Dundee Wastewater Treatment Plant:
A Brief Examination

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1 Introduction

The Dundee wastewater treatment plant (WWTP), in Monroe County, Michigan serves the village of Dundee and its population of roughly 3,500 residents, processing 0.4-2.5 million gallon per day (MGD). The plant is located on the Raisin River, to which treated effluent is discharged. Effluent quality regulations are therefore governed by conditions in the Raisin River, based on studies performed periodically by the Michigan Department of Environmental Quality (MDEQ). A study in 2004 demonstrated dissolved oxygen (DO) values between four and five miles downstream of the Dundee plant were lower than acceptable (regulations require DO concentrations in sovereign waters to be above 5 mg/L, in order to protect aquatic life). Dundee, as the closest point source to the low values, was subsequently required to significantly lower its allowable effluent biochemical oxygen demand (BOD) and raise its effluent DO.

This change in regulations was unobtainable using the original sequencing batch reactor (SBR) system at the Dundee plant, requiring a significant upgrade. To accomplish the necessary increase in effluent quality, they selected to upgrade to a membrane bioreactor (MBR) system. MBRs can be defined as systems that integrate biological treatment of wastewater with membrane filtration techniques. They offer several advantages compared to conventional biological treatment systems, including improved biodegradation efficiency, higher loading rates, lower sludge production, improved effluent quality, and smaller plant size. Additionally, MBRs eliminate settling problems, which are often troublesome in wastewater treatment (Cicek, 2002), and are more automated, allowing for less operator monitoring. Disadvantages associated with MBRs are mainly cost related, due to expensive membrane units, frequent membrane cleaning, and high energy demands. The following report outlines the differences between the original and the upgrade as a comparative study.

2 Process Description

From 1988 until 2005, the secondary treatment unit of the Dundee Wastewater Treatment Plant operated as a sequential batch reactor (SBR) system. This system was then retrofitted to an MBR system in July of 2005, in order to comply with more stringent regulations. Both the former and current systems can be broken down into four basic stages. These are: 1) Preliminary treatment, 2) Secondary treatment, 3) Tertiary Treatment (disinfection and nutrient removal), and 4) Sludge treatment.

Figure 1 below provides a flow chart for the above treatment processes.

