APPENDIX E

NPDES PERMIT APPLICATION

Form Approved. OMB No. 2040-0086. Approval expires 8-31-98.

Please print or type in the unshaded areas only	EPA I.D. NUMBER (*copy from Item 1 of Form 1*)	

Form **2D** NPDES

New Sources and New Dischargers Application for Permit to Discharge Process Wastewater

I. Outfall Location

For each outfall, list the latitude and longitude of its location to the nearest 15 seconds and the name of the receiving water.

Outfall Number (*list*)	Latitude			Longitude			Receiving Water (*name*)
	Deg.	Min.	Sec.	Deg.	Min.	Sec.	

II. Discharge Date (When do you expect to begin discharging?)

III. Flows, Sources of Pollution, and Treatment Technologies

A. For each outfall, provide a description of: (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and storm water runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

Outfall Number	1. Operations Contributing Flow (*List*)	2. Average Flow (*Include Units*)	3. Treatmer (*Descrip on or List codes from Table 2D-1*)
r			

B. Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item III-A. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined (e.g., for certain mining activities), provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

C. Except for storm runoff, leaks, or spills, will any of the discharges described in Items III-A be intermittent or seasonal?

☐ YES (*complete the following table*) ☐ NO (*go to Section IV*)

Outfall Number	1. Frequency		2. Flow		
	a. Days Per Week (*specify average*)	b. Months Per Year (*specify average*)	a. Maximum Daily Flow Rate (*in mgd*)	b. Maximum Total Volume (*specify with units*)	c. Duration (*in days*)

IV. Production

If there is an applicable production-based effluent guideline or NSPS, for each outfall list the estimated level of production (projection of actual production level, not design), expressed in the terms and units used in the applicable effluent guideline or NSPS, for each of the first 3 years of operation. If production is likely to vary, you may also submit alternative estimates (attach a separate sheet).

Year	A. Quantity Per Day	B. Units Of Measure	c. Operation, Product, Material, etc. (*specify*)

CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA I.D. NUMBER (*copy from Item 1 of Form 1*)	Outfall Number

V. Effluent Characteristics

A and B: These items require you to report estimated amounts (*both concentration and mass*) of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*

CONTINUED FROM THE FRONT	EPA I.D. NUMBER (*copy from Item 1 of Form 1*)	Outfall Number
	Liberty Drilling and Production Island	Outfall 002b,002c, and 002d

V. Effluent Characteristics

A and B: These items require you to report estimated amounts (*both concentration and mass*) of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*
Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
Outfall 002b - STP solids slurry			Intermittant flow
TSS	120,100 mg/L	varies	Based on 1 flush per day (by itself), 30 mg/L TSS influent.
Temperature (winter)	15 deg C	2 deg C	Data from similiar plants
Temperature (summer)	25 deg C	10 deg C	Data from similiar plants
TRC	250 ug/L	125 ug/L	Data from similiar plants
Outfall 002c - STP strainer backwash			
TSS	41,600 mg/L	varies	Based on 6 flushes per day, 30 mgL TSS influent.
Temperature (winter)	15 deg C	2 deg C	Data from similiar plants
Temperature (summer)	25 deg C	10 deg C	Data from similiar plants
TRC	250 ug/L	125 ug/L	Data from similiar plants
Outfall 002d - WTP media backwash -	-	-	Intermittant flow
TSS	3,200 mg/L	varies	Based on 1 flush per day, 30 mg/L TSS influent
Temperature (winter)	15 deg C	2 deg C	Data from similiar plants
Temperature (summer)	25 deg C	10 deg C	Data from similiar plants
TRC	250 ug/L	125 ug/L	Data from similiar plants

CONTINUED FROM THE FRONT	EPA I.D. NUMBER (*copy from Item 1 of Form 1*)	

C. Use the space below to list any of the pollutants listed in Table 2D-3 of the instructions which you know or have reason to believe will be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it will be present.

1. Pollutant	2. Reason for Discharge

VI. Engineering Report on Wastewater Treatment

A. If there is any technical evaluation concerning your wastewater treatment, including engineering reports or pilot plant studies, check the appropriate box below.

☐ Report Available ☐ No Report

B. Provide the name and location of any existing plant(s) which, to the best of your knowledge resembles this production facility with respect to production processes, wastewater constituents, or wastewater treatments.

Name	Location

CONTINUE ON NEXT PAGE

EPA I.D. NUMBER (*copy from Item 1 of Form 1*)

VII. Other Information *(Optional)*

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations for the proposed facility. Attach additional sheets if necessary.

A description and map of the facility including the point and non-point source discharges for which an individual permit is being requested is attached to this form (Attachment 1). Additional details about the proposed Liberty Development are provided in Attachment 1 and the Development and Production Plan.

VIII. CERTIFICATION

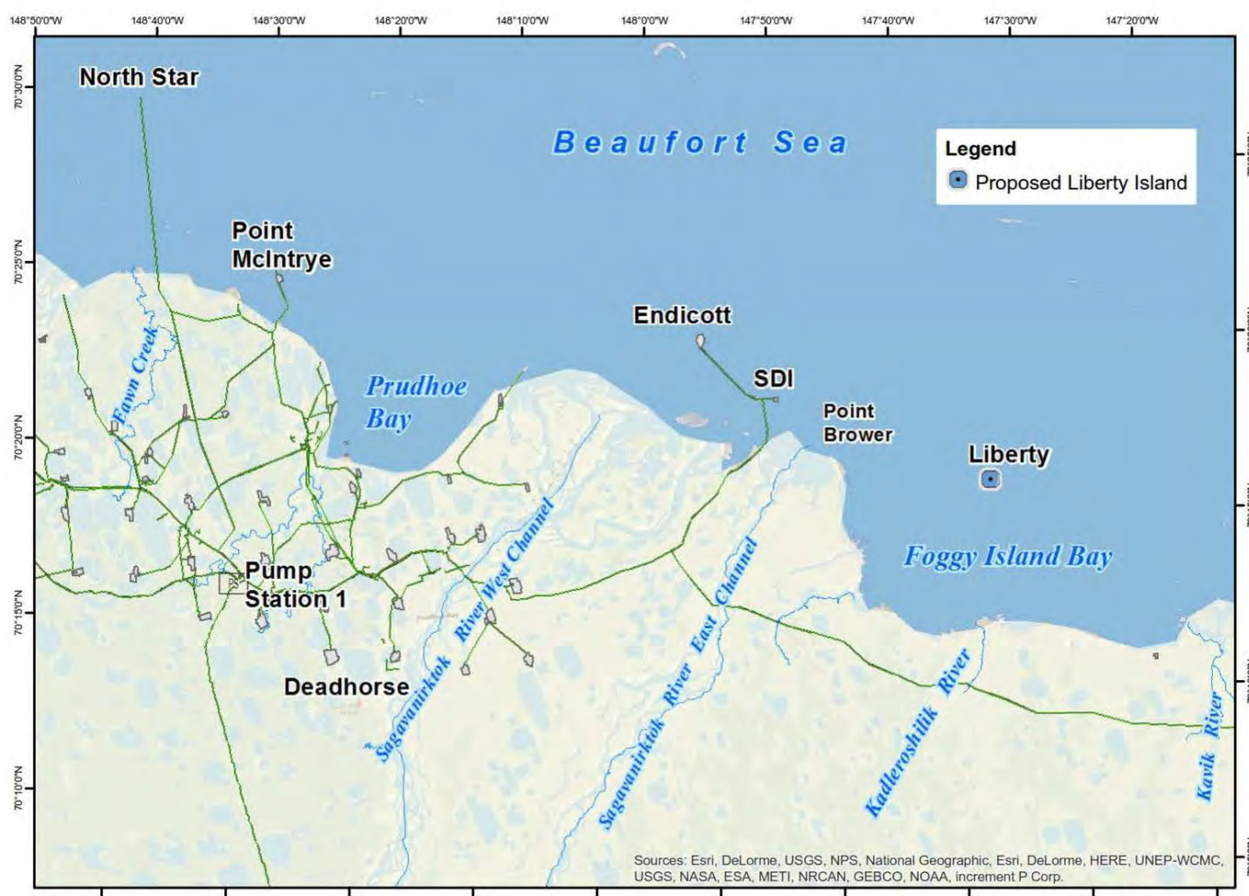
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title (*type or print*)	B. Phone No.
John A. Barnes, North Slope Asset Team Leader	(907) 777-8300
C. Signature [signature]	D. Date Signed 4 September 2015

