can be seen from the graph - the thermotolerant coliform numbers for Soapberry's treated effluent far exceed the Jamaican limit, but manage to meet the suggested limit for unrestricted irrigation for approximately half of the reported values and are significantly better than the limit for restricted irrigation.

Figure 4.5 Trends in Thermotolerant Coliforms (Jan 2010 - Sep 2015) as Compared with Different Limits



Another interesting point, used to support the argument that the Jamaican standard for thermotolerant coliform is excessively stringent and that the suggested values of 1000 MPN/100ml (unrestricted) and 10^5 MPN/100ml (restricted irrigation) have greater application is the fact that the current irrigation source provided by NIC has a thermotolerant coliform count of 1,600 MPN/100ml. This value is greater than the mean number of thermotolerant coliforms for Soapberry's treated effluent. Additionally, a water safety plan for the parish of St. Catherine conducted in 2007 in collaboration with PAHO showed that there may be greater health threats associated with the use of the Rio Cobre water for irrigation. The report stated the following:

> *"The Rio Cobre River is contaminated by industrial, agro industrial and sewage effluents as well as storm water runoff containing sediments and pesticide residues. Also the NIC's canal receives contamination from some small legitimate and informal industries and commercial activities as well as residential houses, some of which are unplanned settlements". (Environmental Solutions, 2007)*

4.2.5 Helminths

Another important consideration, as it regards human health and safety and the use of treated effluent for irrigation, besides thermotolerant coliforms is the presence of helminths. Soapberry's treated effluent has not been tested and monitored for the presence of helminths, as such the data is unavailable. The author was also unable to have this done owing to financial constraints. Although this is not a criterion included in the Jamaican standard, it is an important factor for human health and safety (Blumenthal et al., 2000a, Mara, 2004 and WHO, 2006). Based on WHO guidelines (WHO, 2006a) an estimation of the number of helminths in the treated effluent from Soapberry has been made. This estimated value is <1 egg/litre and is based on the level of treatment the wastewater has undergone, as indicated in Table 3.7 from the WHO guidelines (WHO, 2006a, p. 29). However, a nematode egg count of less than 0.1 is preferable, to protect children under 15 years (Blumenthal et al., 2006a and Mara, 2004, p. 236).

4.3 Other Important Water Quality Parameters for Irrigation

There are several important parameters, outside those stipulated by Jamaica standard governing the use of treated effluent for irrigation. These are: salinity, sodium absorption ratio, specific ion toxicity and pH. There is only data available for salinity and pH, however, the other parameters are discussed and estimated based on local conditions.

4.3.1 Salinity

Salinity is the single most important parameter in determining whether water is suitable for irrigation (Ayers and Westcot, 1985). "Sugar produced from sugarcane grown on saline soils has high ash contents. The ash affects recovery of raw sugar in mills and contributes to the cost of refining sugar. Ash content rises with salinity because the plant absorbs more minerals from the soil, especially potassium, in an attempt to balance the higher salinity of soil water (Holden and McGuire, 2014). Salinity is determined by measuring the electrical conductivity (EC) and/or the total dissolved solids (TDS) in the water. The EC of the treated effluent from Soapberry is not monitored. However, the EC of the influent wastewater is routinely monitored. The monthly means over a five and half year period (January 2010 – June 2015) is presented in Appendix F. The effluent EC is assumed to be equal to the influent EC; however, there is some reduction in EC after treatment, as the main processes that reduce conductivity in wastewater treatment are biological phosphorus and nitrogen removal (Levlin, 2007). The mean EC of the influent and by extension the treated effluent is 0.99 dS/cm (at 25^{o}C). This indicates that there should be a slight to moderate restriction for irrigation with the treated effluent from Soapberry. This is based on Table 2.4 - Guidelines for interpretation of wastewaters for irrigation by the FAO (Ayers and

Westcot, 1985) given in Section 2.8. However, the FAO (Ayers and Westcot, 1985), has provided information on the crop tolerance and yield potential as influenced by irrigation water salinity (Section 2.8) – and it indicates that 100% crop yield for sugarcane is possible with irrigation water salinity of 1.1 dS/m. Since the EC of Soapberry's effluent (0.99 dS/m) is less than this value, irrigating sugarcane with the treated effluent from Soapberry is not expected to pose salinity problems for the crop or soil. Additionally, sugarcane is moderately sensitive to salinity and crop yields begin to be affected by salinity for the range1.3 -3.0 dS/m (Ayers and Westcot, 1985). However care must be taken to achieve the required leaching fraction in order to maintain soil salinity within the tolerance of the crop. Leaching fraction is further discussed and calculated in subsequent sections.

4.3.2 Sodium adsorption ratio (SAR)

SAR is an index used to characterize soil sodicity. When SAR is greater than 13, the soil is sodic. The equation used to calculate SAR is given below:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Where: Na = Sodium in me/l; Ca = Calcium in me/l and Mg = Magnesium in me/l

The values for Soapberry are: Na =3.5me/l, Ca =4.5me/l and Mg = 1.5me/l. The SAR is calculated to be 2.02. This SAR value, along with the EC value determines whether there is an infiltration problem.

4.3.3 Infiltration

"Infiltration problems exist when the normal infiltration rate for the applied water is appreciably reduced and remain on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields" (Ayers and Westcot, 198). The two most common water quality factors which influence the normal infiltration rate are the salinity of the water and the sodium absorption ratio. Based on the values determined for these two parameters and the data provided by Ayers and Westcot (1985) in Table 2.7, an infiltration problem is not likely to exist if Soapberry's effluent is used.

4.3.4 Specific Ion Toxicity

Soapberry's effluent is not monitored for its ion content. However, there are a few ad hoc measurements that were done for the concentrations of chloride and sodium – 1.8 and 3.5me/l respectively. There is no restriction to the use of Soapberry's treated effluent for surface irrigation since it is less than 4me/l, however there is slight-moderate restriction for irrigation by sprinklers, since it exceeds 3me/l (Ayers and Westcot, 1985). One of the five famers interviewed irrigate sections of his field with sprinklers (centre-pivot) - this would therefore pose a challenge.

4.3.5 pH

The typical range for pH for irrigation water is 6.5 to 8.5 (Ayers & Westcot, 1994). The treated effluent from Soapberry WTTP has a mean pH value of 7.94 and minimum and maximum values of 7.19 and 8.92 respectively. The range for the pH values is 1.73, and the variance and standard deviation for the data set is 0.03 and 0.18 respectively. This indicates that there pH values are closely centred around a common and value, and that there are no major fluctuations in the pH values. pH adjustment is therefore not required to meet irrigation water quality standards.

4.4 Potential Barriers for Associated Health Risks

In light of the substantial expenditure required to reduce the number of thermotolerant coliforms in the treated effluent from Soapberry to 12 MPN/100mL, considerations are provided below for using the WHO guideline limit of 1000 MPN/100mL and incorporating some of the protective measures or barriers discussed in the literature review in order to further reduce the associated health risks.

The risk management strategy to prevent exposure to hazardous pathogens involves constructing multiple barriers, which opportunely for the research context are inherent in the current location conditions. For example, Jamaica's hot tropical climate allows pathogen inactivation to occur.

> *"Pathogen inactivation is much more rapid in hot, sunny weather than in cool cloudy, rainy conditions. Low temperatures prolong pathogen survival. This is particularly relevant for post-harvest storage. If plants are harvested and then transported and stored in refrigerated conditions (e.g. 4^{o}C) pathogens may be able to survive long enough to infect product consumers". (WHO, 2006, p. 26)*

These barriers or health protection measures are discussed below, and include: wastewater treatment, crop restriction, wastewater application techniques, exposure control methods and cessation of irrigation.

Wastewater treatment is done in order to remove pathogens and toxic chemicals to levels that do not exceed tolerable risks. Despite the treated effluent not consistently reaching the WHO guideline of 1000 MP/100 mL for unrestricted irrigation, it is important to note that the treatment at Soapberry has afforded a significant reduction in pathogens as compared with the influent quality – making it safer than using raw wastewater for irrigation.

Crop Restriction – the research is focused on sugarcane, and if Soapberry's treated effluent was restricted to sugarcane irrigation only, the health risks would be further reduced. Sugarcane does not have surface properties that protect pathogens from exposure to radiation (its exterior is hard and smooth) and is easily washed off with rain and post-harvest washing (WHO, 2006a, p. 27). On the other hand, the high water content of sugarcane may increase the risk of the exposure to pathogens (WHO, 2006, p. 28). However 98% of the sugarcane grown in the Rio Cobre basin is used to make sugar or rum, and is therefore expected to have minimal health effects because the sugarcane is not eaten raw but is processed. The process of making sugar involves six major stages - three of which involve heat. These are: clarification, evaporation and crystallization. Thus the extensive processes of making sugar inactivate pathogens and reduce the health risks. WHO (2006, p. 27) reports that "the greatest health risks are associated with crops that are eaten raw or crops that grow close to the soil." Therefore, since the sugarcane that is being proposed to be irrigated with treated effluent will not be eaten raw and is reaped at a crop height of approximately 8 feet, health risks are further reduced. Since crop restriction is often practiced in conjunction with wastewater treatment (as with this case), Blumenthal (2000b) suggests that lower quality effluents can be used to irrigate non-vegetable crops.

