Evaluation of the Effectiveness of the Resource Recovery Systems at Silk Caye and Laughing Bird Caye

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Submitted by

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Abstract

Quality analysis of wastewater is important because it provides information on water contamination. The purpose of this research was to evaluate the effectiveness of the Resource Recovery Systems at Silk Caye and Laughing Bird Caye. The results of this research were produced by analyzing physical and chemical parameters of the effluent discharged from the recovery systems into the seawater surrounding the cayes. The recovery system at Laughing Bird Caye proved to be more effective than the one at Silk Caye at removing phosphates and nitrate. The physical parameters were within the standards required by Belize's Department of the Environment, while few were slightly below or above the standard. Overall, only the recovery system at Laughing bird is effective, while the system at Silk Caye is not functioning properly.

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I declare this is my own original work and that it does not contain material that has already been used to any substantial extent for a comparable purpose.

Name of Student: ______________________ Signature: ______________________

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Table of Contents

Table of Figure

Table of Tables

Introduction

Water is an important resource because of its ecological role in the ecosystems. It can be a misconception that water is abundant, but it is scarce in some countries and unavailable in the form of drinkable fresh water in many coastal communities worldwide. Therefore, an integrated approach to managing water resources through local wastewater reclamation and reuse is necessary. The improved management of wastewater using recovery systems may be able to protect public health, increase water availability, prevent coastal pollution, and enhance water resources through coastal conservation (Angelakis *et al.*, 1999)

In cases where wastewater is not properly treated, runoff of untreated waste can increase the uncertainty of the quality of local water supplies as well as impact normal ecosystem functions (Grizzetti, 2011). A common source of ground water contamination is onsite septic systems, due to systems failure, inappropriate siting, improper design, or inadequate long-term maintenance (U.S Environmental Protection Agency, 2002). Furthermore, on beaches in urban areas where sewage is not managed appropriately, water can become contaminated with human waste leading to an unhealthy swimming environment (GESAMP, 2000). Likewise, most marine animals need clean water to survive. If there are high levels of nutrients in the water, this can greatly increase algal growth. The algae use oxygen from the water to grow; reducing the oxygen available in the water for organisms, which could later lead to eutrophication (Laurent *et. al.*, 2007).

Population growth increases the amount of waste in many areas that need to be managed, which demand the use of resource recovery systems (Population Reference Bureau, 2016). These changes bring about the need to collect and analyze water and wastewater samples to understand the present biological, chemical and physical composition of the water bodies, in order to tell whether they are suitable for domestic, industrial, recreational and agricultural uses (Brown *et. al.*,1970).

Therefore, the main focus of this study was to understand whether the recovery systems at Silk Caye and Laughing Bird Caye are proving effective based mainly on the phosphate and nitrate level. Nitrate and phosphate levels from collected samples were compared with the water quality standard of Belize's Department of the Environment (DOE).

The recovery systems at Laughing Bird and Silk Caye are designed to remove fecal coliform, nitrate, and phosphate from the wastewater before being discharged into the environment. The purpose of removing the nutrients and coliform from the waste before it is discharged into the environment is to maintain a healthy seawater for the aquatic organisms. Fecal coliform is removed to indicate that the water is free from fecal waste and tourist can snorkel and dive in a clean environment.

In most parts of the world where recovery systems are used, their effectiveness varies, with most being successful (U.S Environmental Protection Agency, 2002). Therefore, the resource recovery systems in the Stann Creek district should also be effective at producing a clearer, cleaner effluent being discharge into the seawater of Silk Caye and Laughing Bird Caye National Park.

The objectives of the research were: to test for chemical parameters of the seawater around the recovery systems in the two cayes, to compare the mean of each parameter to DOE standards, and to determine the percentage of nutrient that is removed by the recovery systems. It was hypothesized at the outset, that the resource recovery systems at the two cayes would meet the standard for water quality of the DOE because it has been designed to specifically and properly treat wastewater and to reduce the environmental effect of effluents discharged into the sea water around the cayes.

In this project water quality analysis and monitoring are important because it helps to produce clean water that is necessary for the recreational activities that take place at both caye, and for water to support the ecological processes within the seawater that surrounds the two cayes. The Belize's Department of the Environment does not monitor the water quality at the cayes that are stated as marine reserves or national parks like Silk Caye and Laughing Bird Caye (H. Sanchez, personal communication, March 17, 2017). Marine Protected Areas with treatment systems (wastewater recovery systems) are not monitored because they do not pay a fee for water quality monitoring. Therefore, the report that is being produced can be used by the Department of Environment to support the need to monitor the waste recovery systems in marine protected areas. Monitoring water quality and evaluating the effectiveness of the recovery systems at marine protected areas are necessary because the organisms(fish) in the protected areas should not only be protected from human harvesting, but their habitat should have nutrient levels, temperature, ph, and salinity etc. at an acceptable.

Literature Review

According to Iza and Stein (2009) water management dates to ancient times when stone rows and ditches were used for irrigation and structures were built to carry water to the cities. However, during those times water management did not include wastewater. A survey of the literature indicates that for centuries wastewater management was not given consideration by most cultures, so wastewater was disposed of in the streets and near population centers creating serious impacts on the public health and environment (Lofrano & Brown, 2010). Human sanitation and wastewater management has changed over the years due to cultural, social and religious factors (Sorcinelli, 1998; Wolfe,1999; De Feo and Napoli, 2007; Avvannavar and Mani,2008). Sanitation refers to safe and sound handling of human excreta and other waste products (Avvannavar and Mani,2008). The rate at which environmental management evolved was increased by scientific developments such as the stream purification models, and by socioeconomic events such as the second World War (Sorcinelli, 1998; HDR, 2006) as cited by Lofrano and Brown (2010). Progress in wastewater management and sanitation was further driven by political coalitions uniting industrialists, municipalities and social reformers (Human Development Report, 2006).