Attachment 1
Liberty Development Project

Hilcorp Alaska, LLC (HAK) as the Liberty Operator submitted a Development and Production Plan (DPP) to the U.S. Department of the Interior (USDOI) Bureau of Ocean Energy Management (BOEM) in September 2015 (Revision 2). That DPP is referenced for detailed project information, including a list of other permits required for Liberty Development (DPP Section 15.4). When developed, Liberty would be the first field to produce hydrocarbons from a reservoir located entirely from federal leases of the Outer Continental Shelf (OCS) of the U.S. Arctic Ocean.

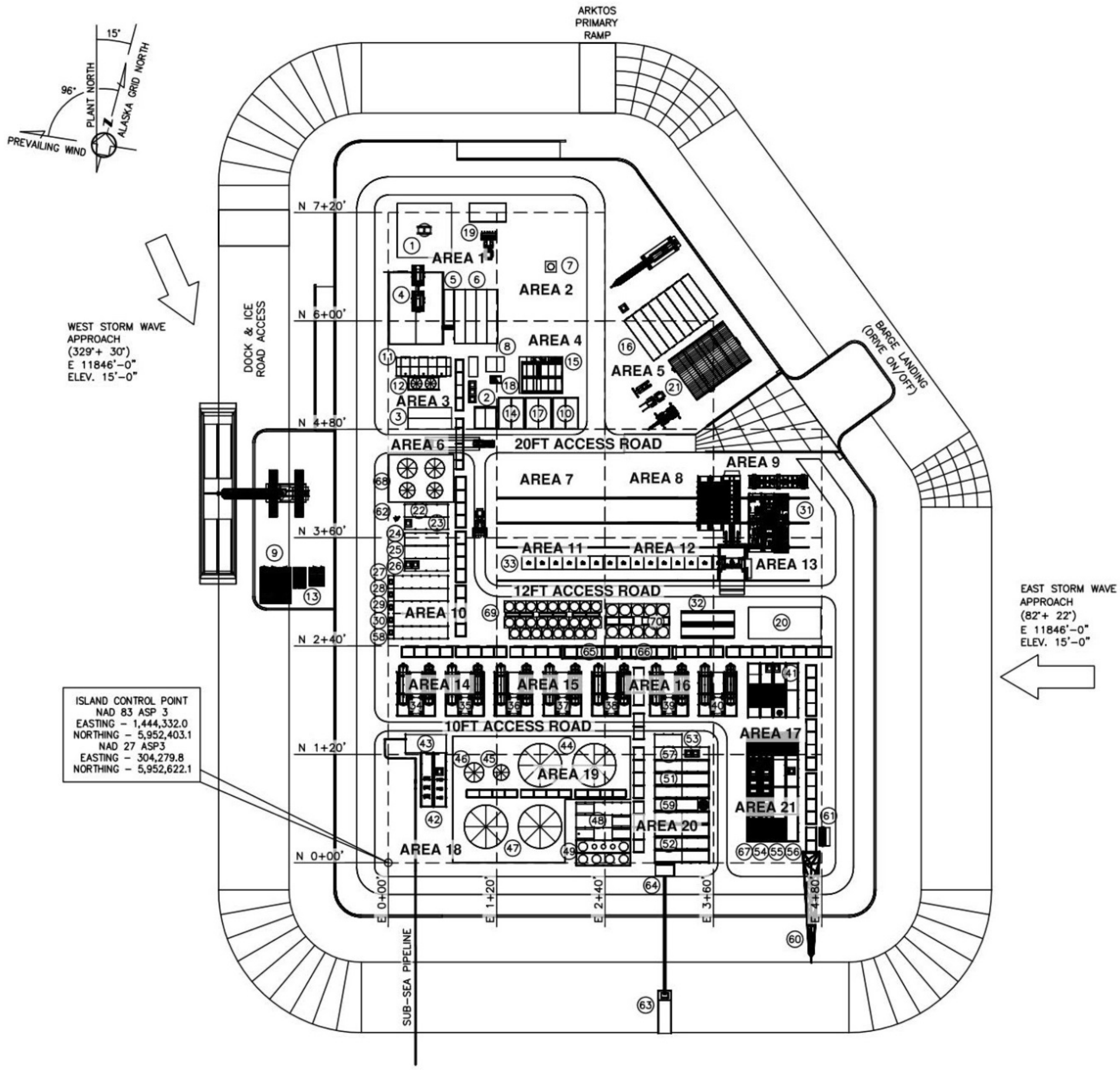
The proposed Liberty Development includes the Liberty Drilling and Production Island (LDPI) which will be constructed of reinforced gravel in 19 feet of water about 5 miles offshore in Foggy Island Bay of the Beaufort Sea OCS. Process facilities on the island will separate crude oil from produced water and gas. Gas and water will be injected into the reservoir to provide pressure support and increase recovery from the field. A single-phase subsea pipe-in-pipe pipeline will transport sales quality crude from the LDPI to shore, where an above ground pipeline will transport crude to the existing Badami pipeline. From there, crude is transported to the Endicott Sales Oil Pipeline, which ties into Pump Station 1 of the Trans-Alaska Pipeline System (TAPS) for eventual delivery to a refinery. The general location of the Liberty Development is shown in the two figures below: a North Slope overview and a location map.