Wastewater application techniques – Two of the six farmers interviewed use drip irrigation. These are small-medium sized sugarcane farmers. The remainder of the farmers (large scale sugarcane farmers) interviewed use furrow irrigation (with the exception of one farmer who uses both furrow and centre-pivot). These irrigation techniques have varying human exposure and crop contamination risks. Studies conducted by (Armon et al., 2002; Bastos and Mara, 1995; El Hamouri et al., 1996; Oron et al., 2001; Solomon et al., 2002), as reported by (Drechsel, et al., 2010) show that drip irrigation, results in comparatively lower contamination on crops than furrow and sprinkler irrigation. Additionally, drip irrigation has the advantage over the other methods of wastewater application in that the WHO does not specify any microbiological quality requirements for treated wastewater when applied to the filed in this way (Mara, 2004). The main challenge for drip irrigation systems as previously discussed is the potential clogging of the emitters. However the TSS content of the treated effluent from Soapberry does not present a problem in this regard.

Cessation of irrigation - is done days before harvest to improve crop quality by reducing bacteria numbers (i.e. allowing time for "bacteria die-off") (WHO, 2006a, p. 78). The cessation of irrigation is a normal requirement for sugarcane cultivation and according to Spencer et al., (1944) “irrigation is suspended a few weeks prior to cutting season in order to ripen the cane. The sucrose content of the stalks increases, and the reducing sugars decrease as the plant approaches maturity”. Vaz da Costas Vargas, et al. (1996) as reported by Blumenthal, et al. (2000b) recommends a period of cessation of irrigation before harvest of 1-2 weeks - which has resulted in improvements in the quality of the irrigated crop to levels seen in crops irrigated by fresh water. The time period for which irrigation is suspended far exceeds the time frame given for pathogen deactivation, as according to SIRI (2015) sugarcane irrigation suspension can last up to six weeks. The sugarcane crop would therefore benefit from the advantages of improved crop bacteriological quality afforded to it by cessation of irrigation.

Human exposure control measures – the discussion thus far has been focused on protecting the consumers of the crop, however measures must be implemented to safeguard the health of persons who will come in contact with the wastewater. Likely persons to be exposed are: farm workers and their families and nearby communities. The WHO Guidelines (WHO, 2006a) therefore recommend, limiting public access to irrigated fields, protective clothing for farm workers (gloves and shoes), as well as good personal hygiene practices among farmers. The agricultural practices themselves (i.e. labour intensive vs. highly mechanized) may increase or decrease the contact with wastewater and therefore increase/reduce the associated health risks. One of the six farmers interviewed uses mechanical harvesters; and his farm accounts for a significant amount (15%) of the sugarcane produced in the Rio Cobre Basin. The use of mechanical harvesters drastically reduces the human exposure to the irrigation water. Of the remaining five farmers interviewed; manual harvesting of the sugarcane is done, and as such, the use of protective clothing is critical. However, the exercise of burning the cane prior to harvesting eliminates much of the risk due pathogens.

4.5 Food Safety – Sugar quality

Safeguarding the quality of the sugarcane and its by-products are critical since sugar is an internationally traded crop for Jamaica, from which well needed foreign exchange is earned. With regard to food safety and international policy implications, the WHO Guidelines (WHO, 2006a) state that strict adherence to its guidelines will help to ensure the international trade of safe products. However, to ensure consumer confidence in the sugar product (since it is internally traded), farm certification may be necessary. This can be provided in the form of GLOBALGAP, as indicated in the WHO Guidelines (WHO, 2006a). GLOBALGAP is a privately operated farm assurance program, which has definitive rules for growers to follow and each production unit is assessed by independent third party auditors.

Sugarcane is listed as one of GLOBALGAP's certifiable crops, and has been listed as a combinable crop (CC). GLOBALGAP defines combinable crops as "products originating from extensive production systems which are commonly designated as producing either grain, pulses, fodder or extract for cooked or processed consumption by humans or animals or for use in industry".

With regard to irrigation water quality, GLOBALGAP prohibits the use of untreated wastewater for crop irrigation but accepts the use of treated wastewater to the guideline values specified in the second edition of the WHO guidelines (WHO, 1989). Therefore, to secure consumer confidence and ensure quality, crop certification may be required.

4.6 Potential Environmental Risks

The two major environmental considerations for wastewater reuse for irrigation are groundwater and soil contamination. Groundwater is the most important of Jamaica's water resources, as 84% of the available water resource is in the form of groundwater (WRA, 2010). Therefore, to prevent jeopardizing the groundwater resources, they must be safeguarded from all potential contaminants. The WHO Guidelines (2006, p.55) report that, "irrigation practices with untreated or partially treated wastewater, impact the quality and safety of groundwater in shallow aquifers and surface waters that may supply drinking water". The depth of the aquifers in the Rio Cobre Basin are greater than the minimum water table depth requirement of 1.5m as reported by WHO (2006a), and should therefore reduce this risk. Another environmental threat is that of organic chemicals. These are industrial solvents and the WHO Guidelines (2006, p. 56) indicate that "these are expected to be removed or degraded during wastewater treatment". The USEPA (1990) as reported by WHO Guidelines (2006) indicates that the frequency of detection for the majority of these organic chemicals was less than 10% and therefore may not need to be considered in wastewater use in agriculture. It is therefore expected that the reuse of Soapberry effluent will not make matters worse for groundwater quality. Although nitrate levels of water sources must be monitored, to ensure no ill effects from irrigation with wastewater.

4.7 Social Aspects of wastewater reuse for irrigation

Even if the treated wastewater surpasses all bacteriological guidelines and standards and does not pose any risk to human health or plant life, the treated wastewater must be accepted as a source of irrigation water by all stakeholders. The stakeholders for this potential effluent reuse scheme include: the sugar cane farmers, sugar importers, consumers of sugar, neighbouring communities and various government agencies (because sugar is an internationally traded good).

This research only elicited the views the sugarcane farmers, and the findings are presented in section 4.7.1 below. However the other stakeholder groups play vital roles in determining the overall acceptance of treated effluent for sugarcane irrigation. In the author's opinion, the sugarcane importers and crop consumers by extension would be concerned with the safety of consuming sugar that has been irrigated with treated wastewater. This issue was discussed in sections 4.3 and 4.4, where the various pathogen reducing measures for sugarcane that was irrigated by treated effluent were presented. Furthermore, if the sugarcane farmlands were to receive GLOBALGAP certification, this would generate confidence in the safety of the sugar produced among the sugar importers and consumers. Also in the author's opinion, neighbouring communities are expected to have some resistance to the use of treated effluent for irrigation, especially if the wastewater has a foul smell or the water drains to the roads or their properties. These are serious considerations which would have to be managed to appease that stakeholder group. The successful implementation of an effluent reuse scheme for irrigation would also require substantial buy-in from the various government agencies. However, the general direction of the country (Vision 2030 Jamaica), with supporting policies (Water sector Policy 2004) strongly support the reuse of treated wastewater for irrigation. The final stakeholder group - sugarcane farmers, which will actually come in contact with the treated wastewater, is discussed below.

4.7.1 Attitudes and perceptions towards effluent reuse for irrigation

User acceptability information was obtained from the analysis of the semi-structured interviews (questions 7-9) conducted with six sugarcane farmers of the Rio Cobre Basin. This is in-keeping with the WHO Guidelines (WHO, 2006a), which state that the social acceptance of treated effluent as a source for irrigation water is subjective and is dependent on the specific user group.

All the farmers interviewed provided responses to every question posed, and even initiated discussions on other issues, relevant to the research. The main findings of the interviews are presented in table 4.2 below. The table shows the thematic codes which were used to group responses of similar themes, the number of responses and general comments on the issues, including some direct quotes. In general, the comments are as expressed by the farmers (verbatim), except the change in narrative from first person to second person. The information is presented in this manner to reduce the bias and subjectivity.

Table 4.2 Results of Semi-structured Interviews

THEME	# RESPONSES	COMMENTS
Acceptance of treated wastewater for irrigation use	5	These Respondents indicated that they would be willing to use treated wastewater for irrigation, Some examples of the responses given are:
		"I wouldn't have a problem with using treated wastewater, once it's treated properly/safe to use".
		"I have no problem with using wastewater for irrigation and would personally use it for irrigation".
Non-Acceptance of treated wastewater for irrigation use	1	One respondent was adamantly against the use of treated wastewater for irrigation. The following reasons were given:
		Does not think it is acceptable to ask persons to work with it
		Think it's disrespectful to even suggest using it for irrigation.
		Thinks it's not safe to reuse wastewater
		Zero confidence in the sustainability of such a scheme and the quality of effluent that will be produced
		Fears that the total cost for the irrigation scheme will be borne by the farmers through the tariff
		Fears that reusing effluent for irrigation will cause the farmers to pay more than they currently pay
Concerns with the use of treated wastewater for irrigation	6	The following concerns were reported by the farmers:
		Safety while using the treated irrigation (i.e. human exposure to wastewater)
		Cost that will be imposed and who will pay
		Questions the acceptability by all potential users
		Questions if there are long-term health risks
		Questions the effect wastewater use will have on the soil (heavy metals in particular)
		Concerned whether wastewater will be corrosive to irrigation equipment (centre pivot system)
		Will the wastewater be piped directly to the farm?
Perceptions on the use of treated wastewater for irrigation	6	Good for the crop
		Thinks it's a good proposition but would need public education
		Believes Soapberry's treated effluent is currently being wasted and should be put to good use
		Welcomes the use of treated effluent, as current irrigation supply is inadequate and unreliable
		Table Continues

Table Cont'd

THEME	# RESPONSES	COMMENTS
Issues with current Irrigation supply	6	The farmers interviewed reported that they have been experiencing challenges with their current irrigation supply, such as:
		Unreliability of supply
		Low pressures (these farms were supplied by NIC's groundwater sources). One respondent indicated that drip irrigation systems require water at 30-45 psi and he was only getting 15 psi. Because of this, he irrigates his cane in sections and does not irrigate the entire area at once.
		Inconsistency in supply
		The water is channelled away by community members before it reaches the farm. (these farms are supplied by water from Rio Cobre River which is conveyed in open channels to the farms)
		Some of the larger farmers (600 ha -1400ha) have their own wells and have licences to abstract water, however the medium size farmers (200-600ha) indicated that it was too expensive to operate their own wells (water purchased from NIC is cheaper, as it is heavily subsidized by the government). Additionally, the farmers are forced to incur extra costs for security when their pumps are in operation because of possible theft. The large framers (1400ha) indicated that it was cheaper to use their own water supplies but the licenced abstraction limit prevented them from meeting the full crop requirement and as a result purchased additional water from NIC (economies of scale).
Willingness to pay for treated wastewater for irrigation	5	The respondents who indicated acceptance of the use of treated wastewater for irrigation indicated that they were either willing to pay the same amount or less than what they currently pay for irrigation – provided there is an improvement in the supply

With regard to acceptance, the findings indicate acceptance by five (5) of the respondents and total non-acceptance by one (1) respondent. Based on the above findings, the author has concluded that the majority (5 out of 6) of the respondents accept the use of treated wastewater for irrigation, and would be willing to use this is as a source of irrigation water – provided it is safe and will not cost more than what they currently spend. Based on the responses given, it is the author's opinion that the general dissatisfaction with the current source of irrigation water could have had an effect on the high level of acceptance. Additionally, the farmers were found to be very knowledgeable of the potential benefits of wastewater reuse and this too could possibly have been a factor.