In a global study on waste management carried out by Sato et. al (2013), data from 181 countries were examined and it was concluded that only 55 countries (30.4%) have data available on wastewater production, treatment, and use. In Melbourne, Australia, wastewater has been mainly used for irrigation (Baker *et. al.*, 2011). The wastewater used is mainly from the city's two major wastewater treatment plants and a smaller proportion comes from reclamtion of 'grey' water produced at the household level. In the United States (1946), public health efforts lead to a five year study of septic tanks that was directed towards developing and improving the design, installation, and maintenance of septic tanks (U.S Public Heath Service, 1969). The study resulted in a document “Guidance of septic tank practice manual” developed in 1957. Thereafter, in 1980 the United States Environmental Protection Agency (USEPA) first issued detailed guidance on the design, construction, and operation of onsite wastewater treatment focused on both treatment and disposal (U.S Environmental Protection Agency, 2002). Disposal standards of the USEPA included water parameters that should be met before releasing or using the treated wastewater. In the early 1990’s international bodies have been urging reform in national water policies due to the growing scarcity of clean water and significant alternation of habitat (Iza and Stein, 2009). Efforts has led to the development of documents like the World Water Vision, the World commission on Dams report and others.

Recent research on the microbial fuel cell (MFC) examines MFC as a promising technology for wastewater treatment and bioenergy; and presents recent advances in MFC research with emphasis on its configuration and performances (Du *et. al.*, 2007). In the Central American region, there has been effort to study and manage wastewater (Oakley *et. al.*, 2000). In Mexico, some research based on water and wastewater quality have been carried out to test for biological and chemical parameters that are focused on nutrient levels (Hernandez, 1988, Chavira *et. al.*, 1992). With respect to the analyzed nutrient parameters of Phosphate, Nitrate, and Carbon trioxide levels generally did not have significant variations and their reference values were compared with those established by national official standards (Mexican Standard NMX-AA-079, 1996). A study on wastewater entering Chetumal Bay from the Mexican border estimated the raw sewage that entered the bay daily (Hernandez & Morales, 1999). From the study it was found that the average biochemical oxygen demand (BOD) was 32.26 mg l-1, which was low compared to, any other reports and may be indicative of self-depuration processes in Chetumal Bay.

In Belize, research by Gonzales (1980) dealt with water quality in freshwater but not specifically with wastewater. Boles (2001) stated that in Belize there is a need to conserve and manage the barrier reef ecosystem, and urged that limnologic research be undertaken. Boles noted the knowledge gap that he found when studying aquatic ecosystems in Belize, and when searching for other necessary related information. As a member of the Central American Integration System (SICA) and the Caribbean Community (CARICOM) there have been initiative such as the "Vision on Water, Life, and Environment for the 21st Century" (in 2000), international workshops, and conferences geared towards Integrated Water Resource Management in Belize (Frutos, 2003). Most recently, a study on the feasibility of wastewater system for the Placencia Peninsula was carried out and a report was produced (Fedak *et.al.*, 2006). Even after suggested design of a centralized waste treatement system from the report there has been no success with the project. In Belize, drinking water is monitored by the Ministry of Health and water providing companies such as the Belize Water System (Frutos, 2003). The Department of the Environment is given the power to regulate wastewater effluent under the Environmental Protection Regulations (1995) (Belize Act, 1995). The latest legislative change, by the amendment of the wastewater effluent limitation seeks to improve management of wastewater (Belize Act, 2009).

Methodology

Sampling took place on the 15th of December 2015 at the Silk Caye Marine Reserve, with a recorded starting point of N 16°27.049, and W 088°0.2484 (Figure 1). Sampling also took place at Laughing Bird Caye on the same date with a recorded starting point of N 16°26.571 and, W 088°11.862. Silk Caye lies within the central region of the Barrier Reef about 36 km off the coast of Placencia Village (Figure 1) (Southern Environment Association, 2015). In 2001, Gladden Spit and Silk Caye were declared protected areas because they were whale shark sites.

Laughing Bird Caye was declared a protected area in 1981 under the National Parks System Act and on the 21st of December,1991 it was finally declared a National Park. The national park is located on the barrier reef close to the Silk Caye at latitude 16.4333°, and longitude -88.1000° (Terrametrics, 2016). Laughing Bird Caye is a long narrow isle that stands on an elongated ridge of reef known as a faro (Southern Environment Association, 2016). The faro is separated from the mainland, the barrier reef, and other cayes by a steep channels on all sides. The caye is covered with cocunut trees and mangroves (*rhizophora mangle* and *Avicennia germinans*).