Proposed Liberty Project
North Slope Overview
Figure 1

Proposed Liberty Pipeline Route
Figure 2

Following is a preliminary schematic of the LDPI layout. The domestic wastewater treatment plant (WWTP) is currently planned for location in Area 3. It is anticipated that the WWTP outfall (001) will discharge to the Beaufort Sea somewhere in close proximity to the WWTP. Additional engineering will determine the WWTP outfall's exact location and design.



The seawater treatment plant (STP) and the potable water treatment plant (WTP) are currently planned for location in Area 19. It is anticipated that the STP and WTP outfall (002 a-d) will discharge to the Beaufort Sea in close proximity to the STP. Additional engineering will determine the STP outfall exact location and design.

The plan is to inject domestic wastewater effluent, down a permitted well for disposal once the well becomes operational. The disposal well will be the first well drilled. The injection well location has not been finalized, but the production, injection, and disposal wells will be in Areas 12 and 13. Discharge under a National Pollutant Discharge Elimination System (NPDES) permit is requested as a contingency for disposal until the disposal well is operational (planned) or if the well is not available (e.g. undergoing maintenance or testing) in the future (unplanned).

Final plant design and vendor for the WWTP, WTP, and STP have not been determined at this time. Upon selection of vendors for each plant type, vendors will verify or update plant processes and the effluent characteristics provided in Form 2D.

Sources of information for Form 2D included:

- Draft NPDES Permit# AK-005314-7, Liberty Project, 2001
- Alaska Pollutant Discharge Elimination System (APDES) Permit# AK-0053694, ExxonMobil's Pt. Thomson Development, North Slope, Alaska
- U.S. Environmental Protection Agency (EPA) NPDES permit file# AK-0052779, BPXA's Northstar Development, North Slope, Alaska
- General APDES Permit #AKG-33-1 000, North Slope General APDES Permit for Facilities Related to Oil and Gas Extraction

The proposed effluent discharges are typical discharges on the North Slope. As noted above, design of the three treatment plants has not been completed. A general description of the treatment processes and expected effluent s are provided below.

Sanitary Wastewater Treatment Effluent - Discharge 001

The proposed treatment process for domestic sanitary wastewater is membrane bioreactor (MBR) technology. This secondary treatment technology is described in the attached EPA Wastewater Management Fact Sheet: Membrane Bioreactors (Attachment 2). Final engineering decisions have not yet been made, but based on the 2000 plan, it is assumed that disinfection will be by ultraviolet irradiation with no chlorination. The high-quality effluent produced by MBRs makes them particularly applicable for surface water discharge into marine wildlife habitat areas.

Potable Water Treatment - Discharge 002a

The proposed treatment process for desalination for the production of potable water is vapor compression distillation – a treatment technology permitted by EPA in 1999 for use at Northstar (NPDES Permit AK-005277-9). This process was also proposed for the Liberty Development in 2000 – a project nearly identical to that described in the December 2014 DPP. This, and other proposed discharges were considered in an Ocean Discharge Criteria Evaluation (ODCE), NPDES Permit Fact Sheet and Draft NPDES permit prepared at that time (NPDES Permit AK-005314-7), and were published in the Draft EIS. Both the Liberty and Northstar NPDES permit files are referenced for additional information and general plant schematics for the vapor compression process.

Vapor compression technology is used to generate potable water from seawater. The excess feed water that does not evaporate (blowdown) contains concentrated dissolved solids and salts (brine) near twice the concentration of ambient seawater. The resulting brine blowdown will be routed to marine outfall 002. Continuous injection of maintenance chemicals, which are safe for drinking water, will be added during the process. Periodic injection of sulfuric or sulfamic acids will remove mineral buildup in the desalination facility. Chlorine that enters the desalination unit will be off-gassed and vented into the atmosphere. Thus, it is expected that the desalination blowdown or brine will not contain residual chlorine.

Seawater Treatment Plant (STP) Effluent - Discharges 002b-d.

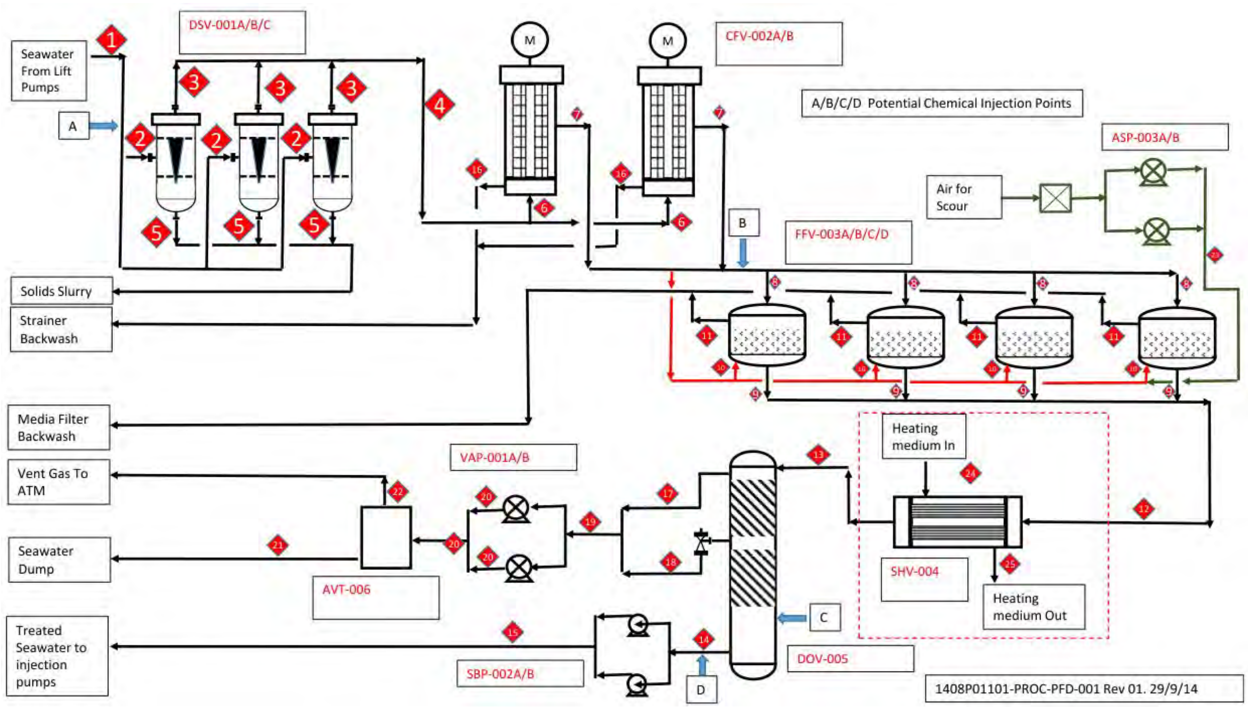
The proposed STP is similar in general function, but slightly different from that proposed in 2000, as described below.