Accessing the credibility of interviews is very difficult, and would require mind-reading capabilities to determine if true opinions and feelings were given. However, it is strongly believed that the respondents expressed their true feelings and attitudes for the following reasons:

- It was made known that their opinions would not alter any outcome.
- The respondents which indicated acceptance – gave examples, which suggested that they were in fact truthful. For example, one respondent said that he was willing to use treated wastewater for irrigation and said that he thinks that it's good for the crop. He went further to give a scenario experienced on his farm: A cesspool truck emptied its contents in one section of his field, and he noticed that the sugarcane growing in this section was bigger and looked healthier than the remainder of the crop, and concluded that wastewater has some benefits. Another respondent, who also indicated acceptance, stated that he was in the process of trying to get treated wastewater from a nearby package WWTP to use for irrigation. These incidences suggest that the respondents were expressing their true feelings, and as such the findings are credible.

One other social aspect for wastewater reuse for irrigation is human behaviour. Human behavioural patterns is equally important and is described as a key determining factor in the transmission of excreta related diseases by the WHO Guidelines (WHO, 2006a). This includes hygiene practices of persons who will come in contact with the treated effluent and the use of protective clothing and the wearing of shoes by farmers. The WHO Guidelines also state that the "social feasibility of changing certain behavioural patterns in order to introduce wastewater schemes must be assessed on an individual project basis". Education and training are therefore essential for the implementation of a successful and safe reuse scheme.

4.8 Irrigation Water requirements

4.8.1 Quantities of wastewater available from Soapberry

The quantity of effluent discharged is estimated because of a malfunctioning meter. The estimated figure is 75,000 m^3/day, as the plant is approaching hydraulic capacity. There are no temperature extremes and as such the evaporation rate from the ponds is assumed to be constant.

4.8.2 Crop Water Requirement - Sugarcane Water Balance

In order to have a sustainable effluent reuse scheme for irrigation, it is essential that the correct amount of treated wastewater is applied at the right time to meet the crop requirements. A water balance was conducted to determine the annual average volume of effluent required for sugarcane irrigation in the Rio Cobre Basin (see Figure 4.6). There are several sugarcane farmlands in the basin, these are: Bernard Lodge (1500ha), Windsor (60ha) and Innswood Estates (600ha). Figure 4.6 shows the entire Bernard Lodge Estate, but only portions of the Windsor and Innswood Estates. The following inputs were determined:

1. *Evapotranspiration*

More than 99 per-cent of the water absorbed by plants is lost by transpiration and evaporation from the plant surface (Pescod, 1992). Evapotranspiration (ET) varies throughout the year depending on temperature, solar radiation, wind, humidity, crop type and growth pattern. The equations used to calculate sugarcane evapotranspiration are:

$$ET_{sugarcane} = Kc.ET_o$$

Where:

$ET_{sugarcane}$ = Evapotranspiration of sugarcane

Kc = crop coefficient (average for ratoon and virgin sugarcane for local condition – little wind and humid)

ET_o = Reference crop evapotranspiration - 8 to 15cm tall grass (Brouwer, 1986)

$$ET_o(mm/day) = p(0.46T_{mean} + 8) \quad \ldots\ldots Blaney\ Criddle\ Fromula$$

Where: T_{mean} = Mean daily temperature (^oC)

p = Mean daily percentage of annual day-time hours

Monthly Sugarcane Evapotranspiration values are shown in Appendix H.
Percolation and Runoff is assumed to zero.

2. Leaching Faction

Continuous irrigation with the treated effluent from Soapberry may cause soil salinity problems. This can be controlled by leaching, which is the application of excess irrigation water to remove the salt accumulated in the soil. The equation used to calculate the leaching fraction as given by Rhoades (1974) and Rhoades and Merril (1976) and quoted from FAO (Ayers and Westcot, 1985) is:

$$LR = \frac{EC_w}{5\,(EC_e) - EC_w}$$

where:

LR	=	The minimum leaching requirement needed to control salts within the tolerance (EC_e) of the crop with ordinary surface methods of irrigation
EC_w	=	Salinity of the applied irrigation water in dS/m Salinity of Soapberry treated effluent = 0.99 dS/m
EC_e	=	Average soil salinity tolerated by sugarcane = 1.7 dS/m The EC_e value is based on a sugarcane yield potential of 100% - obtained from FAO (Ayers and Wetscot, 1985) - Table 4.

The Leaching fraction, LR is therefore calculated to be 0.13, for 100% sugarcane yield potential, and is assumed to be constant.

3. Total Annual Depth of Water

The total annual depth of water that needs to be applied (Aw) to meet both the crop demand and leaching requirement (LR) was estimated from (Ayers and Westcot, 1985) - equation 7.

$$AW = \frac{ET}{1 - LR}$$

Where:

AW	=	depth of applied water (mm/year)
ET	=	total annual crop water demand (mm/year)
LR	=	leaching requirement expressed as a fraction

4. Precipitation:

Rainfall supplies some of the irrigation requirement; precipitation is subtracted from the total annual water depth.

Thirty year average for monthly precipitation values from the Meteorological office of Jamaica:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall - 30 year Average (mm)	53	55	61	91	156	110	85	129	172	188	115	62

5. *Irrigation Efficiency*

Estimated at 75%

6. *Total Effluent to be used for irrigation*

The annual irrigation requirement for sugarcane on 2,160 hectares of farmland is 31,541,760m^3, while Soapberry has the capacity to provide only 27,375,000m^3 annually. However, only 22,534,396m^3 can be safely used for sugarcane irrigation based on the nitrogen content of the effluent (see section 4.10.2 for further details). Therefore Soapberry is able to provide 71% of the annual sugarcane irrigation requirement for 2,160 hectares of farmland. The complete water balance is given in Appendix H.

4.8.3 Storage Requirements

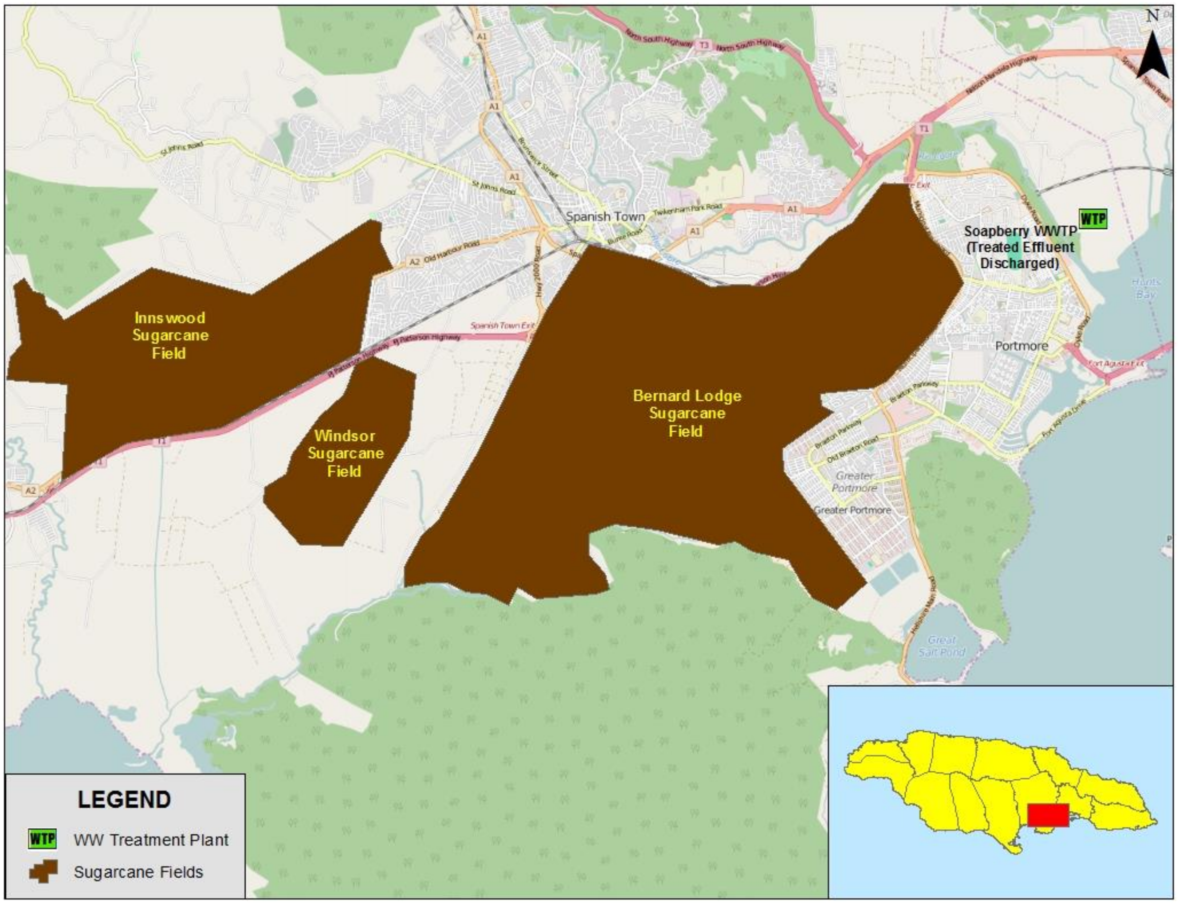
The sugarcane Water Balance (Appendix H) shows that Soapberry will not be able to provide the total water required by 2,160 ha of sugarcane. Furthermore the nitrogen content of the effluent as discussed later (section 4.10.2) limits the use of effluent and indicates that approximately 71% of the crop water requirement can be supplied by Soapberry. As a result, the additional water requirements will still need to be met by other sources, with either: partial effluent discharge to the river or irrigating a larger area of sugarcane farmland. However, storage will still need to be provided to better facilitate the distribution of the treated effluent by pumping. The storage to be provided is 315,000m^3.

