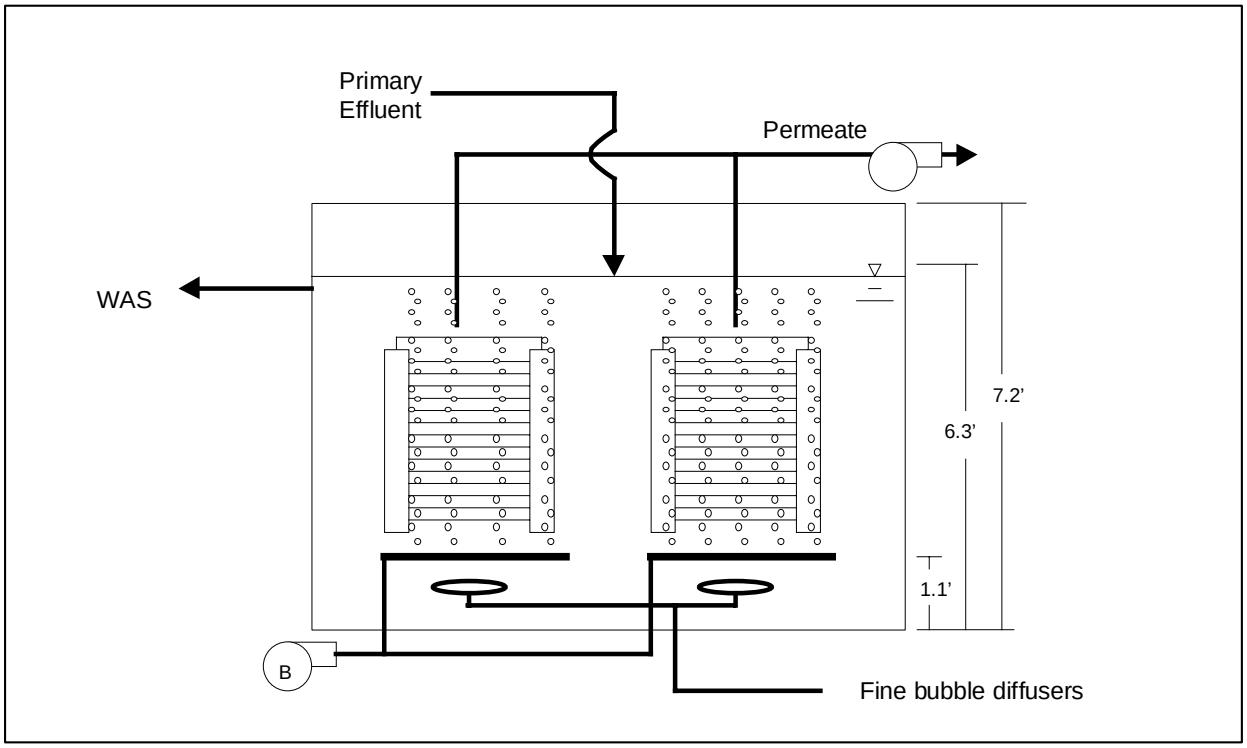


## National Water Research Institute

Final Report on

# Assessing the Ability of the Mitsubishi Membrane Bioreactor to Meet Existing Water Reuse Criteria

September 2001

MWH
MONTGOMERY WATSON HARZA

City of San Diego

# FINAL REPORT

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## Assessing the Ability of the Mitsubushi Membrane Bioreactor to Meet Existing Water Reuse Criteria

September 2001

Prepared by


**MWH**

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**Acknowledgements**

The authors would like to express their gratitude to the following individuals and organizations for their contributions to the successful completion of the project.