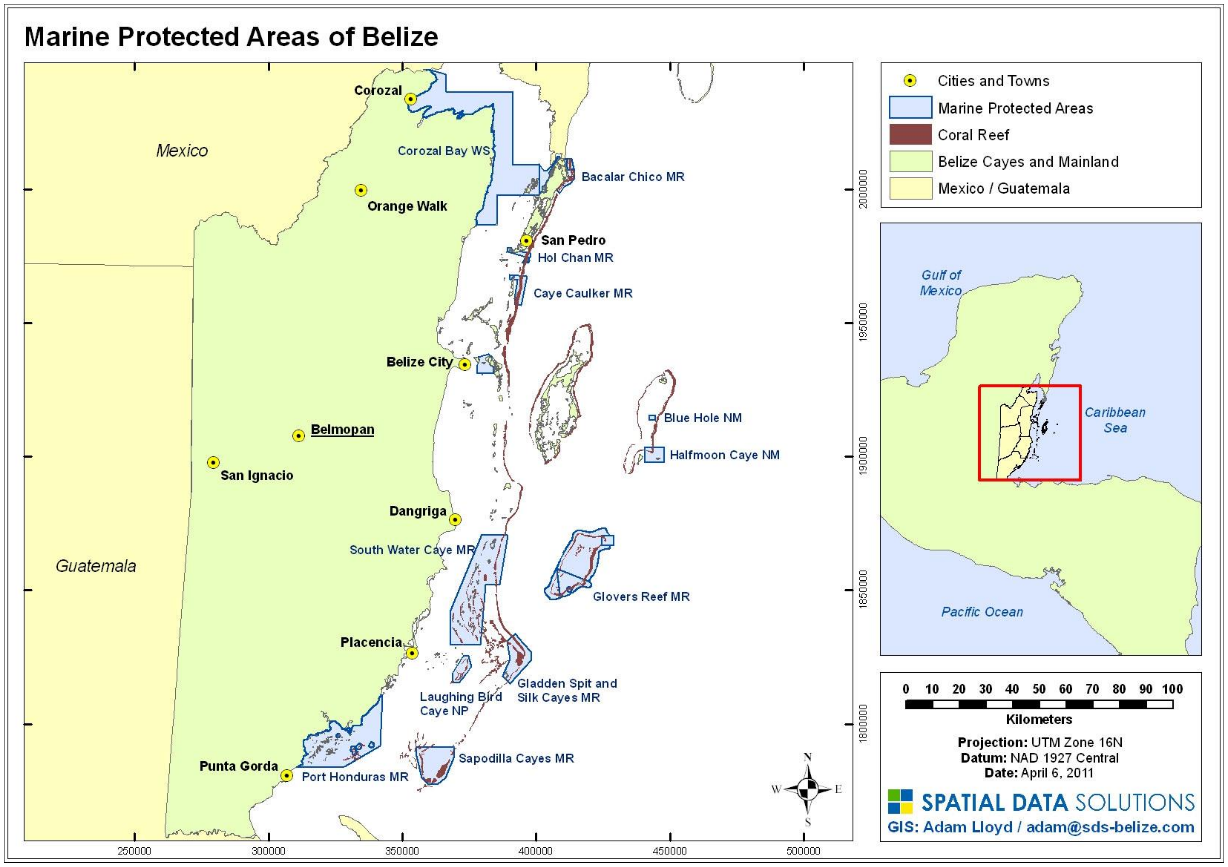

Figure 1 :A map showing Laughing Bird and Silk Caye within the marine protected area system (http://s500848606.onlinehome.us/wp-content/uploads/2013/11/belize_mpa.jpg)

Data for the physical and chemical parameters at the cayes were collected using a calibrator water probe. The seawater (surface water) around the leachate field was collected by submerging a bottle into the water. When filled, it was capped underneath water and brought up and out of the water (grab sample). Wastewater samples were actual waste from within the bio-digesters that were either dipped from the bio-digester or collected from one of the valves.

Figure 2 below shows the sites that were sampled within the Silk Caye Marine Reserve. Sites 1, 2, 3, 4, 5 and 6 were points in shallow water around the leachate field of the recovery system at Silk Caye where the seawater samples were collected (grab sample). Site 7 was the end of the valve that was opened to collect wastewater sample.

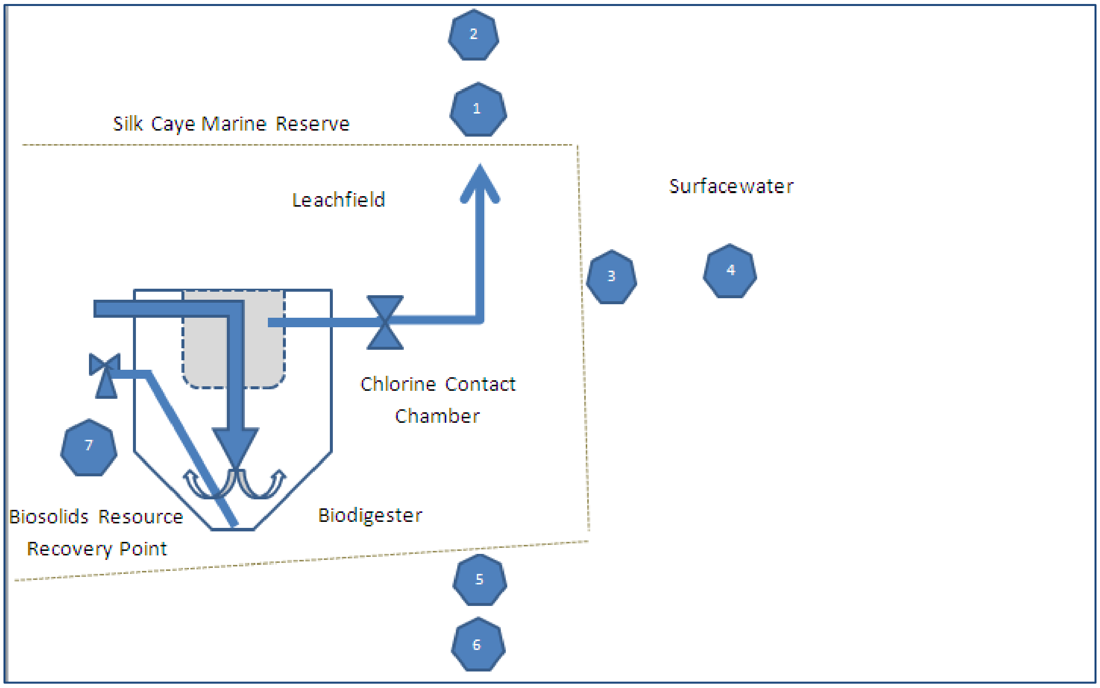

Figure 2 Silk Caye grab sample points

Sites 1, 2, 3, and 4 as shown in figure 3 were the grab sample sites at Laughing Bird Caye. Site 5 is the bio-digester valve that was opened to collect wastewater samples and site 6 was the clarifier where wastewater samples were also collected.