4.9 Preliminary engineering of the proposed effluent reuse scheme

The effluent reuse potential for irrigation requires the consideration of the distribution of the treated wastewater to the sugarcane farmlands. The preliminary design of the effluent reuse irrigation scheme is given below. The following are the design inputs:

Data Group	Description	Remarks
Daily volume of Effluent for irrigation	Information needed to design pipelines and pumping equipment	75,000m^3/day
Effluent quality	The data is required to ensure that water used for irrigation will not pose health risks to farm workers and persons consuming the crop. Data also required to calculate nutrient balance	The potential health risks and protective measure are discussed in section 2.5 and 2.6.
Land area and elevations	The size of the sugarcane farmlands to be irrigated and the pumping requirement	Bernard Lodge 1,500ha (60 masl) Windsor 60ha (22 masl) Innswoood 600ha (50 masl) Total area: 2,160 ha Soapberry (3 masl)
Distances	There are existing irrigation infrastructure to farm gate. Additional piping required to distribute water from Soapberry to Bernard Lodge	10 km

The disinfection for the treated effluent will be achieved through chlorination. This involves the construction of a reinforced concrete chlorination retention chamber and the necessary fittings as described in Appendix G, and amounts to $720,000USD. The Reuse scheme involves the provision of storage and the laying of approximately 10km of pipeline between Soapberry and Bernard Lodge (see Figure 4.6). The existing irrigation distribution infrastructure will be used to get water to farm gate and significant pumping will be required. The cost for the reuse scheme is $22,439,000USD. The total cost to reuse effluent from Soapberry in-keeping with standard of 12 MP/100ml is $29,211,375USD (see Appendix G, for full cost estimate). The monthly O&M expense is estimated to be $35,000USD which is primarily pumping costs. Figure 4.6 shows the location of Soapberry and the sugarcane lands to be irrigated – Bernard Lodge (1500ha), Windsor (60 ha) and part of Innswood (600ha).



4.6 Map of Sugarcane Fields for irrigation
Source: Author (2016)

4.10 Economic and financial implications

The responsibility for collecting, treating and disposing of wastewater lies with NWC. However, Pescod (1992) indicates farmers wishing to take advantage of the effluent are often able and willing to pay for what they use but are not prepared to subsidize general disposal costs. This was found to be the case based on the semi-structured interviews. The five (of six) farmers, who were willing to use effluent for irrigation, were either willing to pay the same or less than what they currently pay. However, based on their current dissatisfaction with the current irrigation source (reliability and low pressure), the effluent reuse scheme must surpass these flaws. Pescod (1992) recommends charging the farmers for only the incremental costs associated with additional treatment and distribution.

4.10.1 Financial Impacts

Proposed tariff - As recommended by Pescod (1992), the proposed tariff will recover only the incremental costs associated with the treatment and distribution – i.e. the costs outlined for disinfection and distribution. The Average Incremental approach was used to estimate the tariff for the effluent reuse scheme. The following assumptions were made: discount rate of 10%, the recurrent costs remain constant and the total capital cost for the project is spread over the first three years. Both CAPEX and O&M will be recovered by the tariff over a twenty year period. Based on this approach the tariff is calculated at 0.14USD/m^3. See Appendix E for Tariff Calculations.

NIC Tariff structure - The NIC's charge for irrigation water is considerably low and is a result of government intervention in the form of subsidies. The tariff structure is as follows:

- Demand Charges: (a) $0.015USD/$m^3$ for the first 5,508m^3 (b) $0.02US/$m^3$ for each additional cubic metre above 5,508m^3.
- Service Charges:

ITEM	DESCRIPTION	CURRENT RATE (USD)
(a)	On land not exceeding 2 hectares	$0.25 per hectare/month
(b)	On land exceeding 2 hectares but not exceeding 4 hectares	$0.50 per hectare/month
(c)	On land exceeding 4 hectares	$0.63 per hectare/month

Comparison of tariffs - A monthly usage of 30,000m^3 for a land area of 100ha (based on actual water used and land area of farmer interviewed) is $635.46 and $4,200 USD monthly, for the existing and proposed irrigation schemes respectively. The effluent reuse scheme will charge a rate that is 15% higher than the current source – which renders it unfavourable to the farmers based on cost. The proposed scheme is not financially viable based on the relatively high costs and lack of willingness to pay more than current costs.

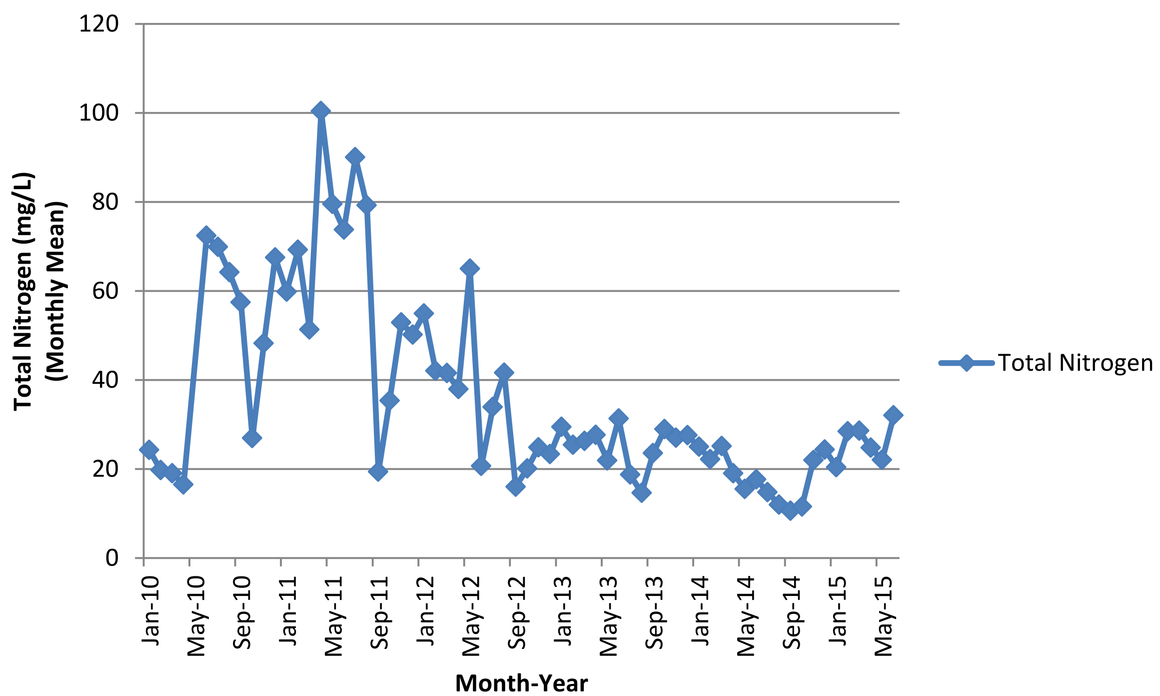
However, current subsidies could be applied to the reuse scheme, although this is not desirable, as the cost to supply water should be funded by the users. The tariff calculated is based on full recovery of CAPEX and O&M costs. Alternate tariff recovery scenarios could be considered to find a balance. Some of these are recommended in Chapter 5.

4.10.2 Economic Benefits

Benefits of nutrients in effluent - From the semi-structured interviews, all six respondents indicated that they used fertilizers (urea and sulphate of ammonia). All farmers indicated that they use ten 110lb bags per/ha/year. They also indicated that SIRI conducts soil and leaf testing after most crop cycles to determine the fertilizer application rate required for each farm. However, the average application rate is as given above and was used for the calculations done. The average cost for ten 110llb bags is $300USD, therefore, for a 100ha farm; it would cost $30,000 USD to fertilize the crop annually.

The treated effluent from Soapberry has mean concentration values of 2.4mg/l of phosphate (i.e. phosphates as phosphorous) and 36mg/l nitrogen (total nitrogen) for the period January 2010-June 2015. However, the concentration of nitrogen in Soapberry's effluent has decreased and showed less variability since August 2012, as shown in Figure 4.7 below.