- Ron Linsky of the National Water Research Institute for funding the project.
- Bill Boegli of the Bureau of Reclamation for funding Agreement No. 98-FC-81-0031, "Membrane Bioreactors for Water Reclamation – Phase II". MBR operational and water quality performance data presented in this report was taken from the final report of this Bureau of Reclamation project.
- Paul Gagliardo of the City of San Diego for providing the test site, operational staff and laboratory services for the project.
- Lei Ge of Mitsubishi for supplying the MBR test equipment and providing partial project funding.
- Jeff Stone of the California Department of Health Services for input in developing MBR approval requirements and review of the Mitsubishi MBR process ability to meet California Title 22 wastewater reclamation criteria.
- Kathy Cupps and Craig Riley of the Washington State Department of Ecology for review of Mitsubishi MBR performance data with respect to meeting applicable state wastewater reclamation criteria.
- David York of the Florida Department of Environmental Protection for review of Mitsubishi MBR performance data with respect to meeting applicable State wastewater reclamation criteria.
- Greg Brown of the Arizona Department of Environmental Quality for review of Mitsubishi MBR performance data with respect to meeting applicable State wastewater reclamation criteria.

Finally, the authors would like to thank Karl Gramith, Rion Merlo and Rene Lucero of MWH for their assistance in preparation and reproduction of this final report.

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# SECTION 1

# Introduction

## 1.1 INTRODUCTION

As areas around the United States and the world have seen an increased need for the use of reclaimed wastewater this has encouraged the development and implementation of new wastewater reclamation technologies. Membrane bioreactors (MBR) are an example of a wastewater reclamation technology that is currently in use in countries around the world and offers greater promise for increased use in the future.

MBR combines the use of a membrane module and a separate bioreactor. Low-pressure membranes, either microfilters (MF) or ultrafilters (UF), are used for the solids separation step. The membrane keeps solids and high-molecular weight compounds in the bioreactor by separating them from the treated water. Sludge concentration in the MBR is controlled by continuous liquid extraction from the bioreactor. As sludge concentration and hydraulic retention time are dissociated in the MBR process, good control of biological processes can be achieved and a high water quality effluent produced. MBR therefore, combines the process elements of secondary, tertiary and advanced wastewater treatment into a single unit operation.

There are two basic configurations of MBR unit processes. They can either be operated "in-series" or "submerged" (Adham, 1998). In the "in-series" configuration, sludge is pumped from the aeration basin to a pressure driven membrane system outside of the bioreactor where the suspended solids are retained and recycled back into the bioreactor. The effluent passes through the membrane. In this configuration, the membranes are regularly backwashed to remove suspended solids build-up and accumulations and are chemically cleaned when operating pressures become too high.

In the "submerged" configuration, a low-pressure membrane is submerged in an aeration basin and operated under vacuum. The membrane is agitated by coarse bubble aeration that helps

prevent suspended solids accumulation at the membrane surface. Submerged membranes are either regularly backwashed or relaxed and are chemically cleaned when the operating pressures become too high.

## 1.2 BUREAU OF RECLAMATION STUDY

In October 1998 the City of San Diego was awarded a grant from the Bureau of Reclamation to evaluate the MBR and its potential application to wastewater reclamation (City of San Diego, 2000). During the study, the City of San Diego and their consultant, MWH, performed a parallel comparison of the two leading manufacturers of MBR. This report includes a description of the results and observations from the study conducted using the Mitsubishi MBR process. An overview of the materials and methods for the pilot-plant study is presented in Section 2 of this report.

During Part 1 of the testing, the system was operated in a nitrification/denitrification mode using an auxiliary anoxic tank. During Part 2, the pilot plants were operated in a nitrification only mode. The primary objectives of the Bureau of Reclamation project were to obtain long-term operational and performance measures for the MBR process in treating primary wastewater effluent. An overview of the results from the Bureau of Reclamation study are provided in Section 3 of this report.

## 1.3 NWRI STUDY OBJECTIVES

During the Bureau of Reclamation funded study, preliminary research and contacts were made into what would be necessary to obtain regulatory approval for the use of MBR to meet California's Title 22 Water Recycling Criteria. This NWRI study builds on that initial work with the primary focus of this NWRI funded study being to develop information on regulatory requirements for wastewater reclamation and request and obtain, if possible, approval from selected State agencies for the use of MBR technologies in meeting their water reclamation criteria.

During initial contacts with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus-seeding experiments were conducted to provide that needed information.

## 1.4 VIRUS SEEDING EXPERIMENTS

Virus seeding experiments were performed under various membrane fouled conditions (low, medium and high) using both primary effluent wastewater and Colorado River Water (CRW). The results of the virus seeding experiments are presented in Section 4 of this report.

