

Retrofitting a Poorly Operating Activated Sludge System with Membranes to Achieve High Quality Effluent That Will Protect the Environment

Hector Marshall, Project Manager, Ionics Freshwater, LTD
Michael T. Sparks, MBR Product Engineer, Ionics, Inc.

Abstract

Tobago, a small island off the coast of South America, relies heavily on tourism to keep its economy afloat. Along with its exceptional beaches, Tobago's main tourist attraction is the Buccoo Reef. The Buccoo reef is considered by many as one of the best diving destinations in all of the Caribbean. But land activities, run off, and improper treatment of wastewater; have contributed to degrading the coral reef. To counter this, the government has chosen to retrofit two existing waste water treatment plants with membranes. The effluent from these two waste water treatment plants is sent to a stream that makes its way out to sea adjacent to the Buccoo Reef.

The two existing treatment plants are located in the Buccoo and Bon Accord communities. The pre-modified plants consist of two circular tanks. Each tank contains an outside and center portion. The outside portion was used as an activated sludge system where nitrification and oxidation of BOD took place. The influent wastewater has the typical characteristics of 44.1 mg/L suspended solids, 129.7 mg/L BOD and 21.7 mg/L free ammonia. Mixed liquor from the aerated section of the tank was transferred to the center ring which acted as a clarifier. Effluent leaving the clarifier had averages of 16.5 mg/L suspended solids, 63 mg/L BOD, 17.3 mg/L free ammonia, and faecal coliforms in excess of 60,000 cfu/100 mL.

Four membranes were placed in the aeration tank of only one circular tank at each location. The four membranes allowed the plants to treat all of the 30,000 gallons that flow into the plant on a daily basis. The clarifier was eliminated and is now being used for sludge holding and aerobic digestion. The second circular tank is being utilized as a flow equalization tank. The Membrane Bioreactor systems (MBR) have significantly improved the quality of effluent now being discharge to the sea. The effluent quality now leaving the plant has the following average data; 2.4 mg/L suspended solids, 2.4 mg/L BOD, 0.6 mg/L free ammonia, and 0 cfu/100 mL counts of faecal coliforms.

The improved water quality discharge to the sea is expected to put a halt on the degradation of the Buccoo Reef. Hard coral, sponges and fish have continued to thrive in the reef's environment. Though the first plant has only been in operation for the past year, lab results have pointed to an effluent that has little or no effect on the reef. The vast improvements have not only ensured that Tobago's tourism will continue to grow but local environmental organizations are pleased with the governments efforts.

Project Background

Tobago is the southern most island in the Caribbean archipelago. Located just off the coast of Venezuela, Tobago is considered by many to be the most “unspoiled” or natural country in the Caribbean. Unlike Trinidad, Tobago’s governmental partner, which relies heavily on industry to drive its economy, Tobago relies heavily on tourism.

The main tourist attraction in Tobago is the Buccoo Reef. The Buccoo Reef is located just off the southwestern tip of Tobago. It is considered by many to be one of the top diving and snorkeling destinations in the world. A negative trend has been noticed over the past 30 years. The reef is slowly being destroyed over time. Scientist have concluded that the damage to the reef has been caused by two main factors. The first factor is the high amount of traffic that the reef experiences. Many divers that visit the reef have a tendency to walk on the reef which crushes the coral. In addition to walking on the reef, anchoring has also been a significant reason for the reef to be destroyed. The second contributing factor to the reefs demise is said to be caused by the poor treatment of the countries sewage. As the popularity of the island has increased so to have the BOD and suspended solids loads that are sent out to the Bon Accord lagoon. The water makes its way through the lagoon and eventually out to the Buccoo Reef. The poorly treated wastewater has caused increased growth of algae and seagrass. The increase in these two items has caused the once crystal clear water to become cloudy.

The Tobago House of Assembly (THA) has made a conscience effort to stop or at least retard the destruction of the reef. The conservation of the reef is not only environmentally important but it will also ensure that the Tobago economy remains steady for years to come. With that in mind, THA had decided to upgrade it existing waste water treatment facilities. The Water and Sewage Authority (WASA) decided to retrofit the Bon Accord plant with a membrane bioreactor system (MBR).

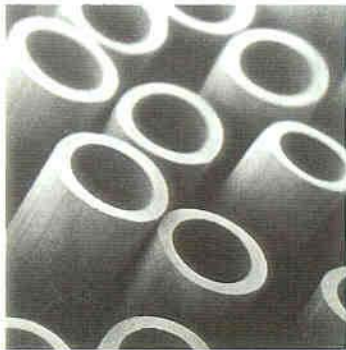
MBR Technology

Membrane Bioreactor technology consists of a traditional activated sludge system coupled with a micro or ultra-filtration membrane. The membrane eliminates the need for a secondary clarifier because it acts as the liquid solid separation step. There are two types of arrangements that can be used when designing a membrane bioreactor. One is a side stream array and the other is a submerged design. The side stream layout places the membranes outside the activated sludge basins. Mixed liquor is re-circulated across the membrane in a cross flow manner. Pressure drives water through the membrane pours. The velocity of the fluid across the membrane surface in addition to the air provided at the base of the membrane is utilized to keep the membrane clean.