Figure 4.7 Total Nitrogen Concentration in Soapberry's Treated Effluent (2010-2015)



This reduction in total nitrogen coincides with changes made to the filter operations at Soapberry. The changes consisted of more frequent backwashing of the filter to remove solids and disinfection of the filter with chlorine bleach to control bacterial growth on the filter media. These changes resulted in a decrease in BOD and TSS. Some degree of correlation between TSS and total nitrogen is reasonable as only a fraction of the total nitrogen is typically associated with TSS. Most total nitrogen is ammonia and nitrate which are soluble and unaffected by TSS. However, the organic nitrogen component of total nitrogen may be insoluble and found in solid particles. Therefore, removal of a portion of the organic nitrogen with the TSS may account for the step decrease in total nitrogen noticed since August 2012. The mean concentration of the nitrogen in the effluent for the period August 2012 to June 2015 is 22mg/l. This figure was used for the nitrogen concentration for Soapberry's treated effluent in subsequent calculations.

The nitrogen content of the effluent is relatively high and this will be of value to the farmers, and result in cost saving, as they would not need to buy fertilizers. Urea contains 46% nitrogen and therefore the annual supply of 1100lbs supplies nitrogen at a rate of 229,517,000mg/ha. However, if 27,375,000 m^3 of treated effluent is supplied annually, then it contains 602,250,000,000mg nitrogen/year. Therefore, for a land area of 2160 ha, the application rate of nitrogen from Soapberry's effluent is 278,819,444mg/ha. The straight use of Soapberry's effluent would over supply the crop with nitrogen by 49,302,444mg/ha. Therefore, the maximum amount of treated effluent from Soapberry that can be used to irrigate sugarcane based on nitrogen needs is 22,534,396m^3 annually (assuming nitrogen concentration of 22mg/l) – i.e. 10,432m^3/ha/year. Since only 82% of the total effluent produced by Soapberry can be safely used for sugarcane irrigation each year on 2160 ha of farmland, then the remaining effluent can be:

- discharged to the river
- used to irrigate other sugarcane farms in the basin

Consequently, based on the nitrogen content of the effluent, the use of Soapberry's treated effluent for sugarcane irrigation should be limited to 22,534,396m^3 annually (for and area of 2160ha). The remainder of the crop water requirement should be met by other sources. Also, if the nitrogen levels in the wastewater increases, additional nitrogen removal at Soapberry would become necessary.

The estimated cost savings realised by using treated effluent is therefore $300USD /ha/year, since no additional fertilizers would be required. Strict monitoring on the quantities of treated effluent used per hectare is required, because excess nitrogen can cause crop damage and have negative environmental impacts on groundwater and surface water bodies, as discussed earlier.

Additionally, 54,082,550,400mg of potassium can be supplied annually by irrigating with 22,534,396m^3 of treated effluent. This is in-keeping with the potassium requirement of sugarcane, and is therefore another benefit of reusing effluent for irrigation.

Other Economic Benefits - The proposed effluent reuse scheme has several economic benefits, which include the opportunity costs of:

- Not using the freshwater sources of the Rio Cobre basin for irrigation, and instead making it available for domestic purposes
- Not discharging the all treated effluent (which is of high nitrogen levels, 22 mg/L) to the Rio Cobre, and therefore prevents environmental degradation and the harmful effects of eutrophication.

4.11 Chapter Summary

The Chapter presented the results and findings of the data collection exercise. It was found that the effluent from Soapberry is fully compliant for Oil and Grease, partially complaint (approximately 80% complaint) for BOD, COD and TSS and 0% compliant for thermotolerant coliforms (946 MPN/100ml) – when compared to the Jamaican standard. The water and soil salinities were found to be 0.99dS/m and 1.7dS/m respectively, and in-keeping with crop tolerance levels given by Ayers and Westcot (1985).

The results of the social survey revealed that five of six farmers accepted the use of treated effluent for irrigation and even welcomed it, while one farmer was vehemently opposed to it. They also indicated an acceptable willingness to pay, by indicating that they would pay the same for treated effluent as they currently pay for irrigation water.

It was determined that only 82% of the effluent from Soapberry can be safely used to irrigate sugarcane based on nitrogen levels. This would provide 71% of the crop water requirement (for a land area of 2,160ha), and therefore irrigation would still be necessary from other sources. The proposed effluent reuse scheme would require: chlorination to reduce thermotolerant coliforms, 10km pipeline and pumping to overcome the 57m difference in elevation, and storage. This is estimated to cost $29,211,375USD, with an annual recurring O&M cost of $420,000USD. The proposed tariff to cover both these costs, over a twenty year period came out at 0.14USD/m^3. This is substantially higher than the cost of the current source and is considered financially non-viable, unless other financing options are explored.

The proposed effluent reuse scheme has several advantages including the potential cost savings of no longer requiring fertilizers and amounts to $300USD/ha annually. It was determined that the irrigation with effluent would not pose serious threats to the crop, once no more than 10,432m^3/ha/year is used to irrigate sugarcane, and the additional crop water requirements are met by other sources.

The next chapter will discuss the conclusions drawn from these findings.

5 RECOMMENDATIONS AND CONCLUSION

5.1 Chapter Overview

The issues of increasing water demands owing to increasing populations, as well as the large quantities of water required for irrigation (which are supplied from fresh water sources) have put a strain on the limited water resources of the Rio Cobre Basin, Jamaica.

To address the issue of water supply shortages for the Rio Cobre Basin, the research investigated whether an integrated water resources management approach (IWRM) involving the reuse of treated effluent from Soapberry wastewater treatment plant, WWTP to irrigate sugarcane could help to ease the problem. A case study methodology that used document analysis, semi-structured interviews and literature review was adopted to evaluate the objectives of the research.

The conclusions drawn from the assessment of whether Soapberry can meet the Jamaican effluent reuse standards, and safely provide irrigation water to meet the crop requirements is discussed in the next section. Also included are the conclusions drawn from the social acceptance surveys conducted with the farmers and the conclusions of the economic and financial appraisal of the proposed effluent reuse scheme. Some key recommendations are also given.

5.2 Conclusions on Soapberry's effluent quality and its suitability for sugarcane irrigation

Soapberry can meet the Jamaican effluent reuse standard for irrigation for all parameters (BOD, TSS, COD and Oil and Grease) except thermotolerant coliforms. To meet the excessively stringent limit of 12MPN thermotolerant coliforms/100ml, disinfection must be provided and the selected means of chlorination costs $720,000USD. However, Soapberry can be safely used for sugarcane irrigation, based on the quality of the current treated effluent - despite not meeting the Jamaican standard. It is deemed acceptable to irrigate sugarcane with Soapberry's effluent which has thermotolerant coliform numbers of 946 MPN/100ml based on the recommended limit of <1000 MPN/100mL by Blumenthal et al., (2000b). The microbiological health risks can be further reduced when combined with other protective measures, such as cessation of irrigation (which is a rule for sugarcane cultivation), among other measures. It was found that irrigating sugarcane with Soapberry's effluent would not pose any salinity or infiltration problems. However, there is a slight to moderate restriction based on ion toxicity, and the high concentration of nitrogen relative to crop requirement.

The following recommendations are therefore made for the safe and effective reuse of Soapberry's treated effluent for sugarcane irrigation:

- Pilot testing with small sugarcane fields immediately adjacent to Soapberry (this will provide useful information without the capital outlay)
- Provide a generator or alternate power source (in the event of power outages) as well as ensure the timely delivery of cationic polymers, to guarantee good quality effluent is produced at all times
- Mandating that Sugarcane irrigation with Soapberry's effluent should be done in conjunction with freshwater sources, so as to limit the quantity of nitrogen applied.
- Schedule irrigation days among farmers, since large volumes of water are required by them, and crops are irrigated twice monthly.
- Ensure that leaching is done by farmers to limit the potential salinity related problems.
- Monitoring/testing/reporting on the following additional parameters: number of helminths and EC of treated effluent monthly and the sodium, calcium and magnesium levels twice annually.
- NIC and SIRI should peruse GLOBALGAP certification jointly with the farmers
- Revision to the Jamaican Effluent reuse standard for irrigation, to increase the standard limit for thermotolerant coliforms from 12MPN/100ml – either to the limit of 1000MPN/100ml or to some other limit based on local epidemiological conditions. It should be mandated that wastewater reuse with this increased limit should be coupled with protective measures identified.

5.3 Farmers' attitudes and perceptions towards treated effluent reuse for sugarcane irrigation

The research revealed that the majority of the farmers were willing to use treated effluent for irrigation, with strong opposition from one farmer. Since this acceptance is contingent on it being safe for the crop and human health, as well as the cost relative to the current irrigation source – the project will not be accepted by the farmers on the basis of the proposed tariffs, despite being safe. It is believed that this sentiment is representative of the sample population despite the low sample size. In any event, Soapberry can only supply a portion of the irrigable sugar lands; as a result acceptance by all farmers is not required.

The following recommendations are therefore made:

- Host stakeholder meetings and adopt a bottom-up approach, if the proposed effluent reuse scheme is to be implemented.
- Public education campaigns to sensitize and train farmers about the safe use of treated effluent for irrigation, including the various human exposure control techniques, such as wearing gloves and shoes while working with effluent.

5.4 Effluent availability versus crop water requirement

It was determined that only 82% of the effluent from Soapberry can be safely used to irrigate sugarcane based on nitrogen levels. This would provide 71% of the crop water requirement (for a land area of 2,160ha), and therefore irrigation would still be necessary from other sources. The reminder of the treated effluent not used for irrigation could be used to irrigate additional sugarcane in the basin or be discharged to the river.

5.4 Economic and financial appraisal of proposed effluent reuse scheme

Although the environmental benefits make the project economically attractive, the proposed tariff is beyond what farmers are willing to pay. Their lack of willingness to pay is worsened by the fact that their current irrigation source is subsidized. This research does not propose a subsidy, but rather the removal of the CAPEX costs from the tariff recovery, i.e. to only recover the recurring O&M costs from the farmers. Alternative funding options such as grants and low interest rates may be available for environmental projects such as these, especially those aimed at climate change adaptation. Partial grant funding is available from agencies such as Caribbean Development Bank, Global Environment Fund and Japan International Corporation Agency. If these avenues are pursued, the project may be financially viable.

