Preliminary Investigation of appropriate options for Leachate and Septage Treatment for the Caribbean Island of Antigua.

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Abstract

On the global scale, the single greatest factor contributing to marine pollution has been identified as untreated wastewater entering the world's oceans and seas. Within the Caribbean region, it has been similarly observed that sewage pollution from land based sources is the most pervasive form of contamination of the coastal environment. For the Caribbean island of Antigua there is no centralized sewage system. The majority of residences utilize the option of Septic Tanks as the preferred option for onsite wastewater treatment. However, the systems in use are operated to varying efficacies where improper design and poor soil conditions can result in septic tank effluent going directly to public drains and eventually the sea. The potential environmental risks of effluent discharge is further exacerbated by the fact that the septic tank derived sludge is routinely removed and discharged untreated into the open environment at the local disposal site.

At the disposal site, the existing sanitary landfill produces leachate which is collected but eventually also discharged into the environment without any prior treatment. The discharge of untreated leachate and untreated septage at the same location suggests the possibility of a combined treatment process to accommodate both waste streams.

The purpose of this paper is to examine the potential wastewater treatment options which can be implemented in the setting of a tropical small island developing state.

Keywords: Caribbean Leachate Treatment, Septage, Landfill Leachate, Combined Septage Treatment

JEL classifications: Ecological Issues

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1. Introduction

The single greatest factor contributing to global marine pollution has been identified as untreated wastewater entering the world's oceans and seas (UNEP/GPA, 2006). Within the Caribbean region, it has been similarly observed that "sewage pollution from land sources and from ships has been the most pervasive form of contamination of the coastal environment" (CARSEA, 2007). As is the case for the Caribbean and other small island developing states, the growing standard of living and increases in populations and industries such as tourism has resulted in increased waste water generation with a concurrent trend for increased incidences of environmental degradation. As such, waste water management is slowly coming to the fore as a key developmental issue within the wider Caribbean region.

Throughout the Caribbean region, it has been estimated that less than 2% of urban sewage is treated prior to disposal (Emanuel, 2010). In the twin island nation of Antigua and Barbuda, there is no centralized sewerage system. The notable local attempts at collection and treatment systems are package plants principally used by Hotels of which 48% were characterized as being in "poor condition or non-operational" (UNEP, 1998a). Individual treatment systems are utilized to varying degrees and efficacies, where the norm is for septic tank effluent to go directly to the sea (UNEP, 1998a). The individual type systems used at the household level include the bucket system (a.k.a. night soil); pit privy (a.k.a. pit latrine) and septic tank & soak-a-way system (UNEP, 1998b).

In Antigua and Barbuda, the thrust towards a concerted effort to mitigate against wastewater related environmental effects is evidenced by the fact that Antigua has signed on to the Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (also known as the Cartagena Convention) and the Protocol on the Control of Pollution from Land-Based Sources and Activities (LBS Protocol).

As with Antigua, the wider Caribbean has had checkered results implementing and sustaining adequate treatment and management options even with the recognition of the current limited management practices and the potential risks to the environment. UNEP/ GPA reported in the 2006 State of the Marine Environment Report that significant financial constraints exist and that there is a lack of adequate, affordable financing available for investments in wastewater management in the Wider Caribbean Region. In addition to financial constraints, other substantial barriers exist: inadequate national policies, laws and regulations; limited enforcement of existing laws and regulations; poor communication and collaboration between various sectors and agencies which contributes to a fragmented approach to wastewater management; and limited awareness, knowledge and understanding of appropriate, alternative and low cost wastewater treatment technologies. Other limitations in technical capacity (e.g. in developing project proposals, operating and maintaining treatment systems, and monitoring and analysing wastewater discharges and impacts) constrain progress in effectively managing wastewater.

An additional problem amongst those Caribbean territories with conventional treatment technologies is the issue of sustainability. The conventional centralized systems generally use large amounts of scarce water resources to flush domestic wastewater out of residential areas. In turn, the wastewater must be treated and the cost of treatment increases as the flow increases. Another reason many treatment systems in the region are not successful is that they were copied from treatment systems in developed countries without considering the appropriateness of the technology for the culture, land, and climate. In the end, many of the implemented installations were abandoned due to the high cost of running the system and repairs, and the lack of technical capacity to properly operate and maintain these systems.