A submerged membrane bioreactor places the membranes directly into the activated sludge. A vacuum is placed on the membranes and the oxidized water is drawn through the membrane pores. Coarse air is used to scour the membrane surface and keep membrane fouling to a minimum.

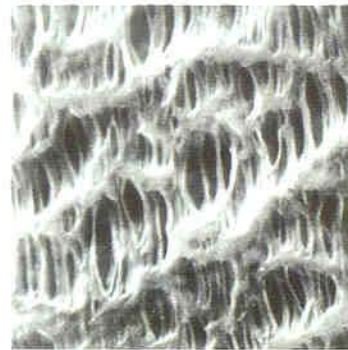
The Bon Accord and Buccoo WWTPs both utilize a submerged design. The membrane used is the hollow fiber Mitsubishi-Rayon Sterapore™ membrane (see Figure 1) with a 0.4 micron nominal pore size.

The Hollow-fiber Membrane Used in Sterapore® SUR Membrane Units



Enlarged view of hollow-fiber membranes (outside diameter, 540 μm)

The polyethylene membranes are highly resistant to flexural fatigue.



SEM image (5,000 ×) of hollow-fiber membrane surface

Because the membranes have been made permanently hydrophilic, they can be stored dry and do not need to be pre-wetted prior to use.

Figure 1 - Sterapore™ Membrane Surface

Course bubble aerators create a continuous flow of mixed liquor around the membrane module and provide the oxygen required for oxidation of waste components. The fibers in the Sterapore™ module are horizontally aligned which allows for sufficient contact of the air and membrane fibers. The system is operated on an 8-minutes-on and 2-minutes-off schedule. The filtrate pump pulls a vacuum on the membranes with the blower operating for 8 minutes at which time the pump turns off and the blower continues to run. This 2-minute period allows for the membranes to relax which improves air-scouring efficiency.

Air scouring does not completely remove all of the fouling on the membrane so over time the trans-membrane pressure (TMP), differential pressure across the membrane, will rise. Once the TMP rises 4.4 psi (30 kPa) above the start-up TMP, a cleaning will need to be performed. There are two types of cleaning methods performed on the Sterapore™ membrane module. One is an in-situ reverse flow of a dilute sodium hypochlorite solution (3,000-ppm) for about two hours. When the in-situ cleaning method proves to be ineffective an out-of-tank cleaning can be performed. The out-of-tank cleaning requires the membrane to be removed from the tank and place in a solution of sodium hydroxide (40,000-ppm) and sodium hypochlorite (5,000-ppm) and allowed to soak for 12 to 15 hours. The out-of-tank cleaning should restore TMP levels at or below initial operation levels.

Each Sterapore™ membrane module contains 105 m² (1,130 ft²) of membrane area. Four membranes are placed at both plants to handle an average daily flow of 30,000 gpd. The membrane modules can also be stacked two or three tiers high. Stack of the modules reduces air required for scouring and reduces the land area needed for the MBR tank. Figure 2 is a picture of a single tier Mitsubishi Sterapore™ membrane module.



Figure 2 - Mitsubishi Sterapore™ Membrane Module

System Design

Both the Bon Accord and Buccoo Wastewater treatment plants are responsible for treating all of the domestic wastewater generated in each of the neighborhoods. Each plant treats roughly 30,000 gallons per day. The collection systems are segregated so that rain water is sent directly to the Bon Accord lagoon and not sent to the treatment plant. Each waste water treatment plant has two pump stations that feed the first of two circular tanks. Each circular tank has a separate inner circular tank that acts as the clarifier. Figure 2A is a photograph of one of the already existing circular tanks at Bon Accord.



Figure 2A: Photo of Circular Tank

Previous to the retrofitting the system with membranes, the tanks were operated in parallel to handle the daily flow. With the addition of the membranes only one of the two basins was required to handle the daily flow. This allows one of the basins to be used as an equalization basin. The equalization, though not necessary, eliminates any concern of shock loads because ample time is provided for the waste water to balance.

The existing bar screen was insufficient in removing small stringy materials from the influent waste water. A 1.5 mm rotary drum screen was added to the system directly above the activated sludge system that contains the four membrane modules. Waste water from the equalization basin is air lifted to the fine screen. Screenings are sent down a chute to the inner tank of the equalization basin.