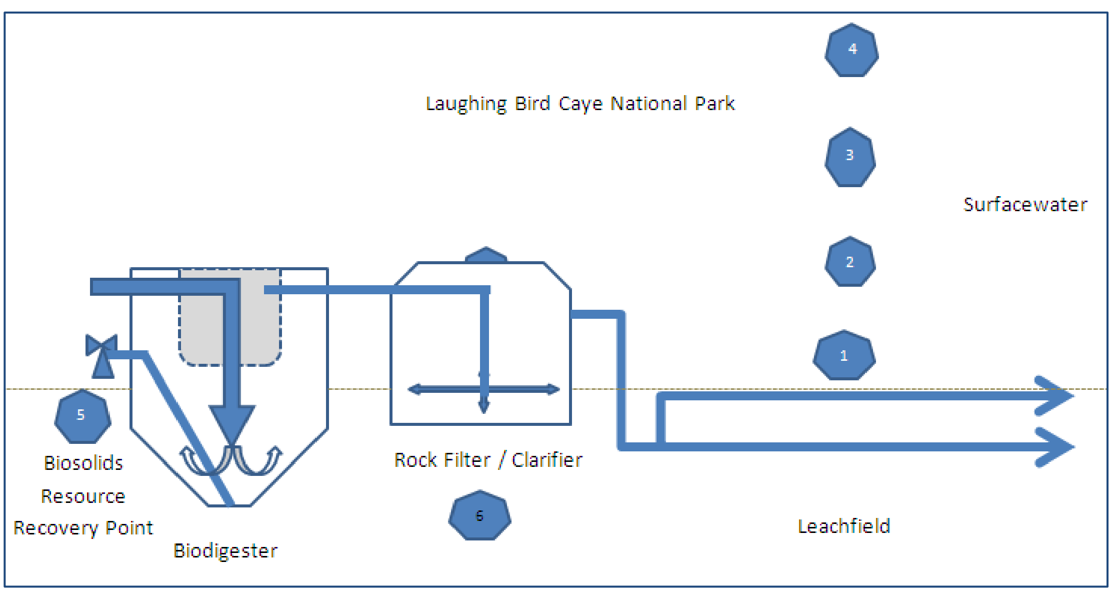

Figure 3: Laughing Bird sampling points

Water Probe System

The water probe that was used was the YSI 556 MPS (Multi-Probe System), (Geo Scientific Inc., 2001), which provided the data for the main physical parameters that were collected. In-situ, the parameters collected were conductivity, dissolved oxygen, and water temperature. The MPS had to be calibrated by setting the normal or neutral standards for the parameters that were to be recorded in the field. To avoid contamination, the probe end was washed with distilled water immediately before placing it into the sample water for reading, and when putting away the probe. To collect the samples, gloves had to be used to avoid contamination of samples and other possible effects.

Surface Water Sampling Methods

The surface water grab samples were collected using 500 mL bottles from the Belize Water Service Lab in Placencia. Surface water grab samples were taken based on the direction that the effluent was released or from the closest water surface that was available. Wherever applicable the adjacent water areas were sampled to investigate the potential peripheral movement of contaminants from the system's leached field to the surrounding aquatic areas. For the two locations, the grab samples were taken from the shoreline at approximate three feet away from the shoreline, where some samples were taken along the same trajectory with an additional three feet from the first shoreline sample point. In cases of flowing tidal waters, the sample bottles were held upstream or in the opposite direction to the flow. In the case where waves were crashing on the shoreline, the mouth of the sample bottle was held away from the shoreline, but with care not to touch any exposed rocks, sand, vegetation, or corals.

Wastewater Sampling Methods

Separate grab samples were collected at the different locations along the wastewater treatment chain. Wastewater samples were collected to provide a picture of the change in water quality parameters throughout the treatment process. When collecting the sample, it was collected from the cleanest location first, continuing through to the dirtiest. The wastewater was collected last in the overall grab sampling.

When collecting wastewater samples at Silk Caye, the bio-digesters was opened from the top and two samples were obtained using a ladle to dip for the samples that were filled into the 500mL bottles. The ladle was made locally by using a glass curtain holder stick and an unused clear glass which was tied at one end of the stick.

At Laughing Bird Caye the wastewater in the system was too low to use the ladle, so a zip-lock plastic bag was secured over the evacuation valve to collect the sample and then it was poured into the bottles. The evacuation valve is the side of the tank responsible for emptying the digested sludge. The valve was slowly turned to “open” position, to take the sludge into the bag and it was filled only halfway so it did not spill, avoiding any contamination of the environment. At each sample point, a duplicate grab sample were collected.

Data Analysis

To evaluate the effectiveness of the wastewater recovery system at both cayes the data for Phosphate (PO_4^{3-}) and Nitrate (NO_3^-) were compared with the wastewater standards of the Department of the Environment in Belize. T-test produced by an SPSS program were used to analyze the data, based on the level of significance and alpha. T-tests were used to calculate whether each nutrient level at each caye was within DOE standards and by how many mg/l it was above or below DOE standard. The mean of in-situ parameters like pH, temperature and dissolved oxygen were compared to DOE standards in table format for each caye. For the table with percent values, the difference between the mean wastewater and mean surface water level were first calculated. The result gained (waste recovered in mg/l) were then divided by the same mean wastewater level and then multiplied by 100. The calculation is to represent the percentage of nutrient that was lost.

Results

Six sites were sampled for phosphate (PO4 3-) and nitrate (NO3-) at Silk Caye and 4 sites at Laughing Bird Caye, with each site having a duplicate sample. Therefore, Silk Caye had 12 samples, and Laughing Bird had 8 samples. However, the sample ($PO_4{}^{3-}$) collected at Silk Caye for site 1 were lost, and another sample (NO_3^-) was not used because there was dilution error in the laboratory. For Laughing Bird Caye all sample data were produced and used for the results included in this report.

The mean displayed in figure 4 was 0.2540 mg/l, the standard deviation was 0.27742, and the standard error of the mean was 0.88773. In figure 5 below, it can be observed that the level of the significant figure for the p-value was 0.000, this means that the P value is less than alpha (0.05) therefore, it can be concluded with a 95% confidence that the system does not have the level of phosphate within the confidence interval. The negative T value indicates that the mean level of the sample is less than the DOE standards (5 mg/l). The mean difference as shown in the one sample test is -4.74500 which represents 4.74 mg/l.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
PO4 silk	10	.2540	.27742	.08773

Figure 4: Display the mean, standard deviation and standard error mean for Phosphate in samples collected from Silk Caye

One-Sample Test

	Test Value = 5					
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
PO4 silk	-54.100	9	.000	-4.74600	-4.9445	-4.5475

Figure 5 Displays the P-Value, confidence interval, and the value by which phosphate at Silk Caye is below the DOE standard

Figure 6 and 7 below displays the calculated result from the 11 samples. Figure 6 display the mean as 0.0845 mg/l, the standard deviation was 0.04458, and the standard error of the mean was 0.01344. In figure 7, the level of the significant figure for the P-Value was 0.000. This means that the p value is less than alpha (0.05), therefore it can be concluded with a 95% of confidence that the recovery system does not have the level of phosphate within the confidence interval. The negative T value indicates that the level of phosphate at Laughing Bird Caye is also below the standards of the DOE. The mean difference which is -4.91545 from the one sample test represents 4.91 mg/l.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
birdPH	11	.0845	.04458	.01344