The wastewater effluent stream from the STP will carry primarily concentrated total suspended solids (TSS) that have been removed from the raw seawater, a small temperature increase, and low concentrations of total chlorine residual, similar to STP discharges at other North Slope operating areas. The desander, coarse strainer, and fine filters will produce liquid effluent streams that contain the solids removed from the sea water and a small volume of sea water to transport the solids to the disposal point. The unit operations have been designed to minimize the frequency of backwashing / flushing, however, the ultimate frequency for backwash is a function of the solids loading in the feed to the system. If there is high solids loading due to sand being sucked into the pump pit (storm conditions) or there is a high concentration of organic material (e.g. algal bloom) the backwash frequency may increase and the discharge concentration of TSS will also increase. Assuming all of the incoming seawater solids (30 mg/L) are removed, the daily average discharge rate is expected to be < 1.0 MGD, and the average effluent TSS concentration is expected to be approximately 15,000 mg/L. Additional characteristics of the expected effluent are provided in Form 20.

The design of the system is such that disposal of residual chemicals is minimized. There will be an amount (yet to be determined) of sodium hypochlorite discharged directly to sea during backwash of the coarse and fine filters and possibly some biocide and scale inhibitor depending on final selection of dosing points. Chemical dosing will be considered in detail during detailed design since it typically has the largest direct environmental impact on water flood system design.

A generalized plant schematic is provided on the next page.

Other proposed waste streams: stormwater (Outfall 003), construction dewatering (Outfall 004), secondary containment dewatering (Outfall 005), and hydrostatic test waters (Outfall 006) will be similar to those described by EPA in the Fact Sheet associated with the EPA General Wastewater Discharge Permit for Facilities Related to Oil and Gas Extraction on the North Slope (AKG-33-0000) and subsequent AKG-33-1000 (currently issued under the State of Alaska APDES program).



Seawater From Lift Pumps
A
DSV-001A/B/C
CFV-002A/B
A/B/C/D Potential Chemical Injection Points
ASP-003A/B
Air for Scour
B
FFV-003A/B/C/D
Solids Slurry
Strainer Backwash
Media Filter Backwash
Vent Gas To ATM
Seawater Dump
Treated Seawater to injection pumps
VAP-001A/B
AVT-006
SBP-002A/B
Heating medium In
SHV-004
Heating medium Out
C
D
DOV-005
1408P01101-PROC-PFD-001 Rev 01. 29/9/14

Attachment 2
EPA Wastewater Management Fact Sheet: Membrane Bioreactors

Wastewater Management Fact Sheet
Membrane Bioreactors

United States Environmental Protection Agency

INTRODUCTION

The technologies most commonly used for performing secondary treatment of municipal wastewater rely on microorganisms suspended in the wastewater to treat it. Although these technologies work well in many situations, they have several drawbacks, including the difficulty of growing the right types of microorganisms and the physical requirement of a large site. The use of microfiltration membrane bioreactors (MBRs), a technology that has become increasingly used in the past 10 years, overcomes many of the limitations of conventional systems. These systems have the advantage of combining a suspended growth biological reactor with solids removal via filtration. The membranes can be designed for and operated in small spaces and with high removal efficiency of contaminants such as nitrogen, phosphorus, bacteria, biochemical oxygen demand, and total suspended solids. The membrane filtration system in effect can replace the secondary clarifier and sand filters in a typical activated sludge treatment system. Membrane filtration allows a higher biomass concentration to be maintained, thereby allowing smaller bioreactors to be used.

APPLICABILITY

For new installations, the use of MBR systems allows for higher wastewater flow or improved treatment performance in a smaller space than a conventional design, i.e., a facility using secondary clarifiers and sand filters. Historically, membranes have been used for smaller-flow systems due to the high capital cost of the equipment and high operation and maintenance (O&M) costs. Today however, they are receiving increased use in larger systems. MBR systems are also well suited for some industrial and commercial applications. The high-quality effluent produced by MBRs makes them particularly applicable to reuse applications and for surface water discharge applications requiring extensive nutrient (nitrogen and phosphorus) removal.

ADVANTAGES AND DISADVANTAGES

The advantages of MBR systems over conventional biological systems include better effluent quality, smaller space requirements, and ease of automation. Specifically, MBRs operate at higher volumetric loading rates which result in lower hydraulic retention times. The low retention times mean that less space is required compared to a conventional system. MBRs have often been operated with longer solids residence times (SRTs), which results in lower sludge production; but this is not a requirement, and more conventional SRTs have been used (Crawford et al. 2000). The effluent from MBRs contains low concentrations of bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD), and phosphorus. This facilitates high-level disinfection. Effluents are readily discharged to surface streams or can be sold for reuse, such as irrigtion.

The primary disadvantage of MBR systems is the typically higher capital and operating costs than conventional systems for the same throughput. O&M costs include membrane cleaning and fouling control, and eventual membrane replacement. Energy costs are also higher because of the need for air scouring to control bacterial growth on the membranes. In addition, the waste sludge from such a system might have a low settling rate, resulting in the need for chemicals to produce biosolids acceptable for disposal (Hermanowicz et al. 2006). Fleischer et al. 2005 have demonstrated that waste sludges from MBRs can be processed using standard technologies used for activated sludge processes.

Membrane Filtration

Membrane filtration involves the flow of water-containing pollutants across a membrane. Water permeates through the membrane into a separate channel for recovery (Figure 1). Because of the cross-flow movement of water and the waste constituents, materials left behind do not accumulate at the membrane surface but are carried out of the system for later recovery or disposal. The water passing through the membrane is called the *permeate*, while the water with the more-concentrated materials is called the *concentrate* or *retentate*.