5.5 Institutional Aspects

The proposed effluent reuse scheme will require institutional changes. The current “owner” of the wastewater is NWC, however NIC has the mandate to supply irrigation water. These ownership and management issues would have to be determined. Decisions must also be taken on: maintenance of quality standards and system reliability as well as capacity building for technical and managerial staff.

5.6 Future Study

The current effluent reuse standard for irrigation is prohibitive and therefore prevents effluent reuse for irrigation island-wide. Quantification of the health risks associated with effluent reuse should be done based on epidemiological studies and quantitative microbial risk analysis, so that the standard can be modified to fit local conditions.

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APPENDICES

Appendix A: The 1989 WHO guidelines for using treated wastewater in agriculture[a]

Category	Reuse Conditions	Exposed Group	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100ml[c])	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncookded, sports fields, public parks[d]	Workers, consumers, public	≤1	≤1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees [e]	Workers, consumers, public	≤1	No standard recommended	Retention in stabilization ponds 8-10 days or equivalent helminth and faecal coliform removal
C	Localized Irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by irrigation technology but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] Ascaris and Trichuris species and hookworms

[c] During the irrigation period

[d] A more stringent guideline limit (≤200 faecal coliforms/100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come in contact

[e] In the case of fruit trees, irrigation should cease two weeks before the fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should be used.

Appendix B: Recommended Revised microbiological guidelines for treated wastewater use in agriculture[a] by Blumenthal et al., (2000a)

Category	Reuse Conditions	Exposed Group	Irrigation technique	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100ml[d])	Wastewater treatment expected to achieve the required microbiological quality
A	Unrestricted irrigation					
	A1 For vegetable and salad crops eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	Any	≤0.1[f]	$\leq 10^3$	Well designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
B	Restricted irrigation					
	Cereal crops, industrial crops, fodder crops, pasture and trees [g]	B1 Workers (but no children <15 years), nearby communities	Spray or sprinkler	≤1	$\leq 10^5$	Retention in WSP series including one maturation pond or in sequential WSTR or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration)
		B2 and B1	Flood/furrow	≤1	$\leq 10^3$	As for Category A
		B3 Workers including children <15years, nearby communities	Any	≤0.1	$\leq 10^3$	As for Category A
C	Localized Irrigation of crops in category B if exposure to workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable	Pre-treatment as required by irrigation technology but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] Ascaris and Trichuris species and hookworms; the guideline limit is also intended to protect against the risk of parasitic protozoa.

[c] During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve egg numbers, then routine effluent quality monitoring is not required).

[d] During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly)

[e] A more stringent guideline limit (≤200 faecal coliforms/100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come in contact

[f] This guideline limit can be increased to ≤1 egg/litre if (i) conditions are hot and dry and surface irrigation is not used or (ii) wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater reuse.

[g] In the case of fruit trees, irrigation should cease two weeks before the fruit is picked, and no fruit should be picked off the ground. Spray/Sprinkler irrigation should be used.

Appendix C: Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (EC_w) or Soil Salinity (EC_e)[1]

FIELD CROPS	YIELD POTENTIAL[2]									
	100%		90%		75%		50%		0% maximum[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Sugarcane (Saccharum officinarum)	1.7	1.1	3.4	2.3	5.9	4.0	10.0	6.8	19.0	12.0
Tomato (Lycopersicon esculentum)	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13.0	8.4
Pepper (Caspium annum)	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Sweet Potato (Ipomoea batatas)	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11.0	7.1

Source: FAO (Ayers and Westcot, 1985)

[1] Adapted from Maas and Hoffman (1977) and Maas (1984). These data should only serve as a guide to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices. In gypsiferous soils, plants will tolerate about 2 dS/m higher soil salinity (ECe) than indicated but the water salinity (ECw) will remain the same as shown in this table.

[2] ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in deciSiemens per metre (dS/m) at 25°C. ECw means electrical conductivity of the irrigation water in deciSiemens per metre (dS/m). The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15–20 per-cent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone. These assumptions were used in developing the guidelines in Table 1.

[3] The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) at which crop growth ceases.

Appendix D: Monthly mean, minimum and maximum values of monitored parameters for Soapberry's Treated Effluent (January 2010 – June 2015)

YEAR 2010		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	7.90	3.7	34.4	4.9	3.0	24.3	143
	Min	7.83	2.60	29.50	2.60	1.57	21.50	16.00
	Max	8.05	5.00	41.00	7.60	3.82	30.00	460.00
February	Mean	8.10	8.70	42.25	3.40	2.20	19.75	338.41
	Min	8.05	1.80	35.00	2.50	0.88	9.00	220.00
	Max	8.15	21.00	50.00	4.30	3.26	26.00	540.00
March	Mean	7.98	17.80	52.25	3.93	3.87	19.00	213.39
	Min	7.68	15.00	45.00	2.50	2.81	9.00	150.00
	Max	8.09	22.00	57.00	5.60	4.83	28.00	240.00
April	Mean	8.01	20.63	41.50	4.23	1.28	16.50	251.08
	Min	7.86	10.60	35.00	2.60	0.13	3.80	150.00
	Max	8.23	29.50	49.00	5.10	2.33	28.00	460.00
May	Mean	NS	NS	NS	NS	NS	NS	NS
	Min	NS	NS	NS	NS	NS	NS	NS
	Max	NS	NS	NS	NS	NS	NS	NS
June	Mean	7.60	12.50	35.25	4.78	2.59	72.38	396.20
	Min	7.50	4.80	24.00	2.80	2.22	63.10	93.00
	Max	7.70	19.00	46.00	6.00	3.07	82.30	2400.00
July	Mean	7.87	5.08	39.50	3.80	1.94	69.85	1974.72
	Min	7.70	0.40	35.00	2.00	0.61	50.60	1100.00
	Max	7.99	8.70	43.00	5.80	3.85	93.60	2400.00
August	Mean	7.83	8.40	38.60	6.96	1.37	64.16	1502.87
	Min	7.19	1.40	31.00	3.00	0.69	55.90	1100.00
	Max	8.14	17.00	52.00	13.00	2.15	71.30	2400.00
September	Mean	7.94	7.55	46.50	5.63	2.56	57.45	864.53
	Min	7.73	4.20	39.00	3.00	0.11	15.80	460.00
	Max	8.15	11.00	55.00	11.30	4.08	140.00	2400.00
October	Mean	7.73	7.85	34.13	6.05	2.52	26.90	251.08
	Min	7.58	0.80	25.50	2.80	2.19	14.00	150.00
	Max	7.90	15.00	42.00	8.40	2.84	54.00	460.00
November	Mean	7.78	9.30	33.60	4.56	1.17	48.20	1475.56
	Min	7.63	1.00	29.00	2.50	0.70	37.00	460.00
	Max	7.85	16.00	39.00	6.00	1.44	60.00	2400.00
December	Mean	7.87	2.73	49.00	11.80	0.64	67.50	1426.70
	Min	7.75	1.20	45.00	6.80	0.63	51.50	1100.00
	Max	7.98	4.20	52.00	18.00	0.65	79.00	2400.00

Appendix D – Cont'd

YEAR 2011		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	7.97	5.46	42.00	6.84	0.84	59.80	205.85
	Min	7.71	2.20	39.00	3.20	0.55	35.00	93.00
	Max	8.18	10.40	49.00	12.20	1.11	74.00	460.00
February	Mean	7.85	5.38	42.50	6.20	1.63	69.20	340.03
	Min	7.59	1.20	35.00	4.20	0.20	51.00	93.00
	Max	8.06	12.70	59.50	10.00	2.68	80.00	1100.00
March	Mean	7.91	6.76	45.20	5.44	1.65	51.30	669.06
	Min	7.83	4.80	40.00	4.70	0.42	24.50	240.00
	Max	8.12	9.20	52.00	6.20	3.39	71.00	2400.00
April	Mean	8.22	77.55	189.50	73.08	1.81	100.38	1974.72
	Min	7.67	17.20	42.00	7.20	0.02	85.00	1100.00
	Max	8.76	120.00	249.00	101.10	4.57	114.00	2400.00
May	Mean	8.65	102.35	271.25	113.08	0.47	79.50	1624.81
	Min	8.48	72.40	211.00	71.00	0.01	63.00	1100.00
	Max	8.74	134.00	313.00	153.00	1.70	100.00	2400.00
June	Mean	8.23	72.88	216.25	74.50	2.17	73.75	604.56
	Min	7.93	59.50	191.00	53.00	0.05	41.00	240.00
	Max	8.42	89.00	274.00	100.00	3.69	100.00	1100.00
July	Mean	8.35	46.00	226.50	73.50	1.99	90.00	1050.71
	Min	7.98	24.50	196.00	51.00	0.27	30.00	460.00
	Max	8.83	77.00	309.00	106.00	3.33	126.00	2400.00
August	Mean	8.12	66.25	223.25	70.98	0.29	79.25	1075.07
	Min	7.51	41.00	210.00	56.50	0.01	59.00	460.00
	Max	8.53	80.00	229.00	80.00	0.64	114.00	2400.00
September	Mean	8.03	13.75	65.25	27.20	2.02	19.33	864.53
	Min	7.64	3.00	24.00	7.20	1.31	16.20	460.00
	Max	8.60	21.00	186.00	84.00	2.68	22.00	2400.00
October	Mean	8.05	33.94	114.50	46.33	1.05	35.30	2400.00
	Min	7.89	5.77	24.00	5.40	0.62	24.70	2400.00
	Max	8.12	73.00	216.00	95.30	1.63	53.00	2400.00
November	Mean	7.87	8.48	33.75	7.90	1.39	52.88	864.53
	Min	7.78	4.30	28.00	4.40	0.03	30.50	460.00
	Max	8.05	12.50	39.00	15.60	2.15	68.00	2400.00
December	Mean	7.69	7.00	28.67	4.83	1.50	50.17	2400.00
	Min	7.68	4.20	19.00	2.50	0.60	40.00	2400.00
	Max	7.71	10.40	38.00	8.00	2.56	61.50	2400.00