## 1.5 STATE REGULATORY REQUIREMENTS

In addition to California DHS, contacts with state regulatory agencies were made in Arizona, Florida, Oregon, Texas and Washington. Discussions were held to identify state regulations regarding wastewater reclamation criteria and the possibility of obtaining some kind of formal feedback and/or approval regarding the use of the MBR process. Regulators in each state received copies of the California DHS approval letter and a preliminary version of this report. A cover letter requested review of the materials and a written response addressing the capabilities of the system in meeting state wastewater reclamation requirements. The results of this effort are presented in Section 5 of this report.

# SECTION 2

# Materials and Methods

## 2.1 FEED WATER CHARACTERISTICS

The virus seeding experiments were conducted using both primary effluent wastewater and fresh water. The municipal primary effluent wastewater was from the San Pasqual Water Reclamation Plant (SPWRP). This was the same municipal primary effluent wastewater used during the main study investigating the performance of the MBR. The primary treatment processes were a travelling screen, a vortex grit chamber, a rotary drum screen, and a rotary disc filter. Table 2-1 shows water quality of the primary effluent wastewater that the MBR pilot plant treated during the Bureau of Reclamation study. When the virus seedings were performed using fresh water, Colorado river water (CRW) was used for all experiments. Table 2-2 shows representative water quality of CRW.

**Table 2-1 Primary effluent water quality during Bureau of Reclamation pilot study**

| | No. of Analyses | Units | Median | Maximum | Minimum |
|---|---|---|---|---|---|
| Ammonia-N | 13 | mg/L-N | 19.8 | 37.7 | 1.9 |
| Bromide | 15 | mg/L | 0.26 | 0.42 | 0.17 |
| Chloride | 15 | mg/L | 160 | 316 | 141 |
| Nitrate-N | 16 | mg/L-N | ND | 0.055 | ND |
| O-Phosphate-P | 15 | mg/L-P | 10.3 | 13.0 | 1.2 |
| Sulfate | 15 | mg/L | 169 | 296 | 142 |
| $BOD_5$ | 56 | mg/L | 64 | 102 | 29 |
| Nitrite-N | 12 | mg/L-N | 0.01 | 0.03 | ND |
| Phosphorus | 16 | mg/L | 4.7 | 11.5 | 2.3 |
| TKN | 17 | mg/L | 30.1 | 59.6 | 11.5 |
| DOC | 30 | mg/L | 11.5 | 24.8 | 8.9 |

**Table 2-2 Representative water quality for Colorado River Water**

| | No. of Analyses | Units | Median | Maximum | Minimum |
|---|---|---|---|---|---|
| Alkalinity | 5 | mg/L as $CaCO_3$ | 120 | 130 | 120 |
| Total Hardness | 5 | mg/L as $CaCO_3$ | 240 | 240 | 220 |
| Calcium Hardness | 4 | mg/L as $CaCO_3$ | 150 | 160 | 140 |
| Total Suspended Solids | 5 | mg/L | 10 | 15 | 1.8 |
| Total Dissolved Solids | 5 | mg/L | 500 | 500 | 490 |
| TOC | 5 | mg/L | 3.1 | 4.1 | 2.5 |

## 2.2 DESCRIPTION OF PILOT PLANT

The Mitsubishi MBR pilot unit was equipped with a 1,886 gal (7.14 $m^3$) aerobic tank. The MBR was fed with domestic primary effluent wastewater using a submersible pump controlled by the programmable logic controller (PLC). Activated sludge was batch wasted once per day.

Two membrane banks were submerged in the aerobic tank. Coarse bubble air diffusers agitated the membranes continuously as well as aerating the mixed liquor. A schematic of the Mitsubishi MBR during the testing is given in Figure 2-1. Each membrane bank consisted of 50, 1 $m^2$ (10.76 $ft^2$) Mitsubishi Sterapore HF microfiltration membranes with a total membrane surface area of 100 $m^2$ (1,076 $ft^2$). The hollow fibers are arranged horizontally and attached at both ends to two permeate lines. The membranes are operated under vacuum pressure. Membrane specifications are given in Table 2-3. The Mitsubishi MBR was operated at a target flux of 13 gfd (22 L/h-$m^2$) during all testing. The membrane was operated using a cycle of a 12 min production period and a 2 min relaxation, when the membrane was no longer producing effluent. The coarse bubble diffusers air flow rate was 41 scfm (1.2 $m^3$/min). The MBR pilot plant was also equipped with two fine air diffuser stones to assist in aeration of the activated sludge.