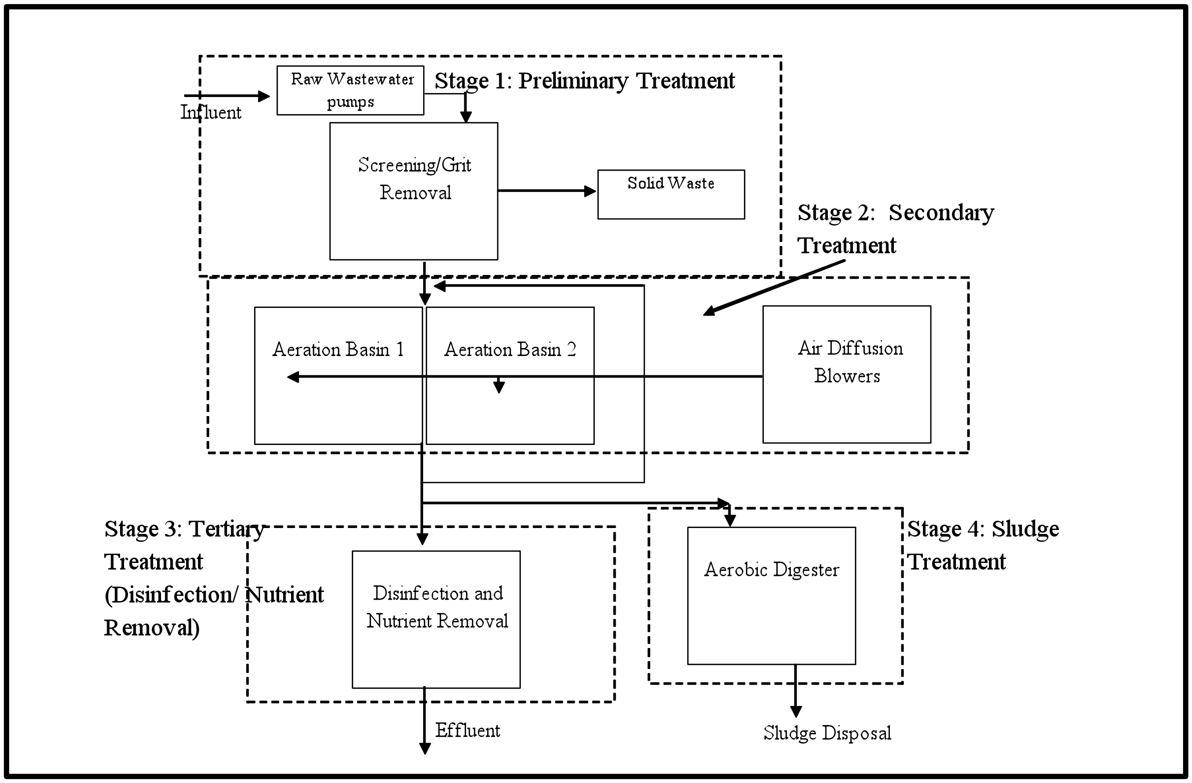

Figure 1. Process Overview

The processes above are broken down and described in more detail for old and new systems in the following sections.

2.1 Preliminary Treatment

2.1.1 SBR and MBR Systems

Both the old and current systems bring in wastewater in essentially the same manner, although the influent raw wastewater pumps have been upgraded to increase capacity. In this stage, three raw wastewater pumps send an average of 0.4 to 2.5 MGD into the "grit room". Once inside the grit room, the raw water is first passed through a 1/8" screen to remove large waste, then into a forced vortex grit chamber, where solid waste is forced to the bottom of the tank while water is allowed to pass. Every two hours, the solids at the bottom of the chamber are pulled out with air, and passed through a grit separator screen. The grits and solids from this process, approximately one-cubic yard per week, are loaded into a dumpster, which is emptied on a weekly basis and discharged to a landfill. Figures 2 - 5 contain a basic outline of this process, along with pictures of the actual equipment.

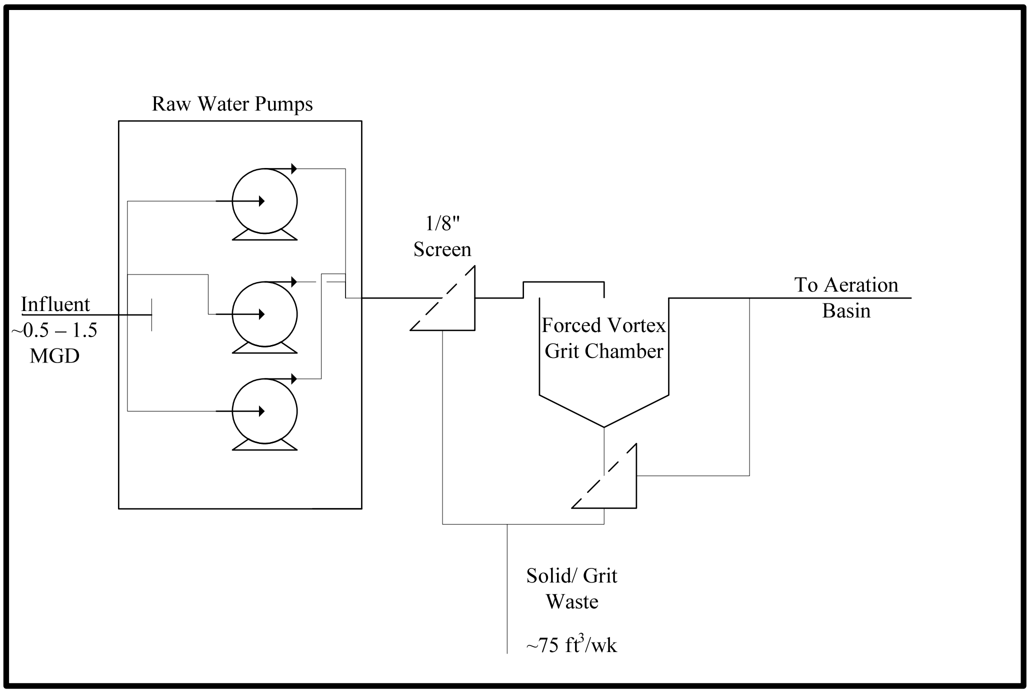

Figure 2. Preliminary Treatment

Figure 3. Raw Wastewater Pumps

Figure 4. Forced Vortex Grit Chamber

Figure 5. Solid Waste/ Grit

2.2 Secondary Treatment

2.2.1 SBR System (Former)

Secondary treatment in the original system was accomplished using a two tank SBR. After passing through the grit room, wastewater was pumped into two 375,000 gallon tanks. The system ran in four hour cycles: two hours of aeration, one hour of settling and one hour of decanting. The tanks ran in opposing cycles, so that while one was aerating, the other was settling. Mixing and aeration was accomplished using two blowers that fed coarse bubble diffusers. Because the tanks ran cyclically, there were both aerobic and anoxic periods, which may have accomplished some denitrification. Phosphorus removal is discussed in Section 4.1. Effluent proceeded to tertiary treatment for disinfection. A fraction of the activated sludge was sent to the aerobic digester for sludge treatment.