Figure 6 Display the mean, standard deviation, and standard error of the mean for Phosphate in samples collected from Laughing Bird Caye

One-Sample Test

	Test Value = 5					
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
birdPH	-365.705	10	.000	-4.91545	-4.9454	-4.8855

Figure 7 Displays the P-Value, confidence interval, and the value by which phosphate at Laughing Bird Caye is below the DOE standard

Figure 8 shows the result for the 12 samples from Silk Caye which are: a mean of 79.2000, a standard deviation of 7.51774, and a standard error of the mean of 2.17018. For Laughing Bird the mean was 84.0125, the standard deviation 5.61412, and standard error of the mean of 2.17018. From the use of the one sample statistics, the one sample test was generated as shown below in figure 9. Figure 9 shows that the significant figure P-Value is 0.000. The P value is less than alpha (0.05), therefore it can be concluded with a 95% of confidence that the system does not have the nitrate level from Silk Caye within the confidence interval. The T value for Silk Caye is positive, and the mean difference is 76.20000 (76.20 mg/l).

From figure 9 it can also be observed that the level of significant figure for the P-Value is 0.00, this means that the p-value is less than alpha (0.05), therefore it can be concluded with a 95% of confidence that the recovery systems at Laughing Bird Caye do not have the level of nitrate within the confidence interval. T result also proves positive with a mean difference of 76.3190 (76.31 mg/l).

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silk	12	79.2000	7.51774	2.17018
Bird	8	84.0125	5.61412	1.98489

Figure 8 Display the mean, standard deviation, and standard error of the mean for Nitrate in samples collected from Silk Caye and Laughing Bird Caye

One-Sample Test

	Test Value = 3					
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silk	35.112	11	.000	76.20000	71.4235	80.9765
Bird	40.815	7	.000	81.01250	76.3190	85.7060

Figure 9 Displays the P-Value, confidence interval, and the value by which Nitrate at both Silk Caye and Laughing Bird Caye exceeds the DOE standard

Table 1 shows that the average pH at Silk Caye was 7.97 and 8.06 at Laughing Bird Caye. The mean pH for Laughing Bird was higher than the mean pH of Silk Caye, but both of the cayes have mean pH within the standards of the Department of the Environment. The mean temperature was 29.74 ^{0}C at Silk Caye and 30.09 ^{0}C at Laughing Bird. Laughing Bird and Silk Caye both have mean temperature below the standards of the Department of the Environment. At Silk Caye the water temperature at different locations were taken around 9:30 am – 10:00 am, and the water temperature at Laughing Bird Caye were taken between 2:30 pm – 3:30 pm. Dissolved oxygen was at a mean of 9.87 at Silk Caye and 10.78 at Laughing Bird.

Table 1: Mean pH, temperature, and dissolved oxygen vs. DOE standard			
Parameters	Silk Caye	Laughing Bird Caye	DOE Standards
PH (standard units)	7.97	8.06	6-9 units
Temperature C	29.74	30.09	33
Dissolved Oxygen (mg/l)	9.29	10.78	5

For table 2 & 3 the difference between the mean wastewater and mean surface water level was calculated (wastewater – surface water). Table 2 shows that the recovery system in Silk Caye removes 97% of the Phosphate in waste and 59.94% of Nitrate.

Table 2: % nutrient recovered by the waste recovery system in Silk Caye			
Parameters	SC Wastewater	SC Surface water	% recovery
PO_4 (mg/L)	7.67	0.25	97%
$N0_3$-N (mg/L)	197.75	79.2	59.94%

The recovery system at Laughing Bird Caye as shown in table 3 removes 96.24% of phosphate from the wastewater and 92.44% of nitrate.

Table 3: % nutrient recovered by the waste recovery system in Laughing Bird Caye			
Parameters	LB Wastewater	LB Surface Water	% recovery
PO_4 (mg/L)	2.13	0.08	96.24%
$N0_3$-N (mg/L)	1111.92	84.01	92.44%

Regression value for correlation coefficient was computed for the five parameters. It was noticed that phosphate and nitrate at Silk Caye had a moderately positive correlation. This means that as nitrate increased, phosphate also increased in the sea water surrounding Silk Caye. When nitrate increased the pH of the seawater decreased. Nitrate and conductivity had a moderate positive correlation, where conductivity increased with the rising level of nitrate. Nitrate level also increased with the rising temperature, and when nitrate increased the level of dissolved oxygen decreased.

Phosphate and conductivity had a very weak correlation. When Phosphate level increased pH also increased, pH and conductivity had a strong positive correlation where the increase in pH resulted in an increase in conductivity. This means that an increase in acid concentration is related to higher conductivity. When temperature level decreased the phosphate level increased along with dissolve oxygen. Dissolved oxygen and pH increased together, while pH rises as temperature decreases. Conductivity and temperature has a moderate positive correlation, of increasing together. Conductivity and dissolved oxygen rise together, while dissolved oxygen decreased as the temperature increased.

At Laughing Bird Caye it was calculated that nitrate and phosphate had a weak correlation. Increased Phosphate level resulted in a lower pH value, while conductivity increased as nitrate level increased. When temperature increased nitrate also increased but the dissolved oxygen level decrease.

The Phosphate level increases along with pH, but conductivity decreases as phosphate increases. Phosphate increases as temperature decreases, and increases (PO_4^{3-}) along with dissolved oxygen. As pH increases conductivity decreases and as pH rises temperature decreases. pH and dissolved oxygen rises together, and conductivity and temperature (both rise). As conductivity increases the dissolved oxygen decreases. When temperature increases oxygen decreases.