**Table 2-3 Specification for the Mitsubishi Sterapore HF Microfiltration Membrane**

| | Units | Value |
|---|---|---|
| Approximate Size of Element (L x W x H) | mm | 886x606x1483 |
| Active Membrane Area (outside) | $ft^2$ ($m^2$) | 1076 (100) |
| Flow Direction | --- | outside-in |
| Nominal Membrane Pore size | um | 0.4 |
| Membrane Material/Construction | --- | polyethylene, hollow fiber |
| Membrane Surface Characteristics | --- | hydrophilic, symmetric |
| Membrane Charge | --- | slightly negative |
| Recommended Design Flux | gfd (L/h-$m^2$) | 9.9 (16.8) |
| Approval Study Test Flux | gfd (L/h-m | 13 (22.1) |
| Vacuum Pressure for System | psi (bar) | <5.8 (<0.4) |

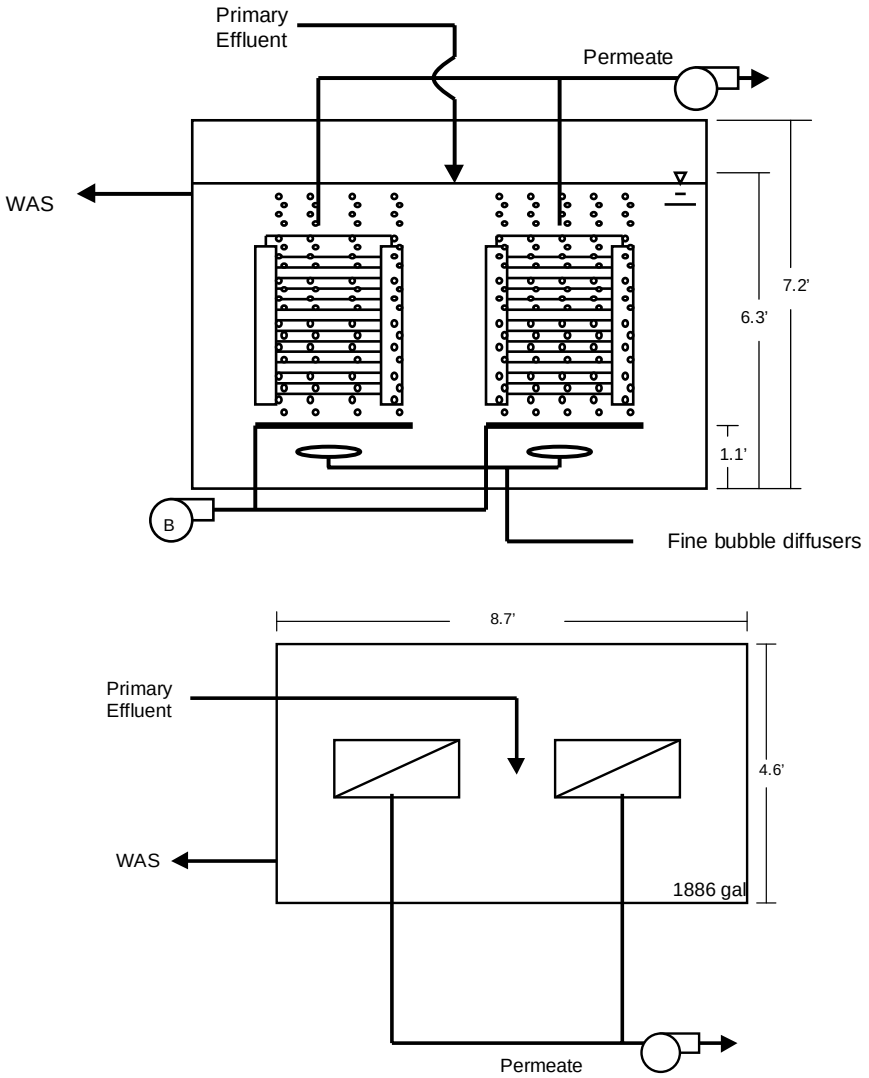



**Figure 2-1 Mitsubishi MBR side view (top) and plan view (bottom)**

## 2.3 CALCULATION OF OPERATING PARAMETERS

### *2.2.1 Flux Calculation*

The flux of the MBR membranes can be calculated as follows:

$$J = \frac{Q_p \times 1440}{A} \quad (1)$$

Where,

J = Membrane flux (gfd)

A = Total membrane surface area ($ft^2$)

### *2.2.2 Temperature Correction*

Low-pressure membrane fluxes are normally adjusted to a temperature of 20°C using:

$$J\,@\,20°C = J \times e^{-0.0239(T-20)} \quad (2)$$

Where,

T = Feed water temperature (°C)

### *2.2.3 Specific Flux*

The specific flux is the relationship between flux and the net operating pressure as follows:

$$J_{SP} = \frac{J}{P_{Net}} \qquad (3)$$

Where,

$J_{SP}$ = Specific flux (gfd/psi)

The temperature-corrected specific flux can be calculated using the temperature corrected flux (equation 2).

### *2.2.4 Log Removal*

The log removal of virus was calculated as follows:

$$Log\ Removal = Log\ (c_f) - Log\ (c_p) \qquad (4)$$

Where,

$c_f$ = virus concentration in the feed (PFU/100 mL)

$c_p$ = virus concentration in the permeate (PFU/100 mL)

Additional details on the experimental conditions, pilot-testing, and materials and methods can be found in the report (Adham, 2000).