2.2.2 MBR System (Present)

The largest change in the Dundee Wastewater Treatment Plant was the addition of an MBR to accomplish secondary treatment. The grit room effluent is still pumped into the same tanks; however, the plant is currently using only one as an aeration basin. Light aeration maintains the other, inactive, basin by keeping it mixed. Originally the plant used both aeration basins, but the resulting hydraulic retention time (HRT) and solids retention time (SRT) were too long. According to the operator, the single basin maintains an HRT of 22 hours and SRT of about 36 days. Based on the estimated flow rates, these values seem rather large. The formulas for SRT (θ_x) and HRT (θ) for this system, being analogous to a continuous stirred reactor with a recycle stream, can be represented by Equations 1 and 2.

$$\theta x = \frac{V}{Q^W}\left(\frac{Q^W + Q^r}{Q + Q^r}\right) \qquad (1)$$

$$\theta = \frac{V + Vm}{Q} \qquad (2)$$

Where Q is the flow rate, Q^r is the recycle flow rate, and Q^W is the waste flow rate. Since the wastage rate is less than the feed rate, the maximum SRT according to Equation 1 would be V/Q^W. Given the maximum volume of the aeration basin and a wastage rate of typically 15,000 gallons per day (gpd), a conservative estimate places the SRT at about 25 days, which is still less than the quoted value. In Equation 2, where V represents the aeration basin volume and V_m is the membrane tank volume, in order to achieve an HRT of over 20 hours, the flow rate would have to be less than 0.45MGD (this may be reasonable at times), or the V_m would have to be greater than the aeration volume. This would seem to indicate that the given HRT is the upper limit of the current operation, and that the SRT is actually lower, unless the plant is wasting less than 10,000 gpd. Since the plant is actually wasting more than 15,000 gpd, due to clogging problems with the membranes, this is unlikely.

Optimal operation of the MBR requires that the mixed liquor is very well mixed. For this reason the aeration basin tanks run constantly. The coarse bubble diffusers were replaced with fine bubble diffusers to improve the mixing efficiency. Because the plant has been having trouble with biological fouling, it is even more important to keep the biomass in suspension and not allow it to settle into the membranes. Occasionally, a premixed polymer flocculating agent is added to improve the dispersion of the flocs and reduce membrane fouling.

Five permeate pumps pull the mixed liquor from the aeration basin through the membranes. The pumps run on a lead-lag system, and operate between 300 and 550 gallons per minute, depending on the aeration basin levels. There are a total of 17,600 flat sheet polyethylene membranes, evenly distributed among four tanks. Each tank has an upper and a lower level with 11 cassettes in each level. Each cassette houses 200 membranes. The mixed liquor runs between the membranes and is drawn through the membrane pores, which are manufactured at 0.4 µm. However, during operation pore diameter is closer to 0.1 µm, due to biofilm growth. For further detail, see Section 4.2. Membranes are constantly cleaned by air diffusers, which pump air between the membranes. These air bubbles not only scour the membranes, but also provide constant mixing, and supply oxygen to the biomass (Enviroquip, 2005). Additional cleaning is done by flushing the membranes with a 1% sodium hypochlorite solution. When the system is running well, chemical cleanings are only required every four to six months.

Membrane permeate goes to tertiary treatment before discharge. The membrane retentate is activated sludge, which is split between the waste activated sludge (WAS) and return activated sludge (RAS) lines which transport concentrated liquor via three large pumps. Typically, over 15,000 gpd of WAS is generated, and the RAS flow is much larger than that of the WAS. Figures 6 - 8 contain pictures of the MBR system diagram, the membrane, and plant photos.