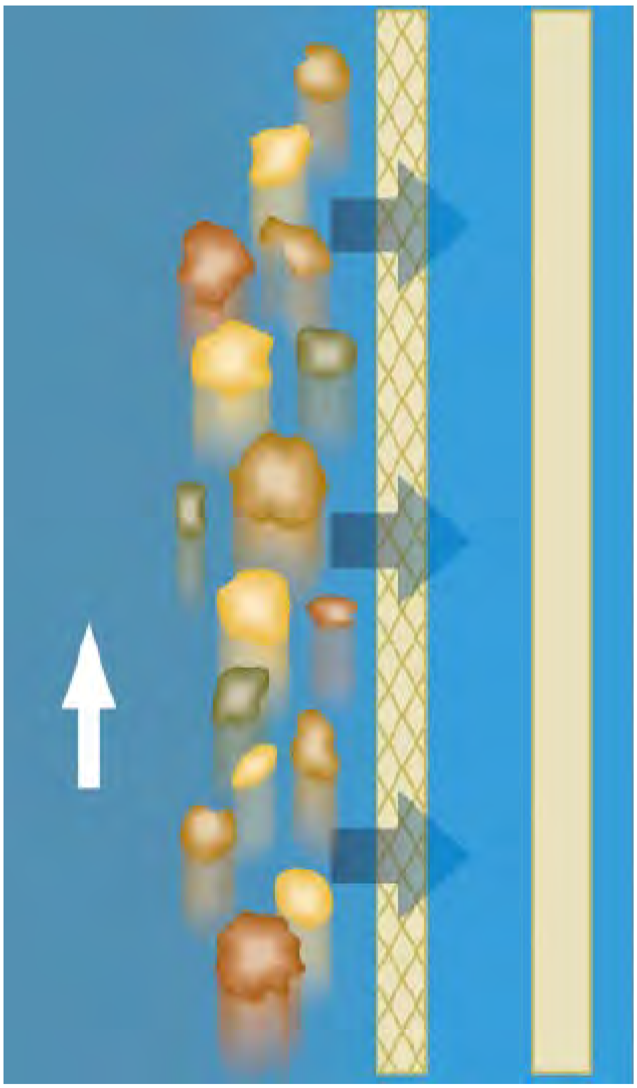


Figure 1. Membrane filtration process (Image from Siemens/U.S. Filter)

Membranes are constructed of cellulose or other polymer material, with a maximum pore size set during the manufacturing process. The requirement is that the membranes prevent passage of particles the size of microorganisms, or about 1 micron (0.001 millimeters), so that they remain in the system. This means that MBR systems are good for removing solid material, but the removal of dissolved wastewater components must be facilitated by using additional treatment steps.

Membranes can be configured in a number of ways. For MBR applications, the two configurations most often used are hollow fibers grouped in bundles, as shown in Figure 2, or as flat plates. The hollow fiber bundles are connected by manifolds in units that are designed for easy changing and servicing.

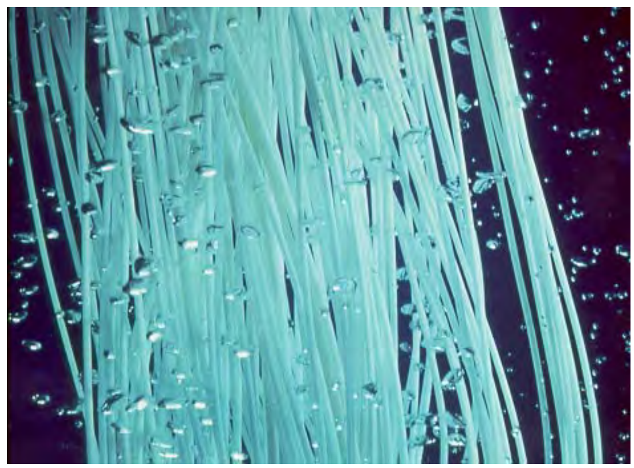


Figure 2. Hollow-fiber membranes (Image from GE/Zenon)

Design Considerations

Designers of MBR systems require only basic information about the wastewater characteristics, (e.g., influent characteristics, effluent requirements, flow data) to design an MBR system. Depending on effluent requirements, certain supplementary options can be included with the MBR system. For example, chemical addition (at various places in the treatment chain, including: before the primary settling tank; before the secondary settling tank [clarifier]; and before the MBR or final filters) for phosphorus removal can be included in an MBR system if needed to achieve low phosphorus concentrations in the effluent.

MBR systems historically have been used for small-scale treatment applications when portions of the treatment system were shut down and the wastewater routed around (or bypassed) during maintenance periods.

However, MBR systems are now often used in full-treatment applications. In these instances, it is recommended that the installation include one additional membrane tank/unit beyond what the design would nominally call for. This "N plus 1" concept is a blend between conventional activated sludge and membrane process design. It is especially important to consider both operations and maintenance requirements when selecting the number of units for MBRs. The inclusion of an extra unit gives operators flexibility and ensures that sufficient operating capacity will be available (Wallis-Lage et al. 2006). For example, bioreactor sizing is often limited by oxygen transfer, rather than the volume required to achieve the required SRT—a factor that significantly affects bioreactor numbers and sizing (Crawford et al. 2000).

Although MBR systems provide operational flexibility with respect to flow rates, as well as the ability to readily add or subtract units as conditions dictate, that flexibility has limits. Membranes typically require that the water surface be maintained above a minimum elevation so that the membranes remain wet during operation. Throughput limitations are dictated by the physical properties of the membrane, and the result is that peak design flows should be no more than 1.5 to 2 times the average design flow. If peak flows exceed that limit, either additional membranes are needed simply to process the peak flow, or equalization should be included in the overall design. The equalization is done by including a separate basin (external equalization) or by maintaining water in the aeration and membrane tanks at depths higher than those required and then removing that water to accommodate higher flows when necessary (internal equalization).

DESIGN FEATURES

Pretreatment

To reduce the chances of membrane damage, wastewater should undergo a high level of debris removal prior to the MBR. Primary treatment is often provided in larger installations, although not in most small to medium sized installations, and is not a requirement. In addition, all MBR systems require 1- to 3-mm-cutoff fine screens immediately before the membranes, depending on the MBR manufacturer. These screens require frequent cleaning. Alternatives for reducing the amount of material reaching the screens include using two stages of screening and locating the screens after primary settling.