# SECTION 3

# Summary of Results from the Bureau of Reclamation Project "Membrane Bioreactors (MBR) for Water Reclamation"

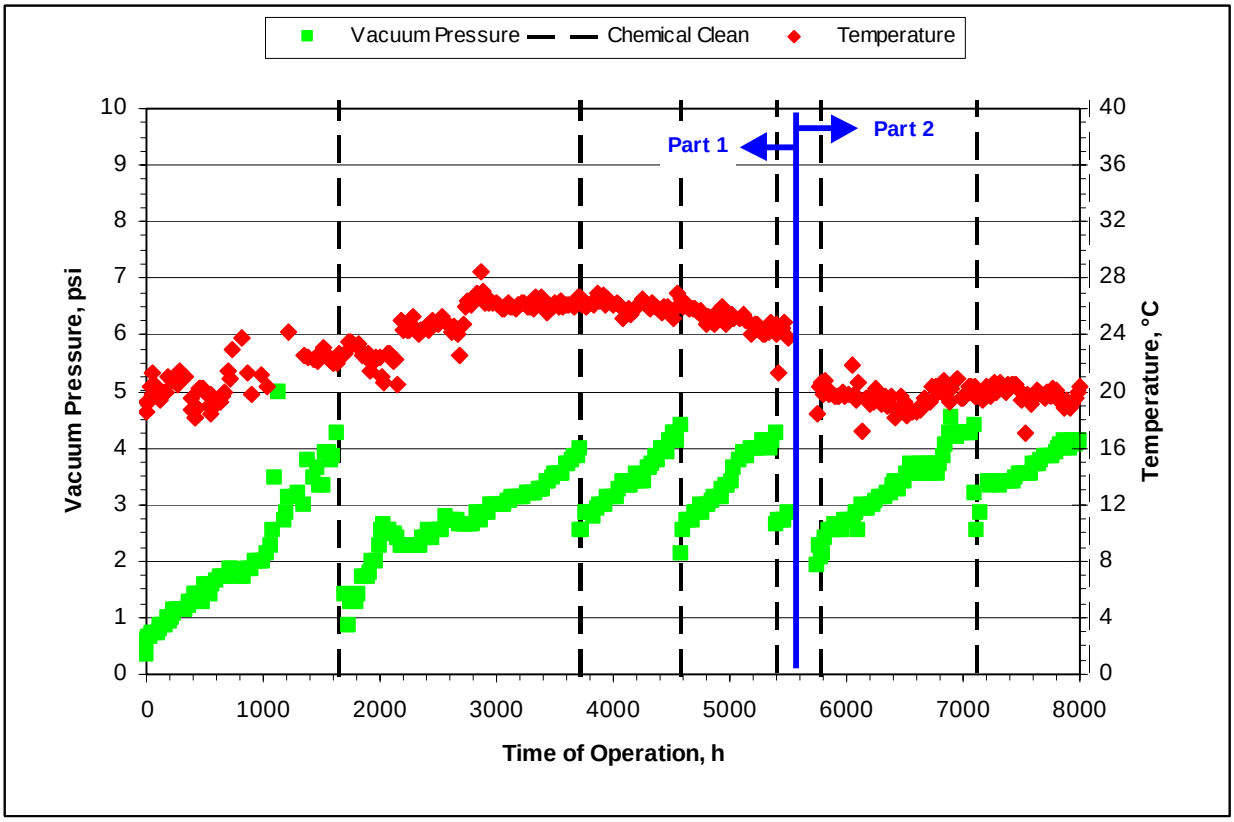
## 3.1 BACKGROUND

During Part 1 of the testing, the pilot plant was operated in a nitrification/denitrification mode using an auxiliary anoxic tank. During Part 2, the pilot plant was operated in a nitrification only mode. The Mitsubishi MBR demonstrated minimal fouling throughout the testing period, producing consistent effluent turbidity values less than 0.1 NTU. The MBR produced $BOD_5$ values <3 mg/L, and achieved up to 6-log removal of total coliforms.

## 3.2 SUMMARY OF RESULTS

### *3.2.1 Membrane Performance*

Figure 3-1 shows the membrane performance of the Mitsubishi MBR during Part 1 and 2 of the testing. A chemical clean was performed after 1,652 h (69 d) reducing the vacuum pressure from 4.27 psi (0.29 bar) to 1.42 psi (0.10 bar). The system ran for another 1,986 h (83 d) before a second chemical clean was performed. The chemical cleaning reduced the vacuum pressure from 3.98 psi (0.27 bar) to 2.56 psi (0.18 bar). Both of these first two cleanings were performed over a 2-h period as recommended by the manufacturer. To achieve better recovery of membrane performance, all subsequent cleanings on the new membranes were performed for a 3 h period. These subsequent cleanings took place after 864 h (36 d), and again after another 823 h (34 d). The third cleaning reduced the vacuum pressure from 4.41 psi (0.30 bar) to 2.13 psi (0.15 bar). The final membrane cleaning during Part 1 reduced the vacuum pressure from 4.27 psi (0.29 bar) to 2.70 psi (0.19 bar).