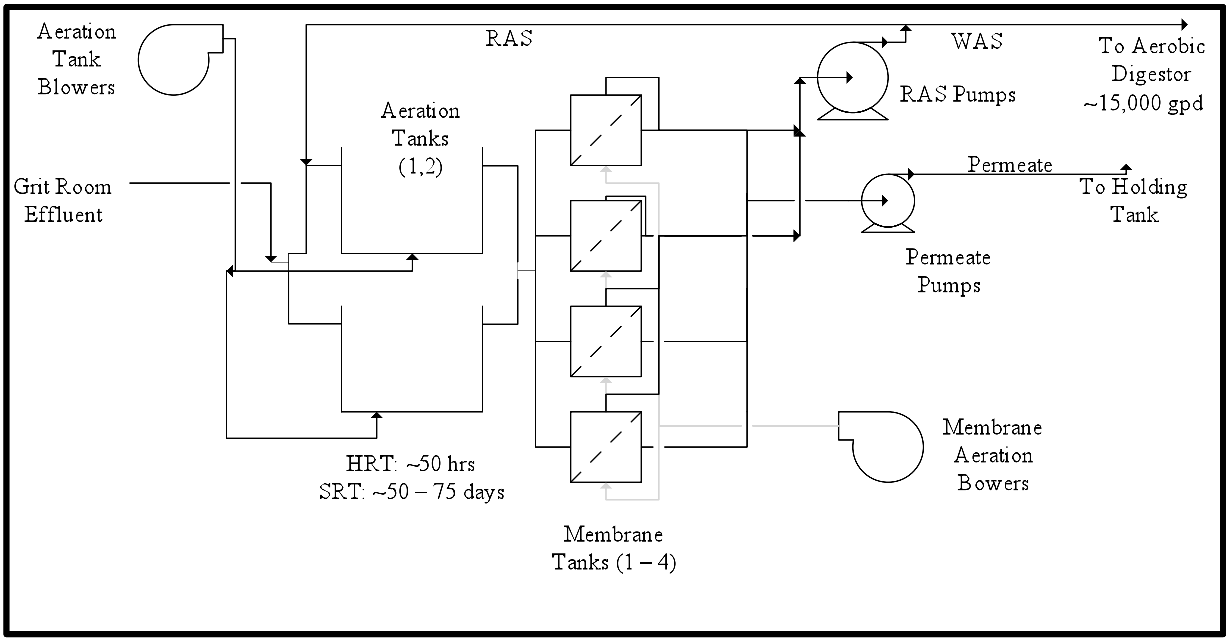

Figure 6. Current Secondary Treatment with MBRs

Figure 7. Aeration Basins

Figure 8. Membrane Tank

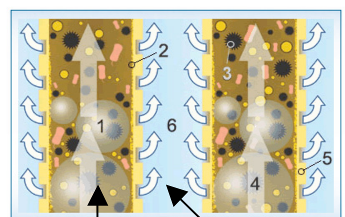

Figure 9. Active Membrane Diagram [picture from Enviroquip, text added]

2.3 Tertiary Treatment (Disinfection/ Nutrient Removal)

2.3.1 SBR System (Former)

The effluent from the previous SBR system was dosed with chlorine gas to provide disinfection for removal of fecal coliforms. A contact tank with baffles provided approximately 30 minutes of contact time. Prior to discharge, the effluent was purged with sulfur dioxide for dechlorination, and allowed to flow over cascade steps in order to increase DO.

2.3.2 MBR System (Present)

The current system employs the same contact tank and cascade steps as the previous system. However, because the membrane bioreactors are much better at removing contaminants and bacteria, chlorination is not required. As a result, dechlorination is also no longer required during tertiary treatment. Sufficient phosphorus removal is not accomplished in the membrane system, so alum is added as needed, usually on the order of 40 gpd.