Appendix D – Cont'd

YEAR 2012		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	7.81	6.30	25.75	4.58	1.77	54.88	1624.81
	Min	7.71	2.60	9.00	2.50	0.39	30.00	1100.00
	Max	7.91	12.20	36.00	9.80	3.98	91.00	2400.00
February	Mean	7.85	4.70	21.25	5.90	1.08	42.00	2400.00
	Min	7.75	3.50	15.00	4.80	0.39	21.00	2400.00
	Max	7.93	6.10	30.00	7.00	2.28	53.00	2400.00
March	Mean	7.80	4.53	30.00	14.65	1.93	41.50	513.81
	Min	7.60	1.60	29.00	2.50	0.36	36.00	240.00
	Max	8.12	11.70	32.00	33.20	4.41	47.50	1100.00
April	Mean	7.88	4.90	28.25	7.55	2.41	37.93	326.00
	Min	7.65	0.40	23.00	3.20	1.93	19.70	93.00
	Max	8.10	8.40	34.00	11.00	3.20	62.00	1100.00
May	Mean	8.24	66.58	193.50	68.13	0.94	65.00	1974.72
	Min	7.81	54.00	185.00	60.00	0.09	35.00	1100.00
	Max	8.92	76.30	217.00	74.00	2.68	138.00	2400.00
June	Mean	7.85	42.33	171.75	55.75	2.72	20.67	1624.81
	Min	7.35	8.70	40.00	10.00	0.00	11.00	1100.00
	Max	8.22	67.00	241.00	82.00	4.41	27.00	2400.00
July	Mean	7.86	11.88	22.75	4.20	2.40	33.90	493.68
	Min	7.76	3.60	12.00	2.50	1.27	2.80	150.00
	Max	8.00	22.10	33.00	7.20	3.34	51.50	2400.00
August	Mean	7.75	6.45	25.50	3.20	3.67	41.63	594.45
	Min	7.63	0.40	14.00	2.50	2.55	29.50	43.00
	Max	8.06	11.40	39.00	4.30	5.12	58.00	2400.00
September	Mean	7.96	10.43	33.25	4.95	1.83	16.00	1306.60
	Min	7.90	7.30	26.00	2.50	0.56	13.40	460.00
	Max	8.12	12.70	39.00	8.00	3.62	19.40	2400.00
October	Mean	7.75	7.03	31.00	6.33	2.09	20.07	1831.54
	Min	7.65	5.80	19.00	3.10	1.37	16.40	1600.00
	Max	7.84	8.30	39.00	10.50	2.55	27.00	2400.00
November	Mean	7.85	6.23	29.50	6.63	2.33	24.85	476.17
	Min	7.76	1.00	24.00	4.00	1.34	19.80	170.00
	Max	7.93	10.80	37.00	12.20	3.13	34.00	1600.00
December	Mean	7.71	5.83	21.75	4.15	1.75	23.30	1393.28
	Min	7.52	1.20	13.00	2.00	1.17	19.80	920.00
	Max	7.93	10.10	29.00	6.20	3.39	27.40	1600.00

Appendix D – Cont'd

YEAR 2013		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	7.71	19.77	85.67	31.30	1.93	29.43	1600.00
	Min	7.60	0.90	26.00	4.60	0.00	16.80	1600.00
	Max	7.84	56.00	203.00	83.50	2.90	49.50	1600.00
February	Mean	7.71	8.00	28.75	6.05	2.29	25.40	686.85
	Min	7.54	1.00	26.00	4.60	1.27	20.00	280.00
	Max	7.82	15.00	33.00	8.00	3.59	28.60	1600.00
March	Mean	7.76	6.68	29.75	8.10	2.45	26.28	742.62
	Min	7.72	3.60	19.00	4.50	1.99	20.90	220.00
	Max	7.82	10.60	42.00	11.80	3.10	30.20	1600.00
April	Mean	8.05	6.67	32.33	8.67	2.83	27.67	692.99
	Min	7.90	5.40	28.00	3.60	1.96	24.20	130.00
	Max	8.16	7.60	37.00	14.60	3.83	31.40	1600.00
May	Mean	7.91	11.33	44.00	6.65	2.91	21.90	206.16
	Min	7.78	4.20	37.00	5.30	1.96	10.40	33.00
	Max	8.20	16.40	53.00	8.00	3.85	36.20	920.00
June	Mean	7.99	7.10	34.67	6.37	3.58	31.27	375.61
	Min	7.92	4.80	31.00	2.50	1.60	26.80	240.00
	Max	8.12	8.30	38.00	10.80	5.12	34.40	920.00
July	Mean	7.81	10.68	54.25	11.30	4.17	18.70	442.99
	Min	7.70	10.30	54.00	7.40	2.68	15.80	130.00
	Max	7.94	11.30	55.00	16.00	5.35	23.80	920.00
August	Mean	7.75	13.55	33.25	8.93	3.62	14.58	704.84
	Min	7.61	8.40	25.00	6.20	2.09	13.50	540.00
	Max	7.90	18.20	40.00	12.90	4.86	15.40	920.00
September	Mean	7.98	11.75	33.25	13.05	3.80	23.55	310.22
	Min	7.88	8.30	29.00	8.20	1.10	16.40	140.00
	Max	8.11	16.80	41.00	25.40	9.00	32.00	540.00
October	Mean	7.97	11.67	31.00	13.70	2.74	28.90	1106.37
	Min	7.92	9.50	29.00	12.90	0.82	16.30	920.00
	Max	8.07	13.60	35.00	14.60	4.70	36.80	1600.00
November	Mean	7.97	6.68	29.50	13.23	1.82	26.98	1094.23
	Min	7.83	2.20	26.00	9.50	0.07	9.00	350.00
	Max	8.14	9.50	34.00	17.00	3.90	40.00	1600.00
December	Mean	7.70	10.40	36.75	12.28	2.82	27.55	1061.95
	Min	7.56	7.40	25.00	9.60	0.08	19.00	540.00
	Max	7.91	13.70	53.00	14.80	8.05	32.00	1600.00

Appendix D – Cont'd

YEAR 2014		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	8.08	7.93	34.75	13.73	2.88	24.95	1219.52
	Min	7.97	5.00	24.00	7.40	0.23	12.20	540.00
	Max	8.21	11.60	53.00	16.30	8.50	33.60	1600.00
February	Mean	8.01	6.58	28.80	10.74	3.21	22.14	498.27
	Min	7.81	2.50	22.00	8.00	0.35	15.60	240.00
	Max	8.17	8.40	38.00	13.70	5.10	35.00	920.00
March	Mean	8.00	8.33	50.00	15.35	1.15	25.13	952.85
	Min	7.58	6.80	36.00	11.70	0.12	17.00	350.00
	Max	8.27	10.00	57.00	21.70	4.00	36.50	1600.00
April	Mean	8.01	9.48	43.25	7.85	11.11	19.00	374.97
	Min	7.89	6.70	37.00	5.40	3.25	13.40	79.00
	Max	8.11	12.60	53.00	12.00	15.50	23.00	1600.00
May	Mean	8.15	11.23	45.00	18.60	4.12	15.47	290.72
	Min	8.07	9.00	22.00	10.30	1.17	12.40	130.00
	Max	8.29	15.30	88.00	26.00	5.90	19.40	540.00
June	Mean	8.19	4.25	14.00	8.75	5.90	17.60	213.31
	Min	8.16	2.50	8.00	6.80	4.60	17.00	130.00
	Max	8.22	6.00	20.00	10.70	7.20	18.20	350.00
July	Mean	8.12	4.75	14.25	12.68	2.69	14.78	149.66
	Min	8.01	1.50	3.00	6.20	2.00	13.00	49.00
	Max	8.35	9.00	22.00	27.00	3.65	15.80	540.00
August	Mean	7.92	4.64	12.40	7.46	1.80	11.92	88.93
	Min	7.70	1.50	4.00	4.00	0.95	10.80	33.00
	Max	8.07	8.60	22.00	11.40	2.61	13.00	540.00
September	Mean	8.19	6.25	27.25	9.73	0.53	10.60	100.60
	Min	7.94	4.50	13.00	6.70	0.33	9.60	49.00
	Max	8.70	7.70	52.00	12.20	0.68	11.80	540.00
October	Mean	7.85	4.23	19.33	10.70	2.66	11.53	256.36
	Min	7.82	3.30	15.00	8.30	1.85	10.80	130.00
	Max	7.86	5.60	22.00	13.50	3.12	12.80	540.00
November	Mean	8.02	6.70	27.25	21.45	1.76	21.95	84.70
	Min	7.75	4.40	23.00	17.50	1.34	13.80	63.00
	Max	8.30	9.00	30.00	30.00	2.05	27.00	110.00
December	Mean	8.09	5.73	31.25	13.68	0.83	24.35	519.04
	Min	7.94	4.10	13.00	12.30	0.31	22.00	240.00
	Max	8.21	7.00	45.00	16.30	1.66	26.40	1600.00