Membrane Location

MBR systems are configured with the mem-

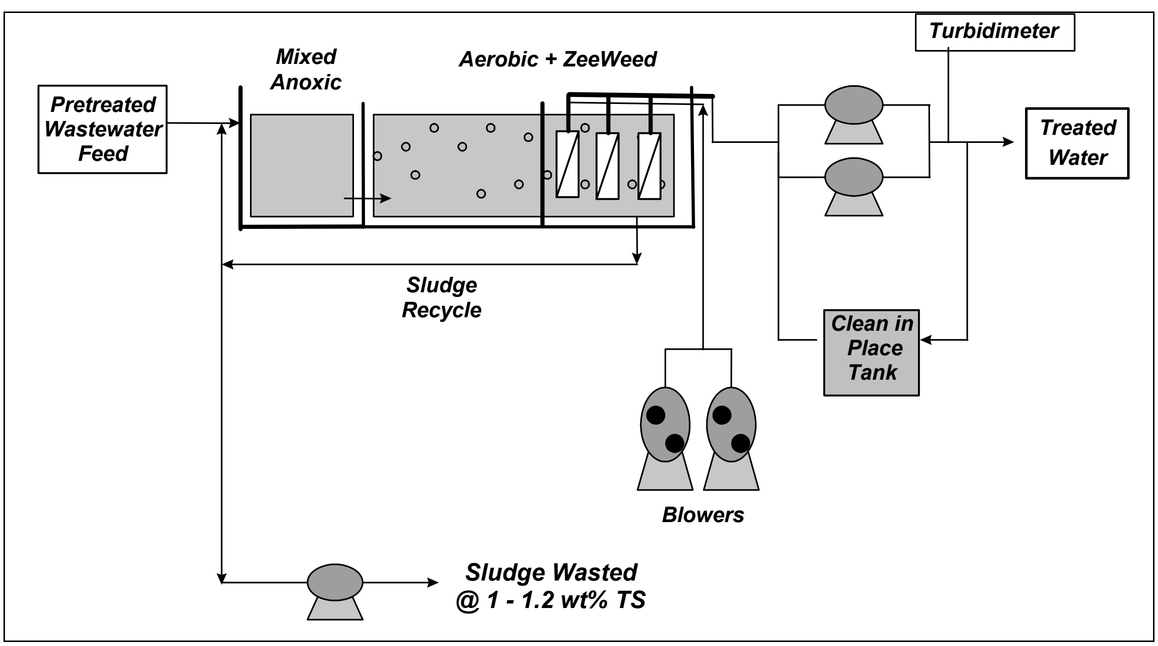


Figure 3. Immersed membrane system configuration (Image from GE/Zenon)

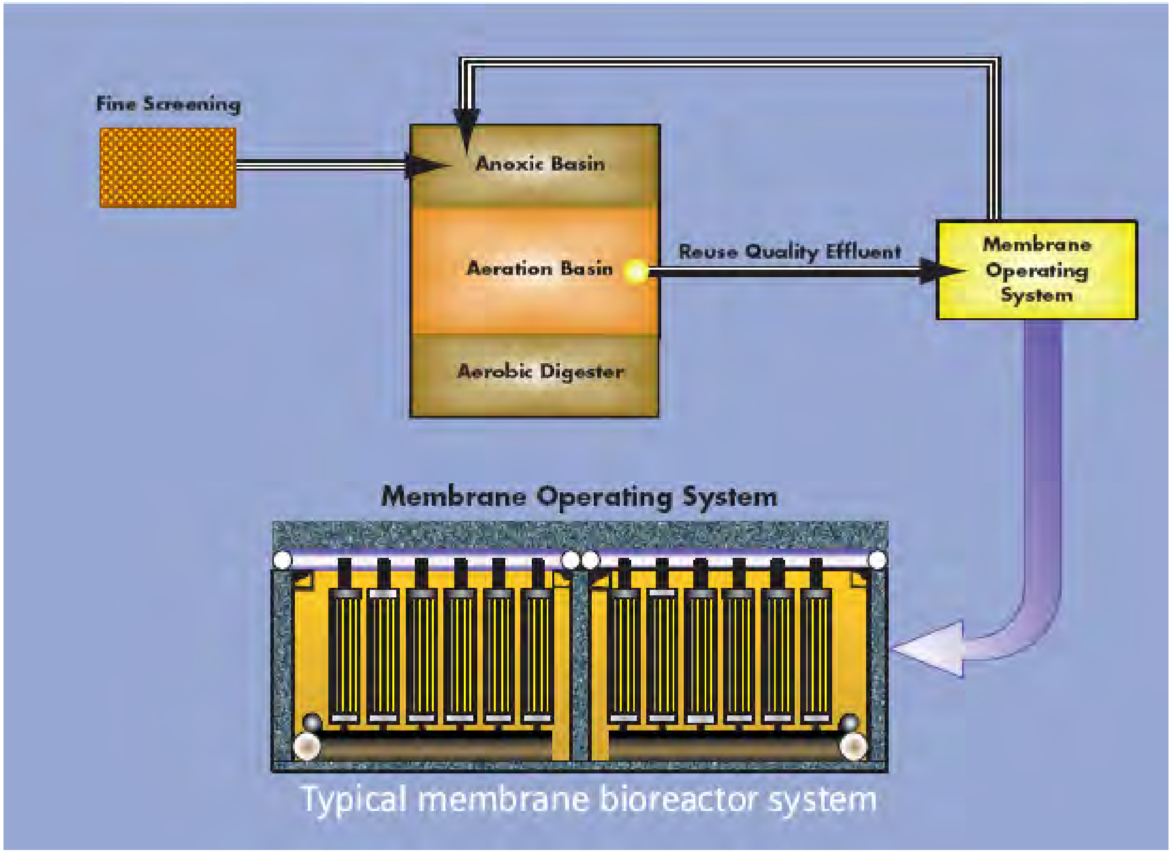


Figure 4. External membrane system configuration (Image from Siemens/U.S. Filter)

branes actually immersed in the biological reactor or, as an alternative, in a separate vessel through which mixed liquor from the biological reactor is circulated. The former configuration is shown in Figure 3; the latter, in Figure 4.

Membrane Configuration

MBR manufacturers employ membranes in two basic configurations: hollow fiber bundles and plate membranes. Siemens/U.S.Filter's Memjet and Memcor systems, GE/Zenon's ZeeWeed and ZenoGem systems, and GE/Ionics' system use hollow-fiber, tubular membranes configured in bundles. A number of bundles are connected by manifolds into units that can be readily changed for maintenance or replacement. The other configuration, such as those provided by Kubota/Enviroquip, employ membranes in a flat-plate configuration, again with manifolds to allow a number of membranes to be connected in readily changed units. Screening requirements for both systems differ: hollow-fiber membranes typically require 1- to 2-mm screening, while plate membranes require 2- to 3-mm screening (Wallis-Lage et al. 2006).

System Operation

All MBR systems require some degree of pumping to force the water flowing through the membrane. While other membrane systems use a pressurized system to push the water through the membranes, the major systems used in MBRs draw a vacuum through the membranes so that the water outside is at ambient pressure. The advantage of the vacuum is that it is gentler to the membranes; the advantage of the pressure is that throughput can be controlled. All systems also include techniques for continually cleaning the system to maintain membrane life and keep the system operational for as long as possible. All the principal membrane systems used in MBRs use an air scour technique to reduce buildup of material on the membranes. This is done by blowing air around the membranes out of the manifolds. The GE/Zenon systems use air scour, as well as a back-pulsing technique, in which permeate is occasionally pumped back into the membranes to keep the pores cleared out. Back-pulsing is typically done on a timer, with the time of pulsing accounting for 1 to 5 percent of the total operating time.