A rotary lobe blower is utilized to provide air to the equalization basin, the activated sludge basin as well as the sludge holding basin which is the inner basin of the activated sludge basin. Air is also sent to the membrane modules to scour the surface of the membrane fibers.

A centrifugal pump is used to pull a vacuum across the membrane surface and draw water through the pores. Once the water is processed through the membranes it is sent through a chlorine contact tank to ensure the effluent is completely disinfected prior to discharge to the lagoon outfall. Figure 3 show the complete process flow diagram for the Bon Accord and Buccoo waste water treatment plant.

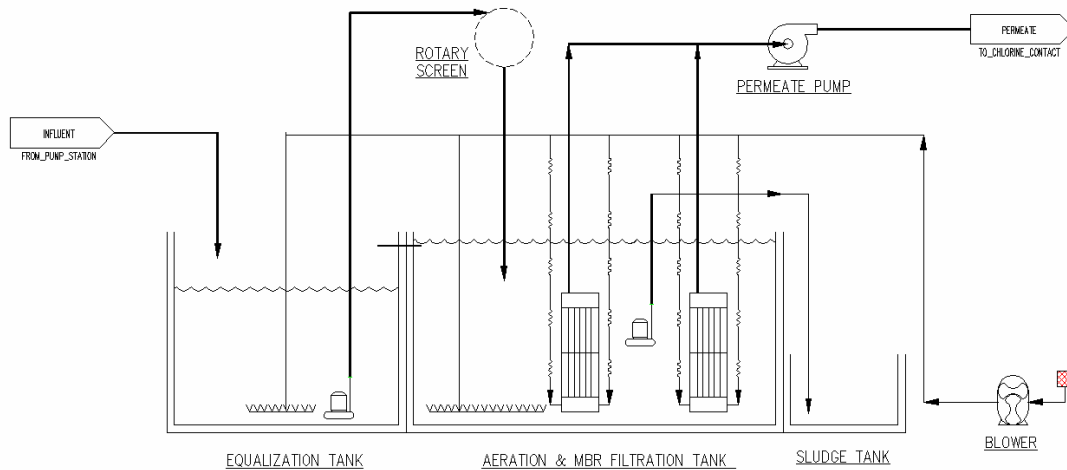


Figure 3: Process Flow Diagram of Bon Accord and Buccoo WWTP

Results

The improvement in effluent quality with the addition of the micro-filtration membranes is having a positive effect on the Buccoo Reef. Figure 8, which shows the removal percentages of the suspended solids, BOD, and Ammonia for both the conventional and MBR plants, demonstrates a significant change in the effluent quality. Suspended solids reduction went from an average of 64% to 87% with the addition of the membranes. BOD was an even more drastic improvement with a reduction of 98% with the MBR as oppose to 52% with the conventional system. Ammonia improvements have also been noticed with an average of 97% being nitrified as oppose to 20% previously noticed.

The complete lab data for the Bon Accord plant as a conventional and membrane bioreactor is displayed in table 1 and 2. In addition to the improve removal rates, the reduction of faecal coliforms from a value of 60,000+ to levels below 11 also demonstrates the high quality of water the membranes produce. The reduction in coliforms has saved the plant on operating cost because it reduces the amount of chlorine required. The high quality effluent also provides the opportunity for non-potable re-use. This will reduce the burden on the potable water plant as population of the island continues to increase in addition to the popularity of the island grows with tourist.

Table 1: Bon Accord Conventional Plant Lab Results

Raw					Effluent				
Date	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	pH	Free Ammonia mg/l	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	Faecal Coliform cfu/100ml	pH	Free Ammonia mg/l
3/28/2002	45	135	6	20	2	95	60 000	6	16
2/7/2002	46	152	6	26	20	70	670 000	6	22
3/10/2002	57	126	7	16	24	73	Not counted	7	16
1/23/2003	29	132	7	29	8	48	Not counted	7	22
2/20/2003	35	109	7	22	13	56	500 000	7	17
3/6/2003	54	112	7	19	28	28	Not counted	7	14
7/9/2003	43	142	7	20	21	72	6 000 000	7	14

Table 2: Bon Accord MBR Lab Results

Raw					Effluent				
Date	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	pH	Free Ammonia mg/l	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	Faecal Coliform cfu/100ml	pH	Free Ammonia mg/l
10/23/2003	50	139	7.2	19	10	1	11	7.5	0.4
11/6/2003	38	137	7.2	19	8	1	0	7.6	0.5
11/13/2003	43	132	7.4	26	7	1	0	7.6	0.1
1/8/2004	39	157	7.8	23	0	10	0	8.0	0.6