Appendix D– Cont'd

YEAR 2015		pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Phosphate PO_4 - P mg/L)	Total Nitrogen (mg/L)	Thermotolerant Coliform (MPN/100ml)
January	Mean	7.93	5.63	32.25	7.98	2.54	20.40	316.59
	Min	7.63	4.90	29.00	4.20	1.83	17.20	130.00
	Max	8.15	6.80	37.00	12.00	3.21	25.00	920.00
February	Mean	7.94	4.18	26.25	7.95	2.54	28.45	338.55
	Min	7.85	2.40	23.00	4.00	1.70	22.10	170.00
	Max	8.12	5.50	28.00	17.00	3.13	32.20	920.00
March	Mean	7.89	5.20	28.00	8.90	2.33	28.60	268.87
	Min	7.62	3.30	20.00	5.00	1.50	18.20	79.00
	Max	8.01	7.10	34.00	16.00	3.26	40.40	540.00
April	Mean	7.86	5.75	27.25	6.75	3.00	24.75	329.78
	Min	7.65	4.00	18.00	5.00	1.00	23.00	140.00
	Max	7.97	7.00	34.00	9.00	6.00	27.00	1600.00
May	Mean	8.11	4.75	25.75	7.75	2.00	22.00	193.66
	Min	7.90	4.00	22.00	5.00	1.00	15.00	49.00
	Max	8.43	5.00	30.00	9.00	3.00	34.00	920.00
June	Mean	7.94	5.00	19.50	10.25	3.00	32.00	518.23
	Min	7.83	3.00	9.00	5.00	2.00	23.00	140.00
	Max	8.01	8.00	34.00	20.00	4.00	40.00	1600.00

Appendix E Tariff Calculations for Effluent Reuse Scheme

Year	Discount Factors	Capital Costs (USD)	Recurrent Costs (USD)	Total Costs (USD)	Present Value of Costs (USD)	Water Consumed (m^3/year)	Present Value of Water Consumed
1	0.926	9,737,125	35,000	9,772,125	9,048,988		
2	0.857	9,737,125	35,000	9,772,125	8,374,711		
3	0.794	9,737,125	35,000	9,772,125	7,759,067		
4	0.735		35,000	35,000	25,725		
5	0.681		35,000	35,000	23,835	27,375,000	18,642,375
6	0.630		35,000	35,000	22,050	27,375,000	17,246,250
7	0.583		35,000	35,000	20,405	27,375,000	15,959,625
8	0.540		35,000	35,000	18,900	27,375,000	14,782,500
9	0.500		35,000	35,000	17,500	27,375,000	13,687,500
10	0.463		35,000	35,000	16,205	27,375,000	12,674,625
11	0.429		35,000	35,000	15,015	27,375,000	11,743,875
12	0.397		35,000	35,000	13,895	27,375,000	10,867,875
13	0.368		35,000	35,000	12,880	27,375,000	10,074,000
14	0.340		35,000	35,000	11,900	27,375,000	9,307,500
15	0.315		35,000	35,000	11,025	27,375,000	8,623,125
16	0.292		35,000	35,000	10,220	27,375,000	7,993,500
17	0.270		35,000	35,000	9,450	27,375,000	7,391,250
18	0.250		35,000	35,000	8,750	27,375,000	6,843,750
19	0.232		35,000	35,000	8,120	27,375,000	6,351,000
20	0.215		35,000	35,000	7,525	27,375,000	5,885,625
				TOTAL PRESENT COSTS	**25,436,166**	**TOTAL PRESENT VALUE**	**178,074,375**
				AIC tariff =	Total present cost / Total present value		0.14 per m^3

Appendix F: Average Influent Conductivity for Soapberry WWTP (Jan 2010 – June 2015)

Month - Year	Average Influent Conductivity (dS/m)
Jan-10	1.13
Feb-10	1.22
Mar-10	1.19
Apr-10	1.30
May-10	1.09
Jun-10	1.10
Jul-10	1.00
Aug-10	0.92
Sep-10	0.90
Oct-10	1.06
Nov-10	1.00
Dec-10	0.93
Jan-11	0.98
Feb-11	0.88
Mar-11	0.89
Apr-11	0.90
May-11	0.85
Jun-11	0.87
Jul-11	0.94
Aug-11	0.87
Sep-11	0.92
Oct-11	0.91
Nov-11	1.06
Dec-11	0.78
Jan-12	0.91
Feb-12	0.90
Mar-12	0.87
Apr-12	0.88
May-12	0.98
Jun-12	0.85
Jul-12	0.86
Aug-12	0.89
Sep-12	0.92
Oct-12	0.91
Nov-12	1.00
Dec-12	0.77
	Table Continues

Appendix F - Cont'd

Month - Year	Average Influent Conductivity (dS/m)
Jan-13	0.98
Feb-13	0.99
Mar-13	0.97
Apr-13	0.99
May-13	0.97
Jun-13	0.99
Jul-13	1.06
Aug-13	0.93
Sep-13	0.89
Oct-13	0.91
Nov-13	0.89
Dec-13	0.88
Jan-14	0.90
Feb-14	0.97
Mar-14	0.97
Apr-14	1.16
May-14	1.00
Jun-14	1.14
Jul-14	1.07
Aug-14	1.38
Sep-14	1.00
Oct-14	0.91
Nov-14	0.98
Dec-14	0.91
Jan-15	0.96
Feb-15	1.01
Mar-15	0.97
Apr-15	1.12
May-15	1.22
Jun-15	1.75
MEAN	**0.99**

Appendix G: Cost Estimate for Effluent Reuse Scheme

Qty.	Item	Dimensions	Cost (USD) Unit rate	Civil Works	Mech. Works	Elec. Works	Total
	Disinfection						
1 pc	R.C. Chlorination Retention Chamber	LxWxH =		75,000.00			
		40 x 4 x 5 m					
1 lump-sum	Retention Chamber: manhole cover, aeration pipes, static mixers (stainless steel and/or concrete walls),		20,000.00		20,000.00		
1 pc	Chlorination Station, complete for chlorine gas in 1 ton tanks, separate storage for 50 tanks, dosing room, Concrete slab with steel constr. , crane, doors windows, ventilation, electrical works,	LxWxH =	590,000.00	590,000.00		115,000.00	
		35 x 20 x 5 m		.			
1 lump-sum	Chlorine gas dosing equipment, occupational health & safety equipment, ventilation,		110,000.00		110,000.00	20,100.00	
Total	**Disinfection**			**665,000.00**	**130,000.00**	**135,100.00**	**930,100.00**
	Reuse and Irrigation						
10,000m	Pressure Pipe (e.g. HDPE) ID 1000, from Soapberry WWTP to Bernard Lodge Irrigation area	ID 1000	1100	11,000,000.00			
	pump station with 4 pumps, civil structure			150,000.00	60,000		
4 pc	pumps, electro-mechanical equipment	4 x 800 m³/h	36,000.00		144,000.00		
1 pc	surge pressure vessel				60,000.00		
315,000 m³	Wet weather storage		35	11,025,000.00			
Total	**Reuse and Irrigation**			**22,175,000.00**	**264,000.00**	**0.00**	**22,439,000.00**
Sub Total				22,840,000.00	394,000.00	135,100.00	23,369,100.00
15%	Engineering			3,426,000.00	59,100.00	20,265.00	3,505,365.00
10%	Contingencies			2,284,000.00	39,400.00	13,510.00	2,336,910.00
Grand Total				28,550,000.00	492,500.00	168,875.00	**29,211,375.00**

Appendix H: Sugarcane Water Balance

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_o (reference crop transpiration) [mm]	153.3	163.8	168.9	179.4	185.7	196.2	200.4	193.8	180	165	160.2	160.2
Kc (sugarcane)	1	1	1	1.05	1.05	1	1	1	1	1	0.8	0.8
Evapotranspiration for sugarcane ($ET_{sugarcane}$) [mm]	153	164	169	188	195	196	200	194	180	165	128	128
Leaching Fraction, LR	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Applied Water Depth, Aw[mm]	176	188	194	217	224	226	230	223	207	190	147	147
Rainfall - 30 year Average [mm]	53	55	61	91	156	110	85	129	172	188	115	62
Sugarcane Water Requirement [mm] - Assuming irrigation efficiencty	164	178	178	167	91	154	194	125	47	2	43	114
Requirement -- Monthly [m^3/ha]	1,643	1,777	1,775	1,674	908	1,540	1,938	1,250	465	22	431	1,137
Irrigation Requirement Bernard Lodge (1,500 ha) [m^3]	2,464,138	2,665,517	2,662,759	2,510,345	1,362,414	2,310,345	2,906,897	1,875,172	697,931	33,103	646,207	1,706,207
Irrigation Requirement Windsor (60 ha) [m^3]	98,566	106,621	106,510	100,414	54,497	92,414	116,276	75,007	27,917	1,324	25,848	68,248
Irrigation Requirement Innswood (600 ha) [m^3]	985,655	1,066,207	1,065,103	1,004,138	544,966	924,138	1,162,759	750,069	279,172	13,241	258,483	682,483
Total Irrigation Requirement (2160ha) Monthly [m^3]	3,548,359	3,838,345	3,834,372	3,614,897	1,961,876	3,326,897	4,185,931	2,700,248	1,005,021	47,669	930,538	2,456,938
Volume of Treated Effluent available from Soapberry, Monthly [m^3]	2,325,000	2,100,000	2,325,000	2,250,000	2,325,000	2,250,000	2,325,000	2,325,000	2,250,000	2,325,000	2,250,000	2,325,000
Volume of Treated Effluent available from Soapberry that can be used for sugarcane irrigation based on nitrogen content, Monthly [m^3]	1,913,880	1,728,666	1,913,880	1,852,142	1,913,880	1,852,142	1,913,880	1,913,880	1,852,142	1,913,880	1,852,142	1,913,880
Surplus/Deficit [m^3]	-1,634,478	-2,109,679	-1,920,492	-1,762,754	-47,996	-1,474,754	-2,272,051	-786,368	847,121	1,866,211	921,604	-543,058