Downstream Treatment

The permeate from an MBR has low levels of suspended solids, meaning the levels of bacteria, BOD, nitrogen, and phosphorus are also low. Disinfection is easy and might not be required, depending on permit requirements..

The solids retained by the membrane are recycled to the biological reactor and build up in the system. As in conventional biological systems, periodic sludge wasting eliminates sludge buildup and controls the SRT within the MBR system. The waste sludge from MBRs goes through standard solids-handling technologies for thickening, dewatering, and ultimate disposal. Hermanowicz et al. (2006) reported a decreased ability to settle in waste MBR sludges due to increased amounts of colloidal-size particles and filamentous bacteria. Chemical addition increased the ability of the sludges to settle. As more MBR facilities are built and operated, a more definitive understanding of the characteristics of the resulting biosolids will be achieved. However, experience to date indicates that conventional biosolids processing unit operations are also applicable to the waste sludge from MBRs.

Membrane Care

The key to the cost-effectiveness of an MBR system is membrane life. If membrane life is curtailed such that frequent replacement is required, costs will significantly increase. Membrane life can be increased in the following ways:

- Good screening of larger solids before the membranes to protect the membranes from physical damage.

- Throughput rates that are not excessive, i.e., that do not push the system to the limits of the design. Such rates reduce the amount of material that is forced into the membrane and thereby reduce the amount that has to be removed by cleaners or that will cause eventual membrane deterioration.

- Regular use of mild cleaners. Cleaning solutions most often used with MBRs include regular bleach (sodium) and citric acid. The cleaning should be in accord with manufacturer-recommended maintenance protocols.

Membrane Guarantees

The length of the guarantee provided by the membrane system provider is also important in determining the cost-effectiveness of the system. For municipal wastewater treatment, longer guarantees might be more readily available compared to those available for industrial systems. Zenon offers a 10-year guarantee; others range from 3 to 5 years. Some guarantees include cost prorating if replacement is needed after a certain service time. Guarantees are typically negotiated during the purchasing process. Some manufacturers' guarantees are tied directly to screen size: longer membrane warranties are granted when smaller screens are used (Wallis-Lage et al. 2006). Appropriate membrane life guarantees can be secured using appropriate membrane procurement strategies (Crawford et al. 2002).

SYSTEM PERFORMANCE

Siemens/U.S. Filter Systems

Siemens/U.S.Filter offers MBR systems under the Memcor and Memjet brands. Data provided by U.S. Filter for its Calls Creek (Georgia) facility are summarized below. The system, as Calls Creek retrofitted it, is shown in Figure 5. In essence, the membrane filters were used to replace secondary clarifiers downstream of an Orbal oxidation ditch. The system includes a fine screen (2-mm cutoff) for inert solids removal just before the membranes.

The facility has an average flow of 0.35 million gallons per day (mgd) and a design flow of 0.67 mgd. The system has 2 modules, each containing 400 units, and each unit consists of a cassette with manifold-connected membranes. As shown in Table 1, removal of BOD, TSS, and ammonia-nitrogen is excellent; BOD and TSS in the effluent are around the detection limit. Phosphorus is also removed well in the system, and the effluent

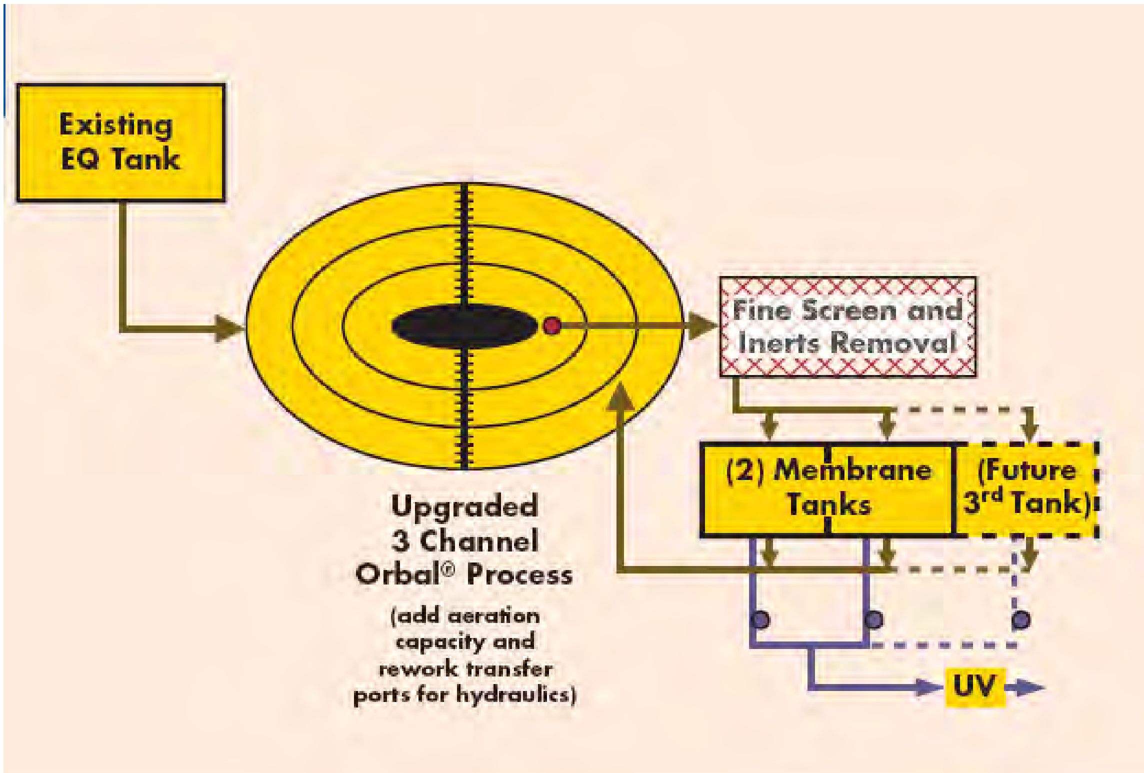


Figure 5. Calls Creek flow diagram (courtesy of Siemens/U.S. Filter)

Table 1.
Calls Creek results 2005

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	0.35	--	0.44	0.26
BOD (mg/L)	145	1	1	1
TSS (mg/L)	248	1	1	1
Ammonia-N (mg/L)	14.8	0.21	0.72	0.10
P (mg/L)	0.88	0.28	0.55	0.12
Fecal coliforms (#/100 mL)	--	14.2	20	0
Turbidity (NTU)	--	0.30	1.31	0.01

has very low turbidity. The effluent has consistently met discharge limits.

Zenon Systems

General Electric/Zenon provides systems under the ZenoGem and ZeeWeed brands. The ZeeWeed brand refers to the membrane, while ZenoGem is the process that uses ZeeWeed.

Performance data for two installed systems are shown below.