Figure 4: Bon Accord Conventional Plant Suspended Solids

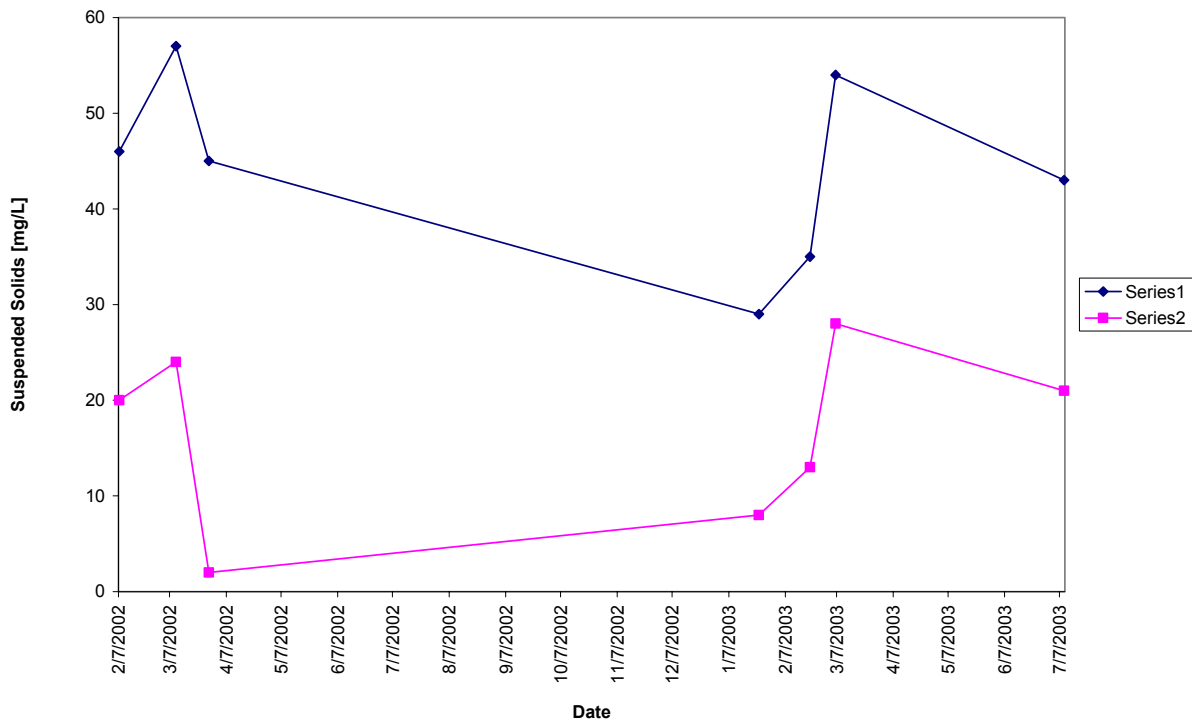


Figure 5: Bon Accord MBR Plant Suspended Solids Reading

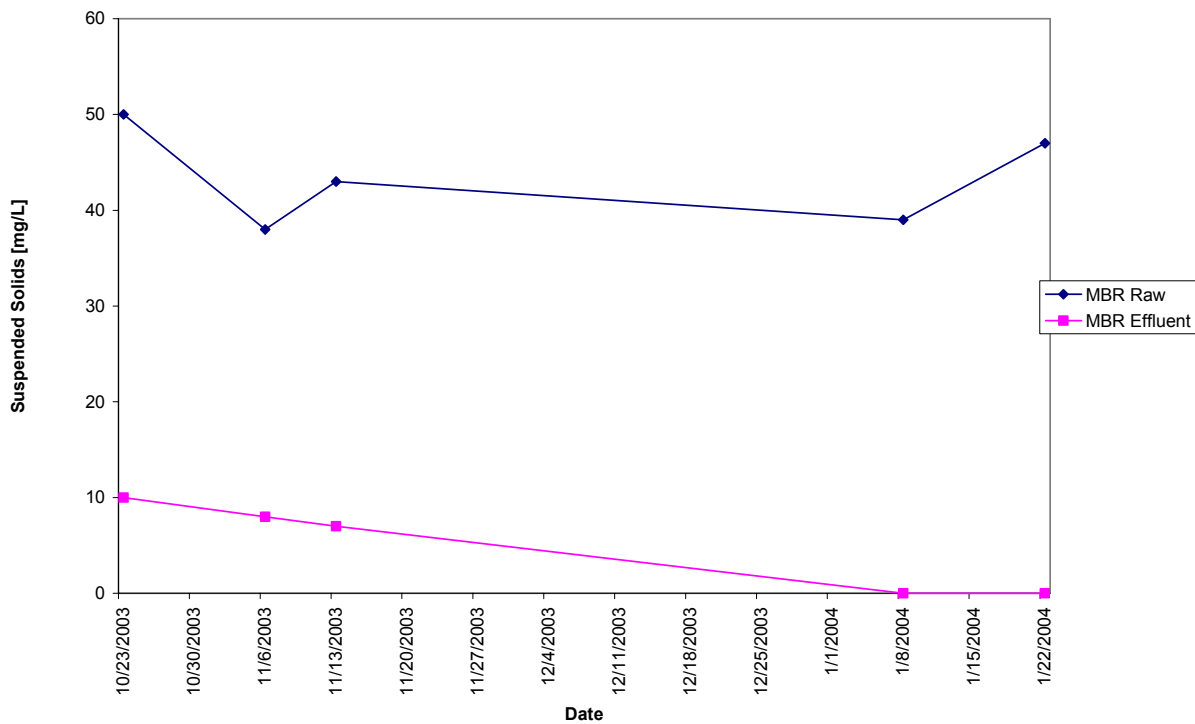


Figure 6: Bon Accord Conventional BOD Readings

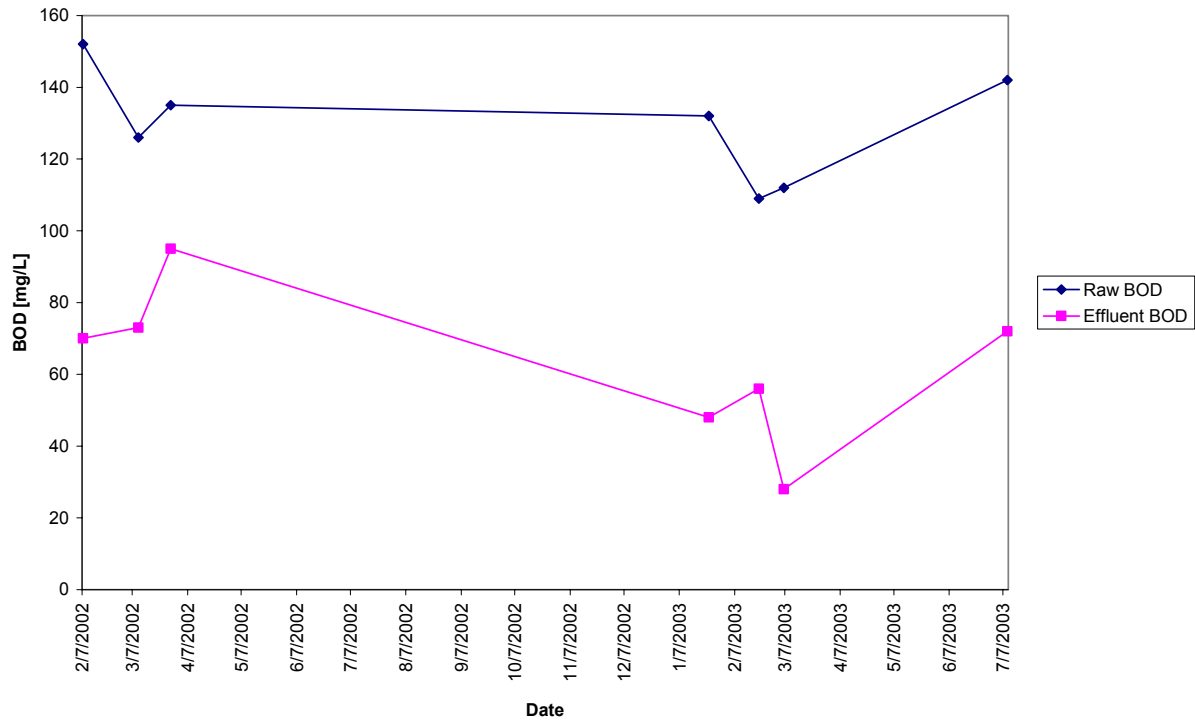


Figure 7: Bon Accord MBR BOD Results

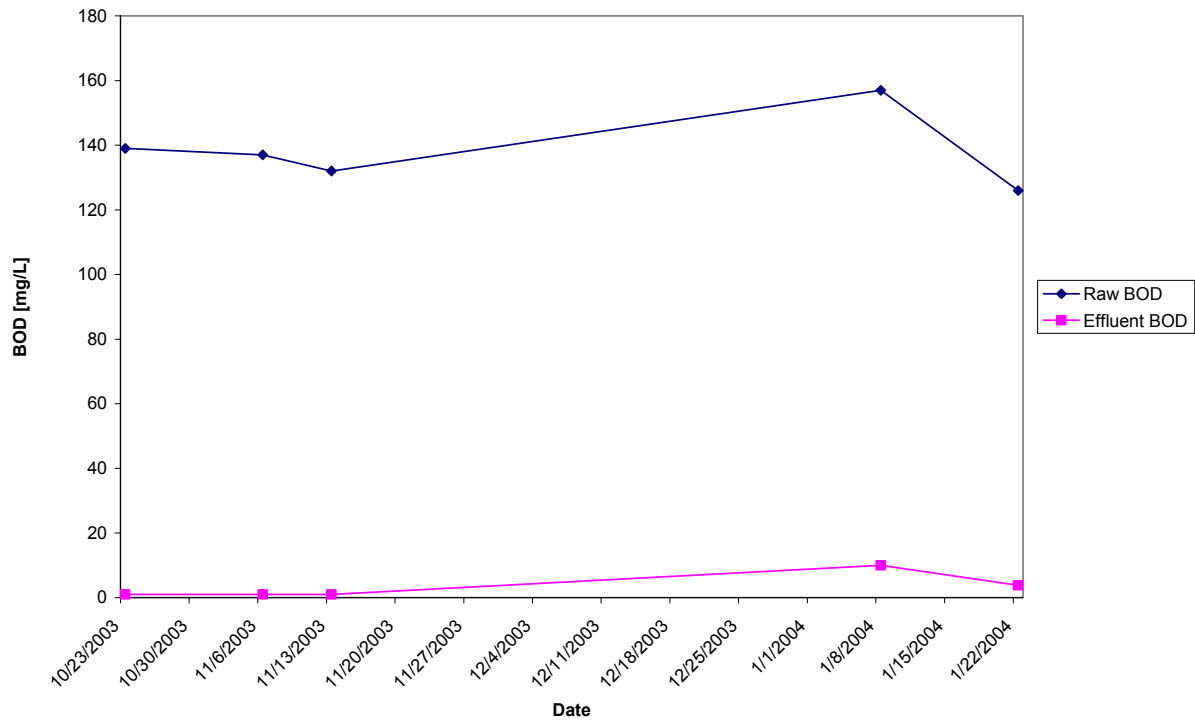