Discussion

Based on the result from figure 5 it can be stated that there is a significant difference in mean phosphate level between the sample from Silk Caye and the DOE standards. The mean phosphate level of the sample is 4.74 mg/l less than the DOE standard. This means that the system is functioning effectively (97%) in recovering phosphate as supported by the results in table 2. There is also a significant difference in mean nitrate level from Silk Caye and the DOE standard. From the result it is displayed that the T value is positive meaning that it is higher than the DOE standards (5mg/l). This means the recovery system is not functioning effectively to recover nitrate from the wastewater. The significant difference is the ineffectiveness of the system in removing nitrate from the wastewater. The system only recovers 59.94% as shown in table 2, which results in a release of 40% of nitrate from wastewater into the environment. Since nitrate and phosphate have a relationship of increasing together it is expected that the level of nitrate influences the level of phosphate and vice versa. An experimental research showed that no nitrate removal took place from a phosphate-deprived culture (Hu *et. al.*, 2000). Therefore, the amount of nitrate that was not removed may be due to the ratio of phosphate: nitrate that existed in the bio-digester. An increased phosphate level may have been required for uptake of nitrate and simultaneous growth of necessary bacteria (nutrient digesters). Based on a research it was found out that the dependency of dissolved phosphate concentrations on phycobilisome levels reflects that the pigment-protein complexes broke down to facilitate some cell growth under nutrient-limiting conditions and then increase significantly with addition of higher phosphate levels (Hu *et. al.*, 2000). Also, anaerobic digester is affected by changes in external factors, where the severity of the effect is dependent upon the type, magnitude, duration and frequency of the imposed changes (Leitao *et. al.*, 2005). The typical responses include a decrease in performance, accumulation of volatile fatty acids, drop in pH and alkalinity, change in effluent production and composition. This may be true for the recovery system at Silk Caye, where external evidence of influencing factors is present. The first observation was that the recovery system no longer discharges the effluents to a leachate field because all the sand that once covered the discharge pipe had eroded and effluents were discharge directly into the sea water.

At Silk Caye the pH falls within the DOE standards, while the dissolved oxygen is slightly higher than the DOE standards. However, since it is not too high it will not disrupt the ecosystem, because oxygen harm aquatic life and affect water quality only when it is too high or too low (Fondriest Environmental Inc., 2016). The temperature is below the standard of DOE. The low temperature of water slows down the metabolic rate of organisms but it means that it holds more oxygen; and organisms affected behave in ways such as moving to warmer waters or resting (Fondriest Environmental Inc., 2016). Since the temperature level is not too low, it is believed that the metabolic rate is not being affected significantly. It was expected based on correlation that the temperature should have been high and dissolved oxygen low, however the level of nitrate in the water seems to have little effect on other parameters like oxygen.

At Laughing Bird Caye the level of phosphate is below the standard of DOE by 4.91 mg/l, perhaps there is no encouragement of algae growth by phosphate from waste. Figure 7 refers to a significant difference in mean phosphate level between the sample and the standards of DOE. The significant difference in this analysis is in reference to the high effectiveness (96.24%) of the system at Laughing Bird to remove phosphate from the wastewater. In figure 9 it is established that there is also a significant difference in mean nitrate level between the sample and the standards of DOE. Figure 9 represents a significant difference in mean nitrate level between the sample from Laughing Bird and DOE standards. The significant difference is the large percentage (92.44%) removal of nitrate from the wastewater. This may be due to the proper design, sitting and management of the recovery system (U.S Environmental Protection Agency, 2002), and a weak relationship to the phosphate level inside the bio-digesters that could have its removal (Hu *et. al.*, 2000).

In the waters where the treated effluent is released, the pH is within the standards. The level of dissolved oxygen is slightly above the standards while the temperature of the water is slightly below the standards. 4-5 mg/l of oxygen supports a large number of fish, and 9 mg/l supports abundant fish populations (Water Research Center, 2014). Temperature below 21^0C cause dormancy and restricted growth in plants (Fondriest Environmental Inc., 2016). However, from the results, both temperature and dissolved oxygen falls below DOE's standards but within a range that encourage activities in the water to be stable. In the relationship shown at Laughing Bird Caye, the oxygen level increased along with increasing phosphate level due to the increase in temperature. Therefore, it is understood that the phosphate level meets the standard of DOE, and is acceptable for the sea water environment because if the phosphate level decreases then dissolved oxygen would also decrease. A decrease in temperature will further bring the parameter below the DOE standard which can affect the metabolic rates of the marine organisms (Water Research Center, 2014).

To increase the effectiveness of the recovery system in removing nitrate, the system should be examined on quarterly basis (3 months) for any dysfunctional parts. Specifically, for Silk Caye the discharge pipe should be cover with sand to provide the necessary leachate field. Checkup of the system can help to fix or replace part of the system that may not be working. Staff managing the Caye should also ensure that they follow the procedure of maintenance based on the recovery system's engineered design requirement.

Conclusion

The recovery system at Silk Caye did not effectively removed nitrate from the wastewater. Forty percent (40%) of nitrate nutrient is not recovered and enters the environment.

Both nutrient parameters for Laughing Bird Caye are below the DOE standards. This means that the recovery system at Laughing Bird Caye is successfully removing the nutrients from the wastewater. The system is also 94.34% effective in removing both nutrients.

This report intends to bring to the attention of the SEA staff to examine the recovery systems every six months to ensure that they are functioning effectively.

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References:

Angelakis, A. N., De Monte, M. M., Bontoux, L., & Asano, T. (1999). *The status of wastewater reuse practice in the Mediterranean basin: need for guidelines.* www.med-reunet.com.

Avvannavar MS, Mani M. A conceptual model of people's approach to sanitation. Sci Total Environ 2008;390:1-12.

Baker, F., Faggian, R., & Hamilto, A. J. (2011). A History of Wastewater Irrigatio in Melbourne, Australia. *Journnal of Water Sustanability* .

Belize Act. (1995). Environmental Protection (Effluent Limitations) Regulations 1995. *Environmental Protection (Effluent Limitations) Regulations 1995* . Belize.

Belize Act. (2009, August 8). Statutory instrument. *Environmetal Protection (Effluent Limitations) (Amendment) Regulations 2009* . Belize: The Gazette.

Belize Tourism Board. (2014). *Belize Travel Guide.* Belize: Belize Tourism Board.

Boles, E. (2001). *Status and Future Needs fo limnologival Research in Belize.* Belize.

Brown, E., Skougstad, M. W., & Fishman, M. J. (1970). *Techniques of Water-Resource Investigations of the United States Geological Survey.* Washington, D.C, U.S: U.S. Government Printing Office.