Cauley Creek, Georgia. The Cauley Creek facility in Fulton County, Georgia, is a 5-mgd wastewater reclamation plant. The system includes biological phosphorus removal, mixed liquor surface wasting, and sludge thickening using a ZeeWeed system to minimize the required volume of the aerobic digester, according to information provided by GE. Ultraviolet disinfection is employed to meet regulatory limits. Table 2 shows that the removal for all parame-

Table 2.
Cauley Creek, Georgia, system performance

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.27	--	4.66	3.72
BOD (mg/L)	182	2.0	2.0	2.0
COD (mg/L)	398	12	22	5
TSS (mg/L)	174	3.2	5	3
TKN (mg/L)	33.0	1.9	2.9	1.4
Ammonia-N (mg/L)	24.8	0.21	0.29	0.10
TP (mg/L)	5.0	0.1	0.13	0.06
Fecal coliforms (#/100 mL)	--	2	2	2
NO3-N (mg/L)	--	2.8		

ters is over 90 percent. The effluent meets all permit limits, and is reused for irrigation and lawn watering.

Traverse City, Michigan. The Traverse City Wastewater Treatment Plant (WWTP) went through an upgrade to increase plant capacity and produce a higher-quality effluent, all within the facility's existing plant footprint (Crawford et al. 2005). With the ZeeWeed system, the facility was able to achieve those goals. As of 2006, the plant is the largest-capacity MBR facility in North America. It has a design average annual flow of 7.1 mgd, maximum monthly flow of 8.5 mgd, and peak hourly flow of 17 mgd. The membrane system consists of a 450,000-gallon tank with eight compartments of equal size. Secondary sludge is distributed evenly to the compartments. Blowers for air scouring, as well as permeate and back-pulse pumps, are housed in a nearby building.

Table 3 presents a summary of plant results over a 12-month period. The facility provides excellent removal of BOD, TSS, ammonia-nitrogen, and phosphorus. Figure 6 shows the influent, effluent, and flow data for the year.

Operating data for the Traverse City WWTP were obtained for the same period. The mixed liquor suspended solids over the period January to August averaged 6,400 mg/L, while the mixed liquor volatile suspended solids averaged 4,400 mg/L. The energy use for the air-scouring blowers averaged 1,800 kW-hr/million gallons (MG) treated.

COSTS

Capital Costs

Capital costs for MBR systems historically have tended to be higher than those for conventional systems with comparable throughput because of the initial costs of the membranes. In certain situations, however, including retrofits, MBR systems can have lower or competitive capital costs compared with alternatives because MBRs have lower land requirements and use smaller tanks, which can reduce the costs for concrete. U.S. Filter/Siemen's Memcor package plants have installed costs of $7–$20/gallon treated.

Fleischer et al. (2005) reported on a cost comparison of technologies for a 12-MGD design in Loudoun County, Virginia. Because of a chemical oxygen demand limit, activated carbon adsorption was included with the MBR system. It was found that the capital cost for MBR plus granular activated carbon at $12/gallon treated was on the same order of magnitude as alternative processes, including multiple-point alum addition, high lime treatment, and post-secondary membrane filtration.

Operating Costs

Operating costs for MBR systems are typically higher than those for comparable conventional systems. This is because of the higher energy

Table 3.
Summary of Traverse City, Michigan, Performance Results

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.3	--	5.1	3.6
BOD (mg/L)	280	< 2	< 2	< 2
TSS (mg/L)	248	< 1	< 1	< 1
Ammonia-N (mg/L)	27.9	< 0.08	< 0.23	< 0.03
TP (mg/L)	6.9	0.7	0.95	0.41
Temperature (deg C)	17.2	--	23.5	11.5

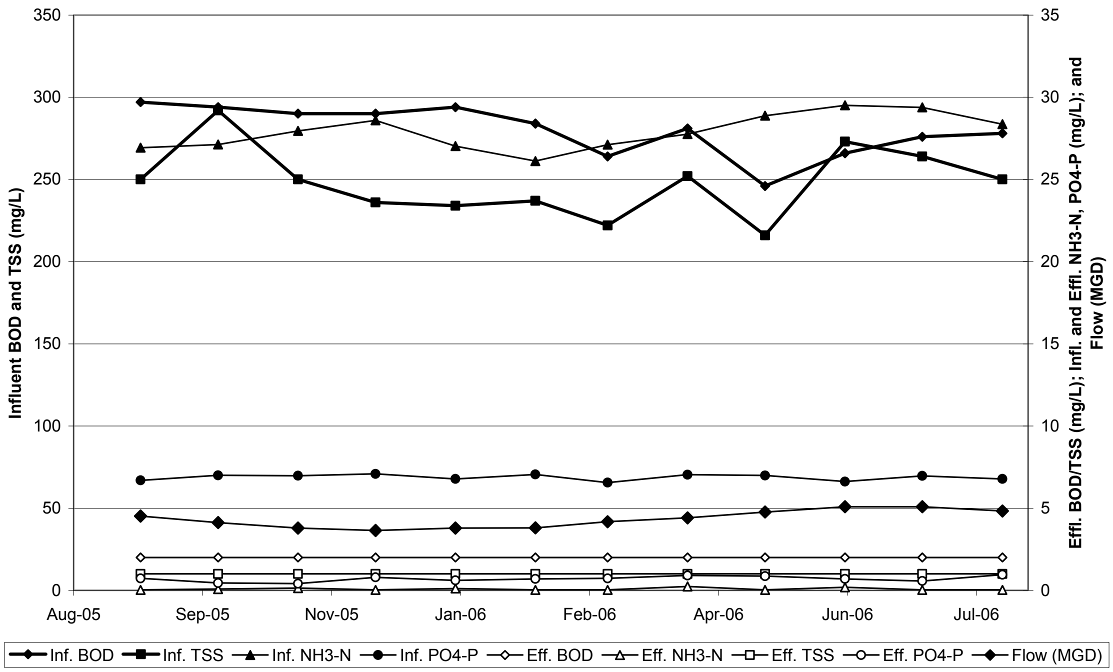


Figure 6. Performance of the Traverse City plant

costs if air scouring is used to reduce membrane fouling. The amount of air needed for the scouring has been reported to be twice that needed to maintain aeration in a conventional activated sludge system (Scott Blair, personal communication, 2006). These higher operating costs are often partially offset by the lower costs for sludge disposal associated with running at longer sludge residence times and with membrane thickening/dewatering of wasted sludge.

Fleischer et al. (2005) compared operating costs. They estimated the operating costs of an MBR system including activated carbon adsorption at $1.77 per 1,000 gallons treated. These costs were of the same order of magnitude as those of alternative processes, and they compared favorably to those of processes that are chemical-intensive, such as lime treatment.

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