In Antigua, a unique opportunity exists wherein household septic tank derived sludge (septage) and night soil are collectively disposed untreated at the sole authorised disposal site for municipal solid waste i.e. the Cooks Sanitary Landfill and Disposal Site. At this sanitary landfill, the collected municipal solid waste leachate is collected, stored and routinely released into the adjacent environment without treatment. Due to the proximity of the two liquid waste streams and the potential environmental risks associated with their untreated release into the environment, the paper will seek to investigate viable and appropriate technologies for separate or combined treatment of septage and leachate.

2. Background

The nation of Antigua and Barbuda is a twin island state within the North-eastern Caribbean. The country is made up of 2 larger inhabited islands and a few other smaller islets. Of the inhabited islands, the larger island of Antigua is 108 square miles (280 sq. km) in size and the smaller island of Barbuda is 62 square miles (160 sq. km) in size. The estimated resident population of the nation is 85,567 with a total of 83,922 living in Antigua and 1,645 living in Barbuda. Including visitors, the population is recorded as 88,566 persons (Government of Antigua and Barbuda, 2014). Atypical for islands of the Lesser Antilles, Antigua and Barbuda is characteristically absent of the dense tropical forests, rivers, expansive watersheds and mountainous landscapes which are generally attributed to the tropical climes of the region. Both islands are exposed to a tropical marine climate, with strong influence of the northeasterly trade Winds, constant high temperatures, and a very marked Wet and Dry season.

There is little variation in temperature throughout the year but very variable levels of precipitation. Average monthly minimum temperatures range from 22.4^{o}C in February to 25.4^{o}C in August, while monthly maximum temperatures range from 27.9^{o}C in February to 30.5^{o}C in September (Cooper & Bowen, 2001) As given by the Antigua and Barbuda Meteorological Office, the average annual rainfall for Antigua is 1203.6mm (for the period 1981 – 2010) however there is a seasonal striation pattern wherein the precipitation is highest during the months of August to December (wet season) and lowest between January and April (dry season) (Cooper & Bowen, 2001)

The extremely variable levels of rainfall coupled with erratic distribution and limited surface or ground water storage areas have combined to produce recurring scenarios where precipitation is insufficient to meet economic, social and environmental demands (Cooper & Bowen, 2001). Antigua is one of the most arid islands in the region, has droughts every 3 to 7 years, and where desalination is the largest contributor (>70%) to the national potable water system (PAHO, 2012). Barbuda is considerably drier compared to Antigua, with an average annual precipitation of 750mm to 900mm for the period 1965 – 2000 (Organisastion of American States, 2001). The high temperatures and local wind patterns give rise to relatively high evapotranspiration rates which has been reported to normally exceed effective precipitation in 11 months of the year (Cooper & Bowen, 2001). However, in the absence of specific monthly values for local evapotranspiration data, for the purposes of the paper, the conservative estimate evapotranspiration rate is taken as 70%.

The country is heavily dependent on tourism as the main driver of the economy, with estimates suggesting it accounts for between 60% (Cooper & Bowen, 2001) to 62.9% of the national GDP (World Travel and Tourism Council , 2014). According to the Pan American Health Organisation (PAHO), the per capita waste generation rate is given as 1.75kg/person/day with "evidence that the transient (tourist) population probably contributing to this generation rate" (PAHO, 2004). From records of the National Solid Waste Management Authority, the annual volumes of household waste and septage disposed in Antigua are captured in Table 1.

Table 1. Waste received at the Cooks Sanitary Landfill and Civic Amenities Site

	Waste Category	
Year	Household Waste (Tonnes)	Septage (Tonnes)
2006	20518.94	12177.96
2007	20790.74	16908.18
2008	22964.02	16551
2009	22682.52	13312.44
2010	24272.3	10746.34
2011	22331.86	11387.32
2012	20918.78	13300.78
2013	20964.21	13862.65
2014	20909.04	15312.93

Whereas the household waste is disposed of in the 2.43 hectare sanitary landfill cell, the septage is disposed of by burial in earthern pits or trenches at the adjacent unlined bulk waste dump site. The leachate generated from the decomposing household waste, though collected, is untreated as is the case for the septage and both waste streams eventually enter the swampland surrounding the disposal site.

3. Methodology and Results

For the purpose of the paper, the term "Appropriate Technology" will be defined as technology that is affordable, and operable by the user and that reliably provides the needed degree of purification (UNEP, 1998a). As an extension of the affordability and operability criteria, consideration of the maintenance costs, consumables restocking costs, energy costs and land space requirements will be critical factors in the decision making process.