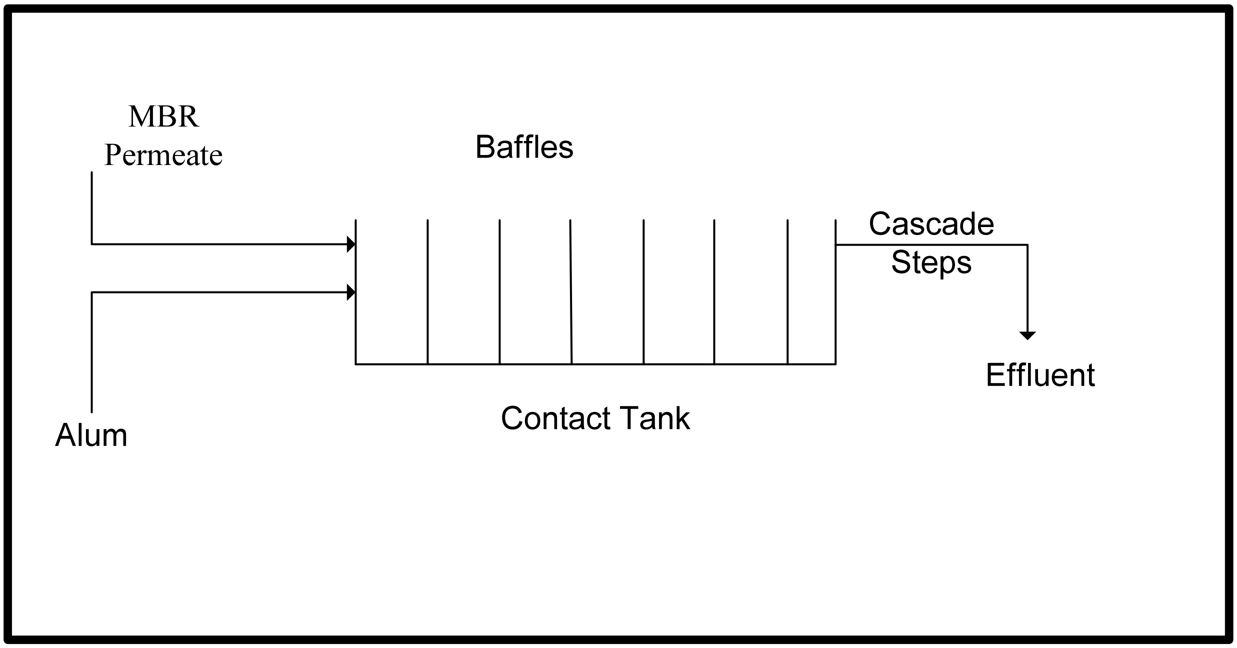

Figure 10. Tertiary Treatment (Disinfection and Nutrient Removal)

Figure 11. Alum Storage Tank

Figure 12. Contact Tank

Figure 13. Effluent Flowing Down Cascade Steps

2.4 Sludge Treatment

2.4.1 SBR System (Former)

In the previous system, the WAS was sent to two open digester basins. The basins were filled during the day, when they were mixed with coarse bubble diffusers, then at night were allowed to settle. The supernatant from the basins was removed each morning, and sent back through the system. The solids concentration of the digested sludge was about 1.5 to 2%. The solids were dewatered with a belt press and in a drying bed prior to hauling, which took place a few times each year. Solids were removed by truck, and used as fertilizer in surrounding farms. There are several regulations for land application that can be found in the document entitled Land Application of Biosolids (Michigan Department of Environmental Quality Surface Water Quality Division, 1999). The major regulations are for heavy metals, pH, pathogens, and the application location.

2.4.2 MBR System (Present)

The new system also uses aerobic digestion for sludge treatment, though some adjustments have been made. A secondary membrane system, with 800 flat sheet polyethylene membranes in four cassettes, has been added to thicken the sludge. The old system lacked enough storage volume to retain digested sludge throughout the winter. Two sludge pumps and two thickening pumps cycle the water through the two tanks and MBRs. The thickening pumps discharge about 13 gpm of permeate, which is returned to the head of the plant. The thickener retentate keeps cycling through the basins, and maintains concentrations of about 3 - 4% solids. Two blowers are used to supply air to the membranes and one blower mixes the sludge. Also, one of the tanks is now covered, in order to maintain temperatures in the winter that prevent freezing. When the sludge is ready for hauling, it can be removed directly, using a newly added pump. Figures 14 - 17 contain pictures of the sludge treatment system.