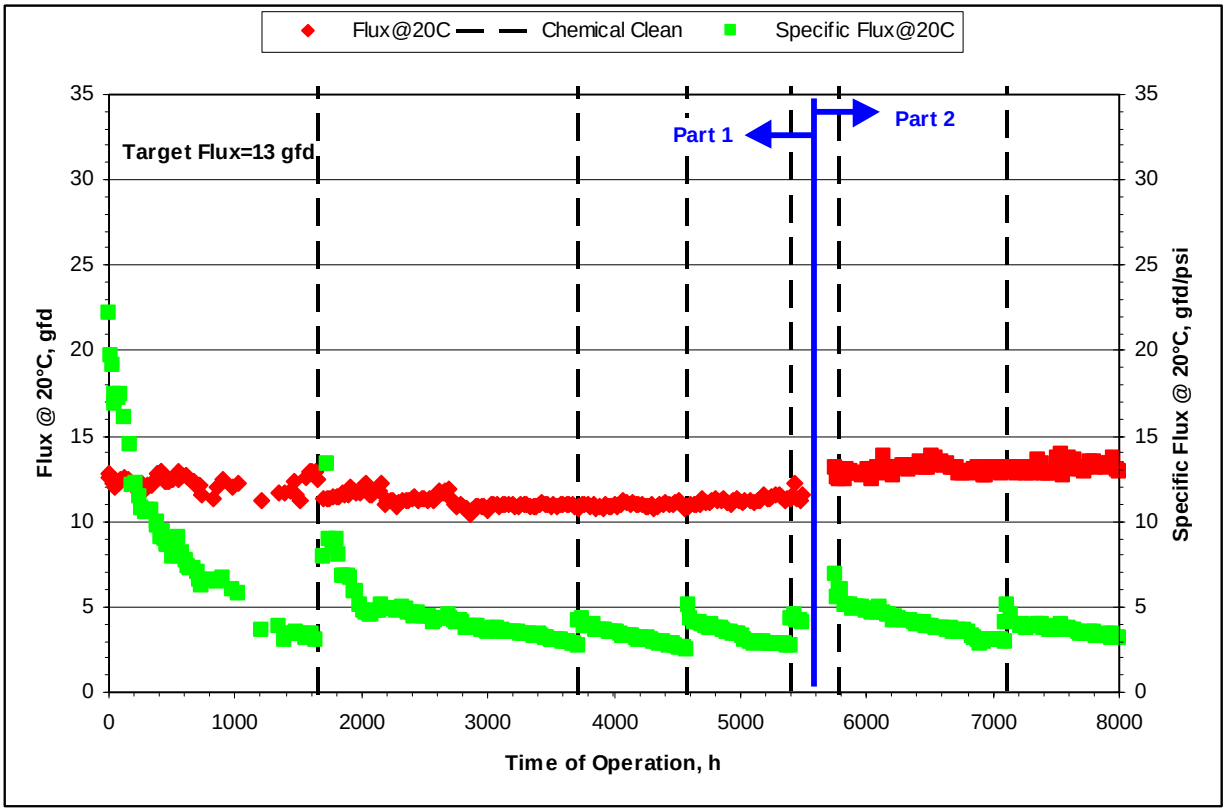
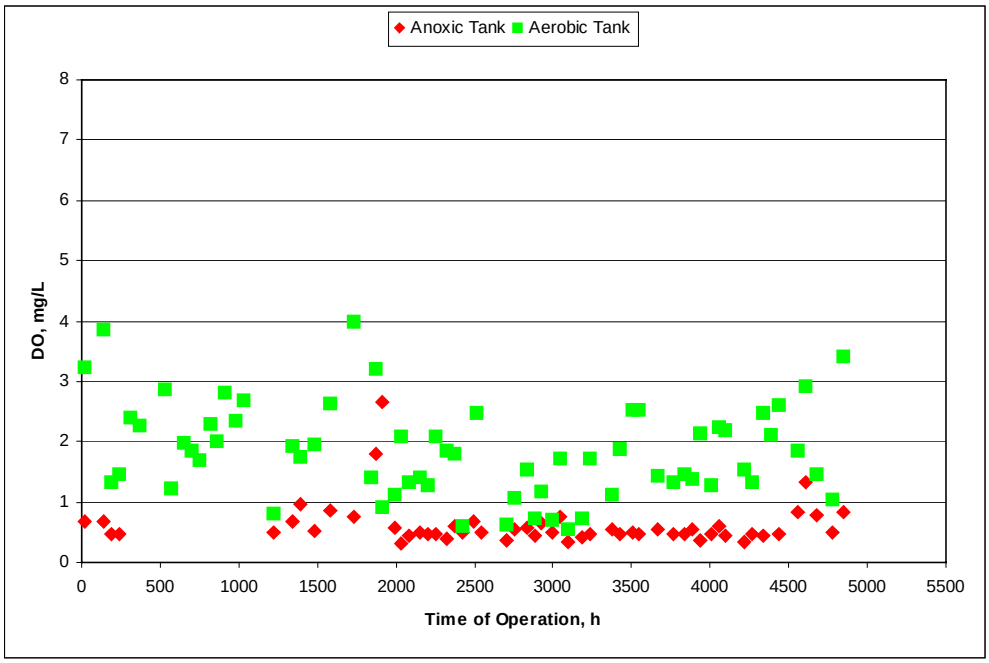