3.1 Septage loads

Over the period 2010 to 2014, the annual volume of septage recorded as received for disposal in Antigua has been on the increase (Figure 1). The fluctuations of septage volumes within a year (2012) is illustrated in Figure 2 to establish the seasonal variations of waste flow rates. Apart from volumetric data, there is sparse data on the physical and chemical properties of the septage reaching the local disposal site. In the absence of such data, certain approximations had to be made for the design parameters (Table 2). Comparing literature data from the US EPA with regional data on the typical pollutant composition of septage, the design criteria was created using the upper values from the two characterisations.

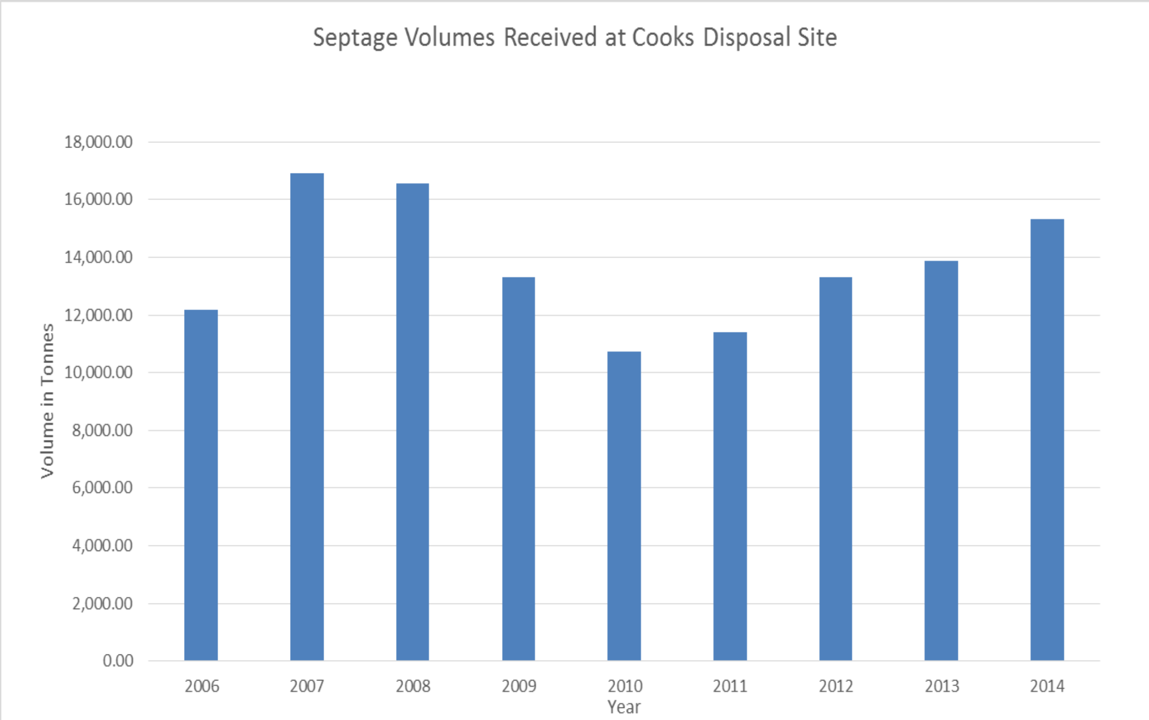

Figure 1. Annual septage volumes for Antigua

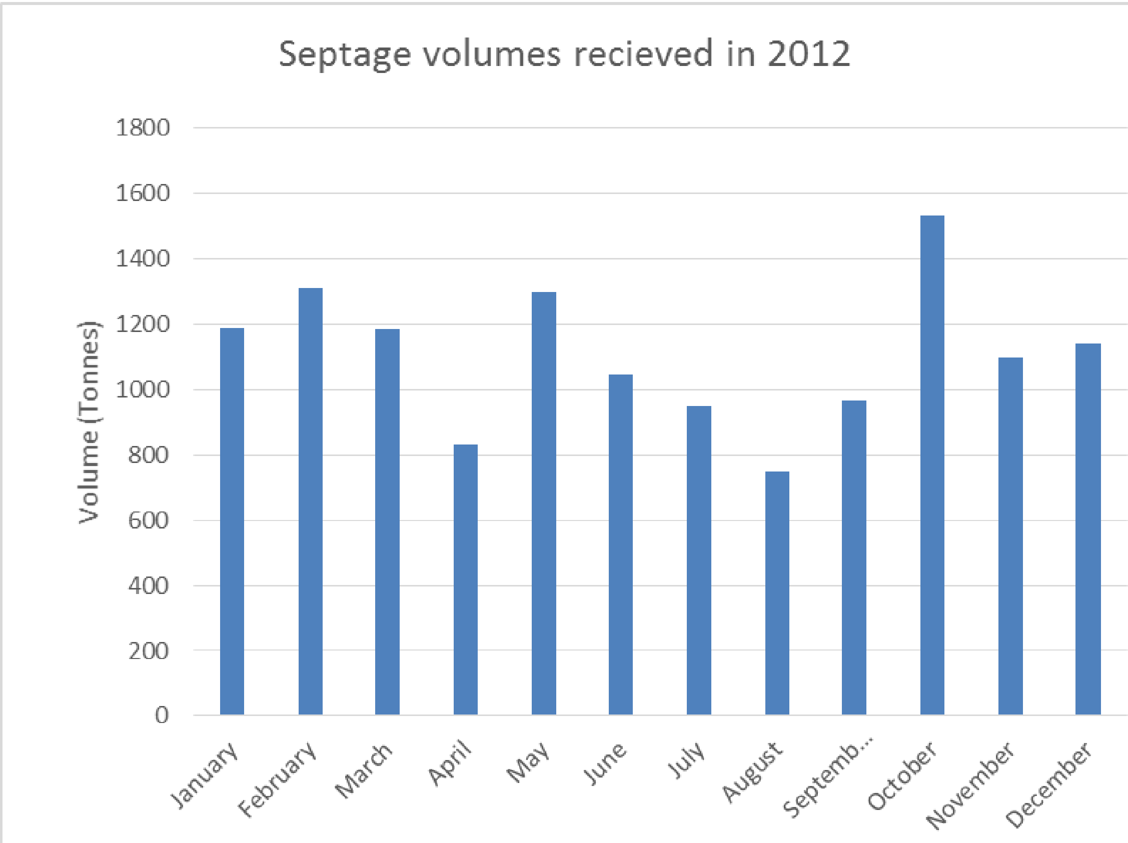

Figure 2. Monthly septage disposal values

Table 2. Typical and proposed concentrations of pollutant substances in Septage

Septage Constituent	Typical Concentration[1] (mg/L)	Typical Caribbean-specific Concentration[2] (mg/L)	Design Criteria (mg/L)
Biochemical Oxygen Demand (BOD)	6,500	5,000	6,500
Chemical Oxygen Demand (COD)	30,000	40,000	40,000
Total Kjeldahl Nitrogen (TKN)	600	700	700
Ammonia Nitrogen (NH3 – N)	100	Not stated	100
Total Phosphorus	210	300	300
Fats, oil, and grease	5,600	7,500	7,500
Alkalinity	1,000	Not stated	1000
Total Solids (TS)	34,000	Not stated	34000
Total Volatile Solids (TVS)	25,000	Not stated	25000
Total Suspended Solids (TSS)	15,000	25,000	25000
Total Volatile Suspended Solids (VSS)	9,000	Not stated	9000

3.2 Leachate Loads

At the Cooks Sanitary Landfill, there are no records of neither the volume nor chemical composition of the landfill effluent. To estimate leachate production, consideration had to be given to rainfall totals, surface runoff, rainwater seepage and the landfill operational practices such as the size of the tipping face area, compaction equipment used and daily waste cover percentage etc.

In calculating leachate generation from a sanitary landfill, the degree of rainfall infiltration is considered the principle contributing factor (Fenn, Hanley, & Degare, 1975). In Antigua, the mean monthly precipitation ranges between 51.8mm and 149.4mm with an annual mean rainfall of 1,203.6mm. Evapotranspiration is conservatively taken as 70% of precipitation, which translates into an annual loss of 842.52mm per year to evapotranspiration. As a result, the annual effective rainfall is thus calculated as 361.08mm. For sensitivity purposes, the maximum annual effective rainfall possible during a year (precipitation equal to the maximum observed historical value) is calculated at 529.23mm.