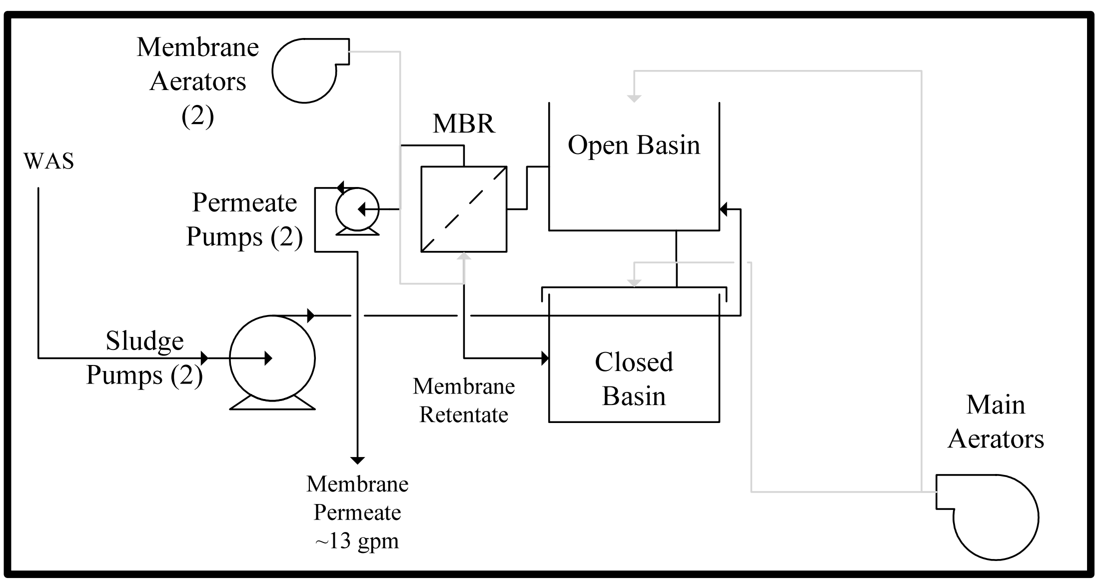

Figure 14. MBR Sludge Treatment

Figure 15. Open Aerobic Digester

Figure 16. Closed Aerobic Digester

Figure17. Sludge Removal Pump

3 Influent and Effluent Concentrations and Regulations

3.1 Influent Conditions and Effluent Federal Regulations

The influent to the Dundee WWTP has an average of 175 mg/L of BOD_5, 134 mg/L of suspended solids, 20.1 mg/L of ammonia nitrogen as N (NH_4-N), 2.9 mg/L of total phosphorus, and a pH of 7.8. The NH_4-N concentration can vary based on inflow and infiltration. When there is a heavy rainfall, extraneous water significantly dilutes the NH_4-N concentration.

Effluent regulations are provided by the National Pollutant Discharge Elimination System (NPDES) Permit, which is a plant-specific federal regulation implemented by the United States Environmental Protection Agency (EPA). Administration of the Dundee WWTP permit falls to the MDEQ, and is contingent on case studies of the Raisin River and discharges thereto. A copy of the permits for both the new and old systems can be found in Appendices 1A and 1B.

3.1.1 Former Regulations (SBR System)

The SBR did not have such stringent effluent quality regulations as the new MBR system. The effluent limitations for the SBR and MBR are summarized in Table 1. The permit includes seasonal regulations for carbonaceous biochemical oxygen demand ($CBOD_5$), total suspended solids, NH_4-N, and DO.

During the summer season, May 1-September 30, the SBR was allowed to have a monthly $CBOD_5$ of 9-12 mg/L, total suspended solids of 26 mg/L, and a DO of 5 mg/L. The regulation for NH_4-N was a daily limit of 4.9 mg/L.

During the winter season, October 1- April 30, the maximum monthly levels of $CBOD_5$, total suspended solids, and DO were 25, 30, and 3 mg/L respectively, and the daily NH_4-N was 3 mg/L. There was also a required minimum percent removal of $CBOD_5$ and total suspended solids of 85% monthly during this period.

Daily limits for total residual chlorine and acute toxicity were 0.0038 mg/L and 1 TU_A. The monthly limit for chronic toxicity was 8.1 TU_C. The monthly total phosphorus limitation was 1 mg/L, and the maximum allowable counts for fecal coliform bacteria were set at 200/100 ml. Finally, the minimum and maximum daily pH were 6.5 and 9.0, respectively.

3.1.2 Current Regulations (MBR system)

The current MBR system is subject to many of the same effluent regulations that were in effect for the previous system, though it is interesting to note that the requirements were increased upon installation of the MBR. The important differences are for the period of May 1-September 30. The monthly $CBOD_5$ regulation is 4.0 mg/l, the total suspended solids is 20 mg/L, and the DO is 6 mg/L. Also, the daily NH_4-N was lowered to 2.0 mg/L, with a 0.5 mg/L maximum monthly concentration. The $CBOD_5$, total suspended solids, and NH_4-N are lower, and the DO level was raised on the permit that took effect on August 1, 2005. The monthly chronic toxicity level was also lowered in the new permit to 4.9 TU_C.