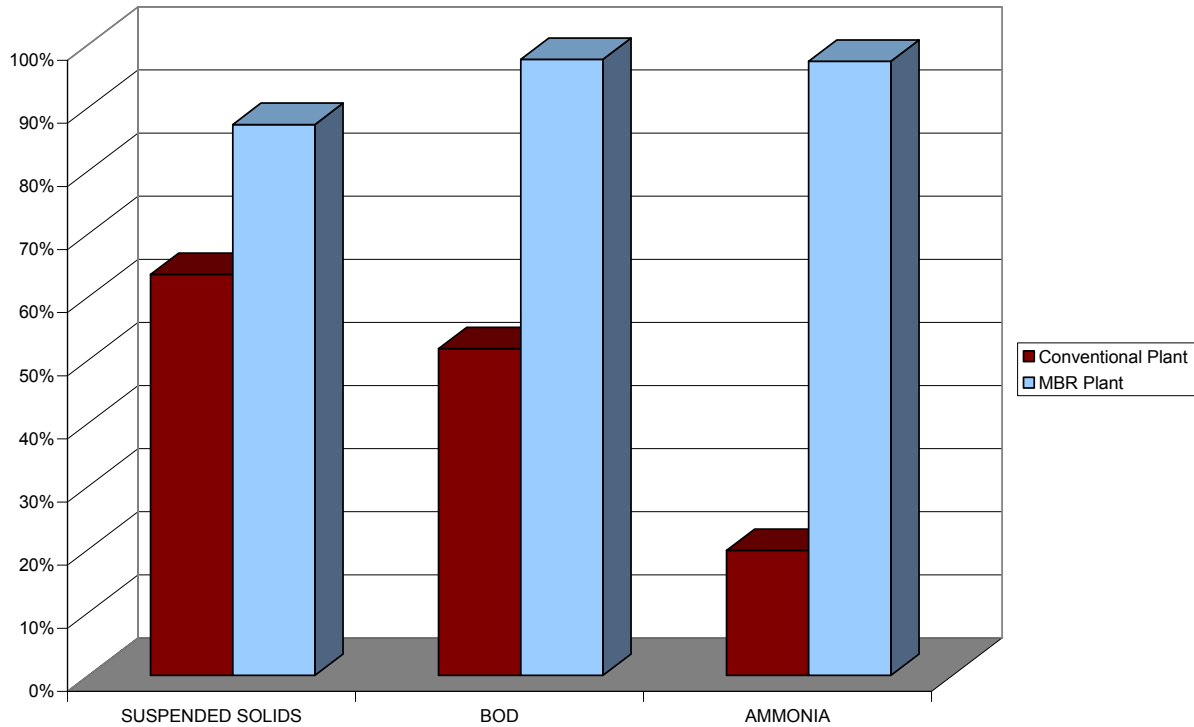


Figure 8: Removal Rates Comparison Between Bon Accord Conventional and MBR Plants



The Buccoo plant's, which changed over to membranes in May of 2004, effluent has also been extremely high quality as well. Suspended solids level in the effluent averaged 0.8 mg/L and BOD₅ had an average level of 1.9 mg/L in the grab samples that were taken. These values represent reduction percentages of 98 and 99% respectfully. Faecal coliform levels have been consistently tested at 0 cfu/100mL which holds well for non-potable re-use. Table 3 provides the entire lab data generated since the plant has been operating as an MBR. Samples were tested on a monthly basis.