The estimation of leachate flow was compiled using the formula (Government of Hong Kong, 2007):

$$\text{Leachate Generation} = \text{Runoff coefficient} * \text{Operation Area} * \text{Effective Rainfall}$$

For the purposes of the paper it was assumed that the runoff coefficient for the landfill is 0.7 (i.e. 70% of surface water infiltrates into the leachate collection system). The operation area was given as

[1] U.S. EPA. 1984. Handbook: Septage treatment and disposal. EPA/625/6-84/009. Cincinnati, OH.
[2] UNEP, 1998. Appropriate Technology for Sewage Pollution Control in the Wider Caribbean Region. CEP Technical Report No. 40. UNEP Caribbean Environment Programme, Kingston

15,600m2 per year[3]. As such, taking the maximum annual effective rainfall figure of 529.23mm into consideration, the volume of leachate projected is 5779.19m3

The only accessible data on leachate characteristics for Antigua were from two analyses in 2009 and one from 2010 to assess the composition of the stabilised leachate in the storage ponds (Table 3). That exercise was to facilitate an assessment prior to discharge of the leachate into the surrounding wetlands. To date, these were the only records where any analyses were completed prior to discharge. There are no records for the composition of fresh leachate from the landfill. As such the design value for the investigation (Table 3) was taken as an average of some extreme values for the composition of leachate developed through a review of technical literature (Meeroff & Teegavarapu, 2010)

Table 3.Concentration of pollutants in stabilised Antiguan leachate, design values for future projections

	Analysis from 3.6.09	Analysis from 19.6.09	Analysis from 10.5.10	Design Value
pH	7.96 - 9.44	7.84 - 9.39	7.9 - 9.0	7.5
COD [mg/l]	47.1 - 64.8			10,300
BOD5 [mg/l]	0 - 33		22 - 35	4,000
Ammonia-N [mg/l] TKN (mg/l)				830
PO4-P [mg/l] Phosphates (mg/l)		0 - 12.7	0.09 - 2.75	
TSS (mg/l)	6 - 120			840
Lead [µg/l]				0.1
Conductivity (µS/cm)	1.15 - 4.56			13,100
DO (mg/l)	0.0 - 9.9			
Nitrate (mg/l)		0 - 17.1	8.4 - 29.8	

3.3 Effluent Limits

Antigua and Barbuda has no established effluent quality criteria for effluent discharge to the sea, but adopts regional standards. In 1998, the Caribbean Environmental Health Institute (CEHI) suggested new regional guidelines (Table 4) for effluent quality including discharge limits for ecologically sensitive areas[4]. Considering the potential application of treated wastewater for some degree of reuse, the US EPA guidelines were also considered.

[3] Using a 20m * 15m area as the weekly Tipping Face.

[4] Areas susceptible to degradation or destruction by human activities, due to inherent and/or unique environmental characteristics and/or a fragile biological or ecological situation.

Table 4. Parameters and standards for domestic and industrial wastewater discharges (Adapted from UNEP, 1998)

Parameter	CEHI Standard for Non-Sensitive Waters	CEHI Standard for Sensitive Waters	US EPA Standard for Restricted Urban reuse
Total Suspended Solids	100 mg/L	30 mg/L	< 30mg/L
Biochemical Oxygen Demand (5 day)	150 mg/L	30 mg/L	< 30mg/L
COD	300 mg/L	150 mg/L	
Faecal Coliform	No standard established	43 MPN/100 mL in shellfish harvesting areas 200 MPN/100 mL in all other areas	< 200 MPN/100mL
Total Inorganic Nitrogen	No standard established	10 mg/L in nutrient sensitive waters	
Soluble Phosphorus	No standard established	1 mg/L in nutrient sensitive waters	
pH	6 to 10	6 to 10	6 to 9
Fats, Oils, And Greases	50 mg/L	2 mg/L	
Ammonia as N	No standard established	5 mg/L	
Total Chlorine Residual	No standard established	0.1 mg/L	1 mg/L
Floatables	No visible floatables	No visible floatables	

4. Discussion

As a result of the unavailability of locally specific data on the physiochemical characteristics of both leachate and Septage in Antigua, certain assumptions and approximations had to be made in conducting this exercise. The literature data used for the design values in the preceding sections, could be significantly different from the local scenario. Furthermore, in the case of Septage arriving at the Cooks Disposal Site, it is expected that even between loads arriving by vacuum tank, the composition would show great variability. The septage variability could be attributed to differences between household sizes, septic tank construction, pumping frequency, users' water usage habits etc. For leachate, the variability could be attributed to waste age, waste composition, compaction rates, climatic changes and temperature. It must therefore be noted that even with the best guess approximations sourced from literature reviews and case studies, the site specificity and temporal specific of each locale, would imply that the calculations and projections can only be used as approximations of actual conditions.