Table 1. Final Effluent Limitations for SBR and MBR Systems

	SBR		MBR		
Parameter	**Monthly**	**Daily**	**Monthly**	**Daily**	**Units**
$CBOD_5$ May 1-Sept 30 October 1-April30	9.0-12 25	----	4.0 25	----	mg/L
Total SS May 1-Sept 30 October 1-April30	26 30	----	20 30	----	mg/L
Dissolved Oxygen May 1-Sept 30 October 1-April30	5.0 3.0	----	6.0 3.0	----	mg/L
Ammonia Nitrogen-N May 1-Sept 30 October 1-April30	4.9 3.0	----	0.5 3.0	2.0 ----	mg/L
$CBOD_5$ % Removal	85	----	85	----	%
Total SS % Removal	85	----	85	----	%
Total Residual Chlorine	----	0.0038	----	0.0038	mg/L
Acute Toxicity	----	1.0	----	1.0	TUA
Chronic Toxicity	8.1	----	4.9	----	TUC
Total Phosphorus-P	1.0	----	1.0	----	mg/L
Fecal Choliform Bacteria	200	----	200	----	cts/100ml
pH		6.5 min 9.0 max		6.5 min 9.0 max	S.U.

3.2 Effluent Quality

3.2.1 Former Effluent Information (SBR System)

Effluent quality data was obtained for the SBR during the first six months of 2005 (January-June), and for the MBR during the rest of 2005 (June - Dec), and is provided in Table 2. The plant had an average $CBOD_5$ concentration of 11.9 mg/L, which is very close to the 12 mg/L limit. In addition, the average $CBOD_5$ removal was 86.3%, which is near the 85% minimum limit. The average total suspended solids were 15.9 mg/L, with an average of 76.1% removal. The average NH_4-N was about 6 mg/L. Finally, the average phosphorus and DO levels were 0.77 and 7.9 mg/L, respectively.

3.2.2 Current Effluent Information (MBR System)

For the MBR, the average $CBOD_5$ was 0.9 mg/L with 99.6% removal. The average total suspended solids was 0.4 mg/L, with a 99.7% removal, and the average NH_4-N was 0.55 mg/L. The total phosphorus was 0.42 mg/L, while the DO was 8.2 mg/L. The plant is now obtaining much lower concentrations and higher percent removals for $CBOD_5$ and total suspended solids. There has also been an increase in the DO level, compared to the SBR.

3.2.3 Comparison

In summary, there were drastic improvements in the effluent quality in the MBR system. The differences in effluent quality for the SBR compared to the MBR are shown in Table 2, below. Despite seasonal variation, it is evident that the MBR is a significant improvement.

Table 2. Key Differences in Effluent Quality for SBR vs. MBR System

Parameter	SBR	MBR
$CBOD_5$ mg/L	11.9	0.9
$CBOD_5$ % Removal	86.3	99.6
SS mg/L	15.9	0.4
SS % Removal	76.1	99.7
Ammonia Nitrogen-N	6.0	0.55
Total Phosphorus-P mg/L	0.77	0.42
Dissolved Oxygen mg/L	7.9	8.2

4 System Advantages, Disadvantages, and Potential Upgrades

4.1 SBR System (Former)

One of the main advantages of the SBR System was that it provided excellent phosphorus removal. Typically, SBRs will not select for phosphorus accumulating organisms (PAOs), however, this system accomplished PAO selection by the addition of a baffle separating the influent from the completely mixed aeration basin. The separated region provided an area with low DO concentrations, but which still had organic compounds, some of which could be used by PAOs. This, along with the relatively short HRTs in the SBR, created an environment wherein phosphorus removal was accomplished.

A considerable disadvantage of the SBR, however, was that the effluent required disinfection following secondary treatment. Dundee accomplished this by using chlorine gas, a dangerous chemical agent, which required strict safety protocols on the part of the operators. Dechlorination was also required, for which they used sulfur dioxide. The use of chemicals is always a disadvantage, because it represents an increase in operating costs, as well as a departure from natural solutions. In particular, chlorine is becoming more of a problem because of new regulations on chlorine byproducts.

A less momentous, but still noteworthy disadvantage of the SBR was that the sludge treatment operation required significant daily attention. Drawing off the supernatant required the operators to monitor the sludge at half hour intervals throughout the morning. Additionally, once the digesters began to fill, sludge had to be removed and dewatered, then placed in drying beds, before it could be removed for land application.

The most critical drawback of the SBR was that meeting the new effluent standards would have required more than doubling the size of the current reactors, a process that would have required a significant increase in the footprint of the wastewater treatment plant.

4.2 MBR System (Present)

Perhaps the most important advantage of the MBR is that the effluent quality not only meets all of the regulations for ammonia removal, CBOD, and TSS, but it also does not require disinfection. Any fecal coliforms in the system are removed by the membranes. Therefore, by association, dechlorination is also not required. With no increase in plant size, the MBR meets all of the regulations except phosphorus removal, and eliminates the chemicals required in SBR treatment, along with the safety hazard that results from the use of chlorine gas.