Table 3: Buccoo MBR Lab Results

Raw Water						MBR Plant Results			
Date	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	Faecal Coliform cfu/100ml	pH	Free Ammonia mg/l	Suspended Solids mg/l	BOD ₅ @ 20° C mg/l	Faecal Coliform cfu/100ml	pH
5/11/2004	39	135	-	7.2	20	2	3	0	7.3
6/16/2004	46	152	-	7	26	1	2	0	6.8
7/13/2004	28	126	-	6.9	16	0	4	2	6.8
8/18/2004	37	132	-	7.4	29	0	1	0	7.5
9/15/2004	27	109	-	7.6	22	1	1	0	7.6
10/13/2004	26	112	-	7.5	19	0	1	0	7.6
11/17/2004	43	142	-	7.2	20	2	2	0	7.2

Suspended solids levels in the influent were exceptionally low for domestic waste water especially when compared to typical values that are seen in the States. This is shown in both table 3 and figure 9. Reason for this has been attributed to the segregation of the sewer. Run-off that typically picks up silt and sand is sent directly to the lagoon rather than combined with waste water. Levels are consistently less than 5 mg/L meeting WASA discharge requirement.

Figure 9: Buccoo Suspended Solids Results

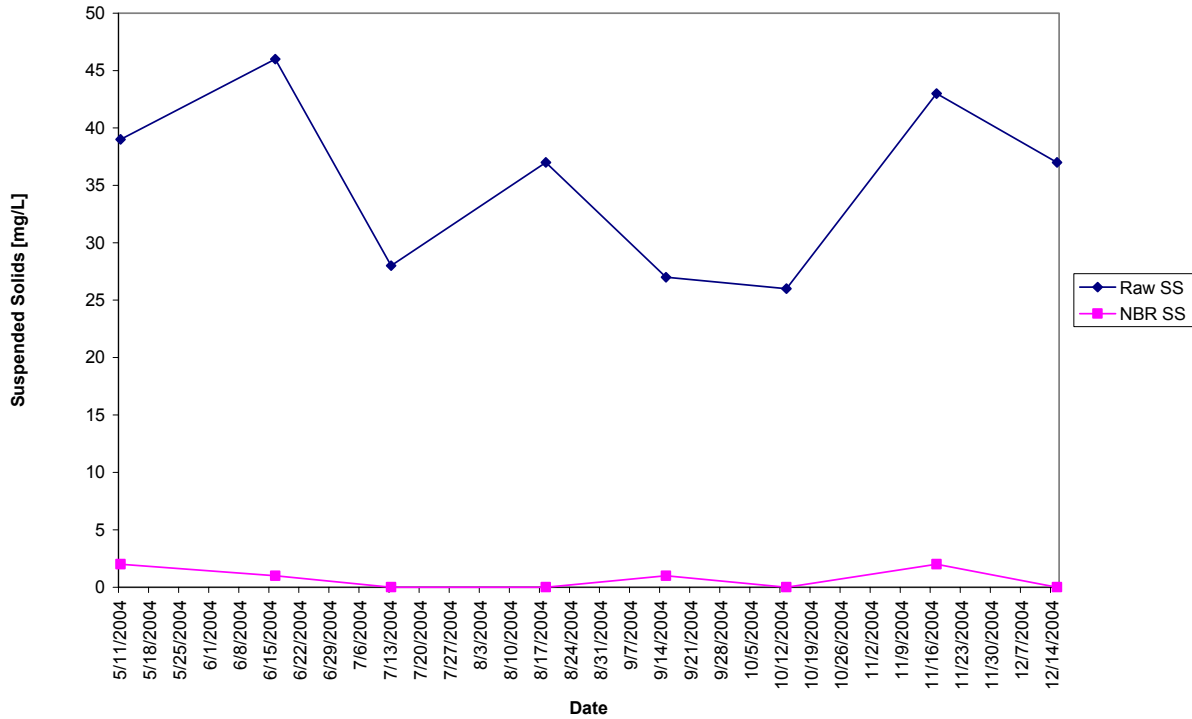
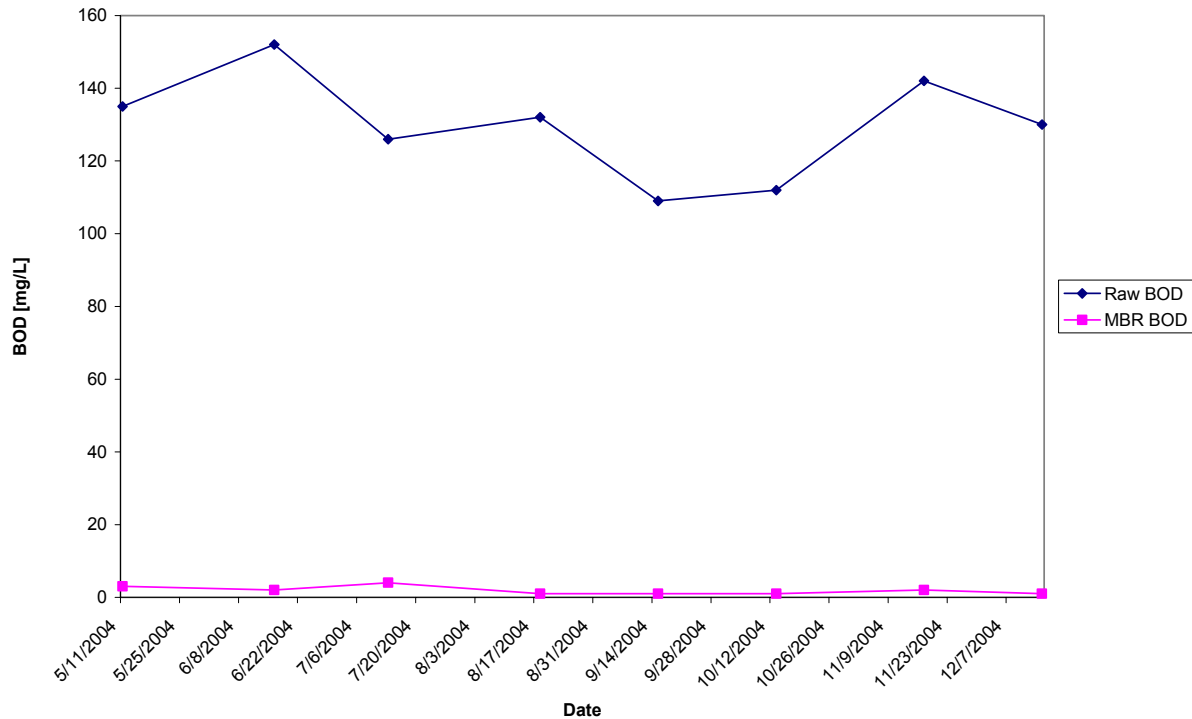