In considering options for treatment, the local dynamics of climate, social economics, availability of human resources, replicability, and general "appropriateness" were the considered factors. The proposed technologies and processes have been detailed in Table 5 below. For the proposed combined treatment processes, reference was made to work done in Taiwan to examine the treatment efficiency of anaerobic digesters (Lin, Bian, & Chou, 1998) and the suitability of using a UASB reactor (Lin, Chang, & Chang, 1999). For all proposed options the treatment efficiency is obviously dependent on the initial influent quality and composition.

Table 5. Options for treatment of municipal solid waste landfill leachate and septage for Antigua. Adapted from (Meeroff D, 2010) and (US EPA,1984)

	Treatment Process	Advantages	Disadvantages
Individual Leachate Treatment	Evaporation: use of shallow lined ponds to reduce liquid volume.	• Great for arid regions like Antigua with high evapotranspiration rates • Efficient on COD • Efficient on Ammonia • Efficient on inorganics	• Post treatment of residuals required • Large space requirement
	Re-circulation: reinject the leachate back into the landfill	• One of least expensive options • Rumoured to be the initially proposed option for Antigua in the landfill design stages • Efficient on COD • Efficient on BOD_5 • Efficient on Ammonia • Efficient on inorganics • Small space requirement	• Efficiency is dependent on initial leachate quality • Performance is highly variable and site specific • Post treatment may be required
	Aerated Lagoon, Extended Aeration: use of mechanical aerators to create a mixed culture microbial environment.	• Used at the sanitary landfill site in the neighbouring island of St. Lucia. • Efficient for BOD_5 • Relatively rapid treatment (>90% removal of BOD_5 in 6-8 hours) • Minimal odour concerns	• Treatment performance is highly variable and may require pre-treatment • Does not address bio-toxics • Potentially large sludge • production • Potentially large energy requirements • Does not address TDS or conductivity

	Lime/coagulant pre-treatment & Activated Sludge	Lime pre-treatment can be: • Efficient on COD • Efficient on inorganics • Efficient on TSS • Disinfectant • Effective in reducing biotoxic substances Activated sludge systems can be: • Effective on removal of BOD, nutrients and ammonia	Lime pre-treatment can be: • Efficient on COD • Efficient on inorganics • Efficient on TSS • Some disinfection action Activated sludge systems can exhibit: • Longer aeration times (energy demand) • Fluctuating leachate quantity and quality can affect performance • Excess sludge production
Individual Septage Treatment	Lime Stabilisation	• Low capital costs • Simple technology • Potential pathogen reduction • May reduce nitrogen concentration	• High pH effluent • No reduction of organics • Increased sludge production
	Activated Sludge	• Relatively low capital costs • Technology in use locally at package plants • Relatively easier to operate compared to anaerobic treatment • Produce an odourless, stable residual that is easy to dewater	• Potential foaming problems. • Energy requirements for aeration
	Anaerobic digestion and aeration of effluent	• Smaller footprint • Production of methane gas • Poor quality supernatant after the anaerobic phase can be addressed by the aeration phase	• Relatively high capital costs • Sensitive to upsets
Combined Treatment of Leachate and Septage	Coagulation of leachate & Activated Sludge	• Combined waste streams to improve the economy of scale	• Large footprint • Energy requirements for aeration
	Upflow anaerobic sludge blanket	• Combined waste streams to improve the economy of scale	• Ammonia content of the leachate can affect removal rates of total COD, soluble COD, total solids, and volatile solids (Lin, C.Y., 2000)

5. Conclusion

As a small island developing state, Antigua is faced with the challenges of increasing standard of living, increases in populations and industries such as tourism and a resultant increase in liquid waste generation. The proposals detailed in the paper are a combination of low cost, low technology, or otherwise viable options for individual or combined treatment of Leachate and Septage at the local disposal site. Of the proposed treatment processes, the options with the greatest likelihood of success will be the options most compatible with the island's climatic and socio economic nuances. The viability of any option or combination thereof, will have to be addressed by a subsequent feasibility analysis which was beyond the scope of this paper. In conjunction with the future feasibility analysis, expansion of the design criteria could include utilising renewable energy (such as solar or wind powered aerators) for subsequent consideration of energy balance in the feasibility assessment.

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