Chavira, D., Brisei'io, J., Negroe, A., Perez, I., Sanchez, T., & Holi, R. (1992). *Diagnostico de la calidad del agua en la Bahia de Chetumal, Quintana Roo.* Mexico: Avacient.

De Feo G, Napoli RMA. Historical development of the Augustan Aqueduct in Southern Italy: twenty centuries of works from Serino to Naples. Water Sci Technol 2007;7:131–8.

Du, Z., Li, H., & Gu, T. (2007). A state of the art review on microbial fuel cells: A promising technology for wastewater treatement and bioenergy. *Elsevier Journal* .

Fondriest Environnmental Inc. (2016). *Fundamentals of Environmental Measurements*. Retrieved from http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/.

Frutos, R. (2003, August 6). *Progress and Constraint in Developing Integrated Water Resources Management in Belize*. Retrieved from Belize National Meteorological Service: http://www.hydromet.gov.bz/hydrological-reports.

Geo Scientific Inc. (2001). *Water Quality Meters*. Retrieved April 23, 2016, from http://www.geoscientific.com/waterquality/

Gonzalez, V. J. (1980). *A limnological Victor J Gonzalez investigation of a tropical freshwater ecosytem :the Belize River, Belize, Central America.* Western Michigan: University Microfilms International.

Grizzetti, B. (2011). Nitrogen as a threat to European water quality. In M. A. Sutton, C. M. Howard, J. W.Erisman, G. Billen, A. Blecker, P. Grennfelt, et al. (Eds.). Cambridge University Press.

Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). (2000). *Report of the Thirtieth Session.* Monaco: International Atomic Energy Agency Press.

Hernandez, E. (1988). *Estudio de los Nivelesde Contaminacion, Bacteriologica Y la indicacion de Enteropaogeos en la Bahia de Chetumal.* Veracruz, Mexico.

Hernandez, O., & Morales, S. (1999). *Effects of organicc material and distribution of feacal coliforms in Chetumal Bay.* Qintana Roo, Mexixo: Environmental and Monitoring Assessment.

Hu, Q., Westerhoff, P., & Vermaas, W. (2000). Removal of Nitrate from Groundwater by Cyanobacteria:Quantitative Assessment of Factors Influencing Nitrate Uptake.

HDR (Human Development Report). Beyond scarcity: power, poverty and the global water crisis. New York: United Nations Development Programme; 2006.

Iza, A. and Stein, R. (Eds) (2009). *RULE – Reforming water governance*. Gland, Switzerland: IUCN.

Laurent, A., Fennel, K., Cai, W.-J., Huang, W.-J., Barbero, L., & Wanninkhof, R. (2007). *Eutrophication-induced acidification of coastal waters in the northern Gulf of Mexico: Insights into origin and processes from a coupled physical-biogeochemical model.*

Leitao, R. C., Adrianus Cornelius Van Haandel, Zeeman, G., & Lettinga, G. (2005). The effects of operational and environmental variations on anaerobic wastewater treatement systems: A review.

Lofrano, G., & Brown, J. (2010). *Science of the Total Environment* (Vol. 408). Science Direct.

Mexican Norm. (1996). *Wastewater.* Official Gazette of the Federation.

Oakley, S. M., Pocasangre, A., Flores, C., Monge, J., & Estrada, M. (2000). *Waste Stabilization Pond Use in Central America: The Experience of El Salvador, Guatemala, Honduras and Nicaragua.*

Population Reference Bureau. (2016). *Human Population: Environment*. Retrieved January 12, 2016, from http://www.prb.org/Publications/Lesson Plans/HumanPopulation/Environment.

Sato, T., Qadir, M., Yamamoto, S., Endo, T., & Zahoor, A. (2013). Agricultural Water Management. *Global, regional,and country level need for data on wastewater generatio, treatement and use* , 3.

Sorcinelli P. Storia sociale dell'acqua. Riti e Culture. Milano: Mondadori; 1998.

Southern Environmental Association. (2015). *Gladden Spit & Silk Caye*. Retrieved April 26, 2016, from http://seabelize.org/protected-areas/gladden-spitsilk-cayes/

Terrametrics. (2016). *Traveling Luck for Little Water Cay, Stann Creek, Belize.* Retrieved April 23, 2016, from Google, NEGI Imagery:http://travelingluck.com/North+America/Belize/ Stann+Creek/_3581802_Little+Water+Cay.

The Placencia Breeze. (2008, January 09). *Southern Environmental Association: Getting to know our parks: Laughing Bird Caye National Park*. Retrieved April 23, 2016, from http://www.placenciabreeze.com/0909/0909Sealbc.html.

U.S Environmental Protection Agency. (2002). *Onsite Wastewater Treatement System Manual.* United States.

U.S Public Heath Service. (1969). *Manual of Septic-tank Practice.* Washington, D.C: U .S Government Printing Office.

Water Research Center. (2014). *Dissolved Oxygen in water*. Retrieved from http://www.water-research.net/index.php/dissovled-oxygen-in-water.

Wolfe, P. History of wastewater. World of water 2000–the past, present and future. Water World/Water and Wastewater International Supplement to Penn Well Magazines, Tulsa, OH, USA; 1999.

Appendices:

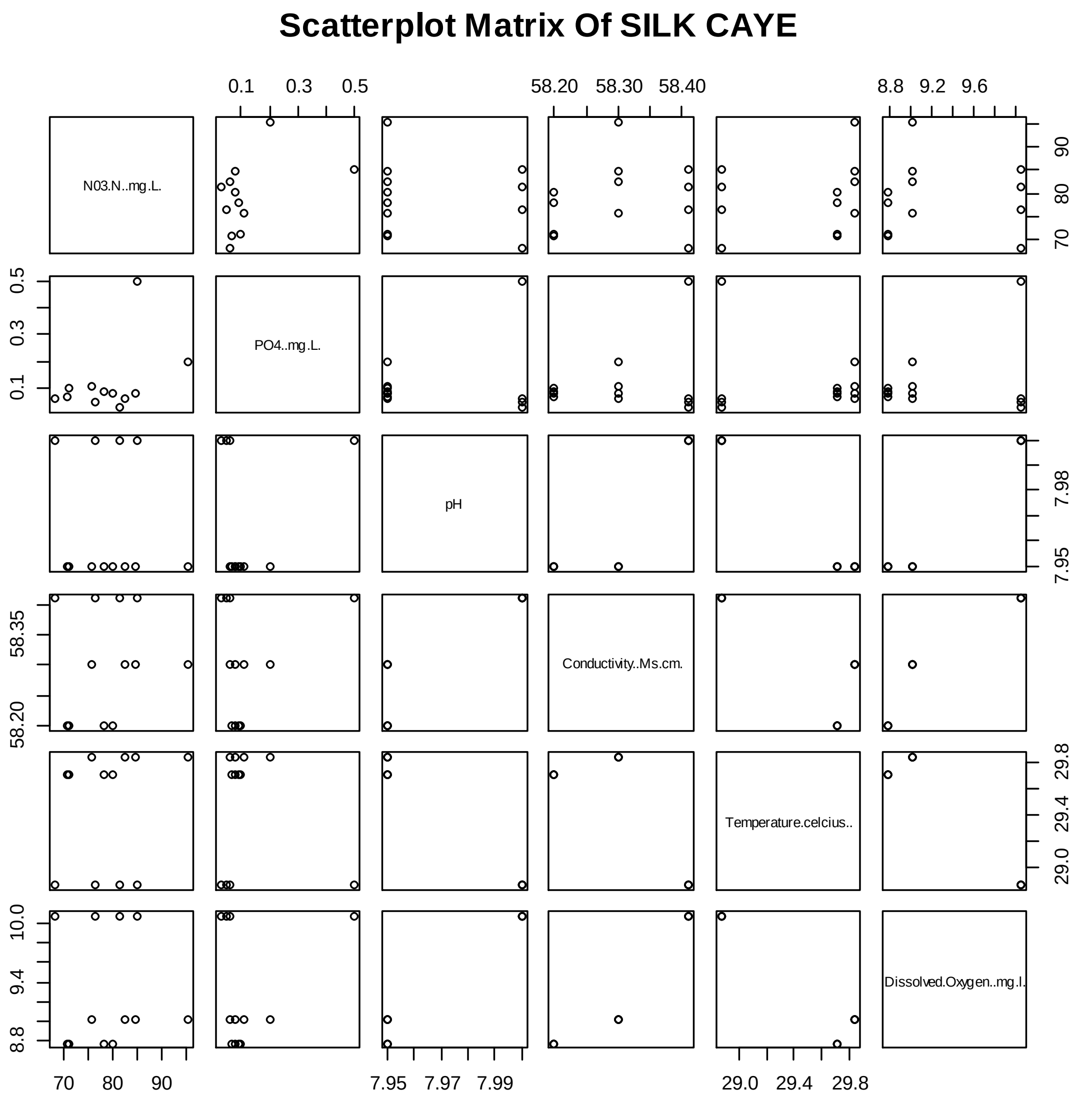

Figure 10: Scatter Matrix Graph for Silk Caye

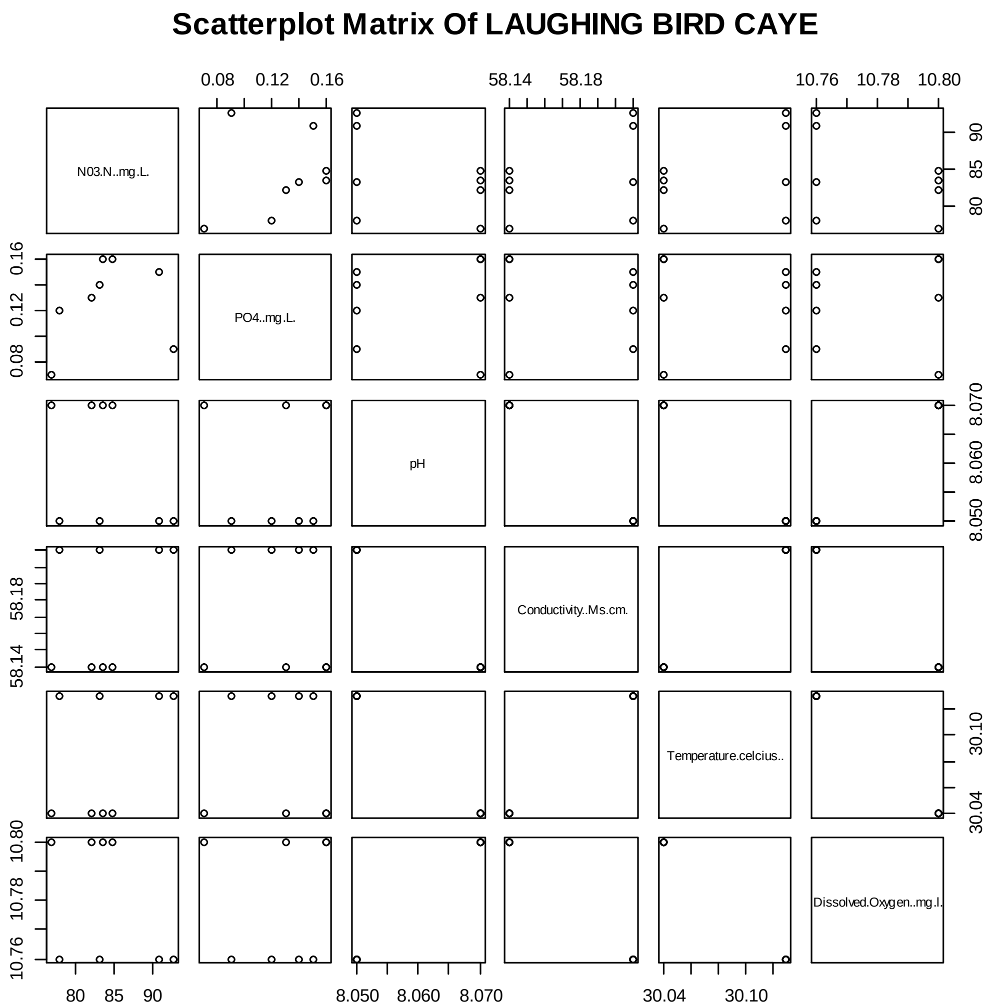

Figure 11: Scatter Matrix Graph for Laughing Bird Caye