Figure 10: Buccoo MBR Results



Conclusion

Change was being mandated by conservation groups all over the Caribbean to preserve the Buccoo Reef. If the decline of the reef continued at the same pace it was currently going at, it was believed by many scientist that one of the crown jewels of the Caribbean had about a 10 year life expectancy. The Tobago House of Assembly (THA), which relies heavily on tourism with its main draw being the reef, took a stance to improve their sewage treatment. The sewage treatment plants had secondary treatment but the quality of the effluent was detrimental to the reef. BOD₅ and suspended solids levels leaving the plant were on average 63 and 16.5 mg/L respectfully.

THA and the Water and Sewage Authority (WASA) decided to retrofit the Bon Accord WWTP with a membrane bioreactor system. Bon Accord effluent is considered to have the largest negative effect on the Buccoo Reef. With the addition of the membranes the plant was only required to operate one of its two existing activated sludge basins and still handle the daily waste water flow. Improvement in effluent quality was on average 27% for suspended solids, 47% for BOD₅, and 80% for ammonia.

WASA was pleased with the operation of the MBR system at Bon Accord. They decided to retrofit the Buccoo WWTP as well. The Buccoo plant has a similar set-up to the Bon Accord plant with two existing circular activated sludge plants. Four

membrane modules were placed in one of the activated sludge tanks. Effluent processed through the membranes has also been of high quality with an average suspended solids discharge of 0.8 mg/L and BOD₅ of 1.9 mg/L. The higher quality of effluent discharged to the lagoon, which makes it way to the reef, will help ensure that the reef is there for many years to come.

References

1. Rojas, N. (2003). Sewage Killing Buccoo Reef – A Disappearing Coral Treasure. www.newsday.co.tt/stories.php?article_id=9613.
2. Wollard, C. and Sparks, M (2002). Membrane Treatment And Subsurface Discharge Of Water From A Seasonal Lodge In Alaska. Proceedings of the American Water Works Association Membrane Technology Conference (AWWA). Atlanta, GA