Because the MBR does not meet the phosphorus regulation, alum is added to precipitate phosphorous after secondary treatment. Therefore, while the original chemicals used in the SBR have been removed, another chemical has been added, making the improvement less significant than it might have been.

An additional benefit of the MBR is that membranes have also been added to sludge treatment. Now, rather than relying on settling and siphoning off supernatant, the sludge is constantly run through the thickener, which sends thickener permeate to the head of the plant and thickener retentate to the aerobic digesters. Because everything is automated, there is little need for constant operator attention in sludge removal. Also, the sludge is now removed as a liquid, rather than being dewatered and placed in drying beds before land application, which further simplifies the process.

The major problems with the membrane upgrade are caused by fouling. Kubota membranes come with a pore diameter of 0.4 μm, but are designed so that biomass growth will reduce the pores to an effective 0.1 μm size. Therefore, a certain amount of biofilm is expected, and even desirable, but an excess of biofilm growth can clog the pores entirely. Membrane fouling can be caused either by this overabundance of biomass, or by mineral buildup on the membranes, both of which obscure membrane pores. Either problem is usually rectified by occasional chemical flushes, typically once or twice a year. A 1% sodium hypochlorite solution treats biomass overgrowth, while a 1% citric acid solution alleviates mineral accumulation.

It became evident shortly after installation that the membranes were fouling. Because the water in Dundee is supplied from Lake Eerie, Enviroquip assumed that there should be no problems with mineral deposits in the Dundee plant. Therefore, in order to solve the fouling problem, the plant began flushing the membranes with a 1% sodium hypochlorite solution. Due to the frequent recurrence of the problem, the plant has used the cleaning solution every two months since the membranes were installed. Recently, the membrane racks were removed for cleaning, at which point mineral deposits were observed on the membrane surfaces. This means that the plant will also have to add flushes of 1% citric acid. However, it is possible that the fouling problems will be resolved by using the proper chemicals, because the problem was related to mineral deposits, rather than to biomass.

As a result of the membrane fouling, the plant is forced to treat a lower quantity of water than it is capable of treating, making the current plant maximum capacity 3.3 MGD instead of the 4.0 MGD possible with the new raw wastewater pumps. Additionally, Enviroquip suggested that they lower the Mixed Liquor Suspended Solids (MLSS), which means that they are wasting a higher volume, and therefore producing more sludge.

Another disadvantage of the MBR system is that there is an increased energy demand due to additional sets of blowers. The MBR tanks have a minimum aeration requirement to keep the solids in motion, and from fouling the membranes. The superintendent mentioned that the energy costs at the Dundee plant have increased significantly since installation of the MBR.

4.3 Comparison

Keeping the SBR would have required more than doubling the size of the current plant (to treat the same quantity of wastewater). The MBR has some problems, but the enhanced effluent quality requires only minimal chemical addition. Not only is the effluent improved, but the safety hazards at the plant have been significantly reduced. Table 3 summarizes the advantages and disadvantages of both systems.

Table 3. Overview Comparison of SBR to MBR

SBR		MBR	
Advantages	Disadvantages	Advantages	Disadvantages
excellent nutrient removal	fecal coliform removal accomplished by disinfection with chlorine	fecal coliform removal accomplished through membrane filtration	nutrient removal accomplished by adding alum
	dechlorination required, sulfur dioxide	no dechlorination required post-treatment	membranes clog, requiring periodic chemical cleanings
	sludge treatment requires constant daily attention	sludge treatment requires little daily attention	fouling potential requires lower treatment volumes than overall system capacity
	meeting new regulations requires doubling original size of plant	improved thickening of sludge compared to SBR	increased energy demands
		meeting new treatment regulations requires no increase in plant size	

5 Conclusions

In short, the only advantages of the SBR system are its ability to remove phosphorus, and its low operational cost. Compared to the improvements from the membrane system, in particular the effluent quality, the removal of phosphorus could be considered insignificant. Not only has effluent quality improved, but it has become more consistent, both on a daily basis, and from season to season. In addition, there is no longer the safety hazard associated with chlorine gas.

The plant has experienced problems with fouling, which limits treatment capacity. Additionally, the requirement for additional blowers has resulted in increased energy costs. However, once they gain more experience with the new system, these problems can be minimized. Additionally, the sludge produced by the MBR is notably more concentrated, which decreases waste disposal costs. Overall, it seems that the problems with the MBR are minimal compared to the advantages gained by the exchange, and that such problems will fuel further studies of the emerging MBR technology.

6 Reference List

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