**Figure 3-1 Membrane Performance by the Mitsubishi MBR**

At the conclustion of Part 1 a full tank clean was performed with NaOCl. Another chemical clean was performed after 31 h (1 d) of operation at the target flux to determine whether any further recovery could be obtained - it was not. After this cleaning, the MBR ran for a further 1,337 h (56 d) before another chemical cleaning was required. This cleaning reduced the vacuum pressure from 4.6 psi (0.3 bar) to 2.6 psi (0.18 bar). Following the second chemical cleaning, the MBR ran for 987 h (41 d) before a third cleaning was required. This lowered the vacuum pressure from 4.1 psi (0.28 bar) to 2.9 psi (0.20 bar).

### *3.2.2 Dissolved Oxygen*

Concentrations of dissolved oxygen during testing of the Mitsubishi MBR are presented in Figure 3-2. Dissolved oxygen concentrations in the aerobic and anoxic tank during Part 1 of the testing are presented in the top figure. Concentrations in the anoxic tank during Part 2 testing are presented in the bottom figure. The figure shows that similar levels of dissolved oxygen (between 0.5 and 4.5 mg/L) were maintained in the aerobic tank during both test phases. The levels of dissolved oxygen in the anoxic tank during Part 1 were consistently near 0.5 mg/L.



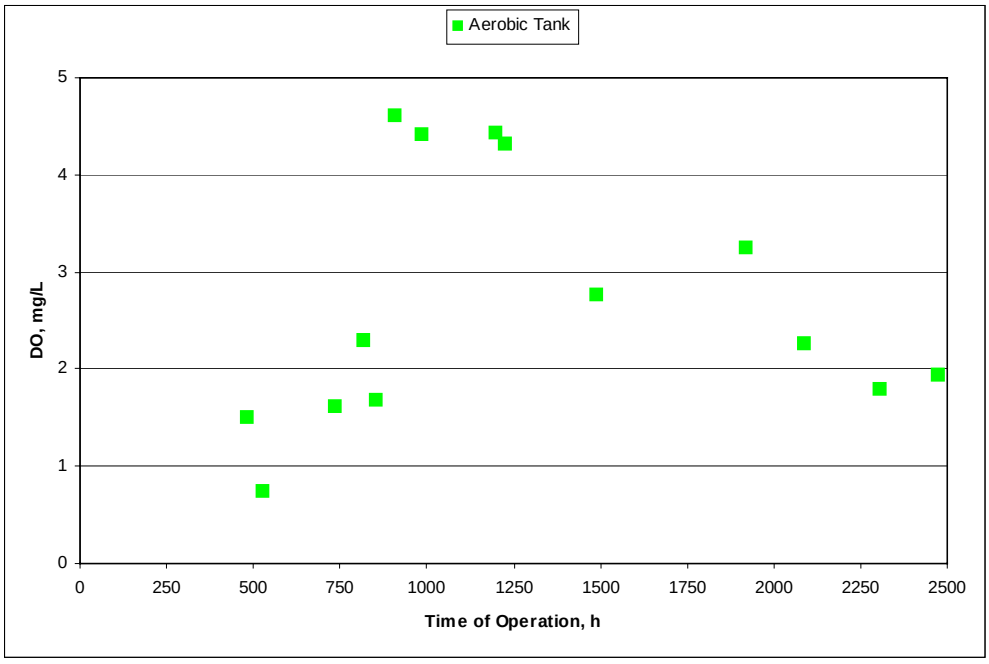




**Figure 3-2 Dissolved oxygen in the Mitsubishi MBR during Part 1 (top) and Part 2 (bottom)**

### *3.2.3 Organics Removal*

The Mitsubishi MBR effluent achieved $BOD_5$ values <3 mg/L in 80% of all samples (Figure 3-3). A majority of the Mitsubishi MBR $BOD_5$ samples that were >3 mg/L were a result of ammonia oxidation in the $BOD_5$ test. $BOD_5$ in the primary effluent ranged from 30 to 180 mg/L while $BOD_5$ in the Mitsubishi MBR filtrate ranged from 2 mg/L to 13 mg/L.

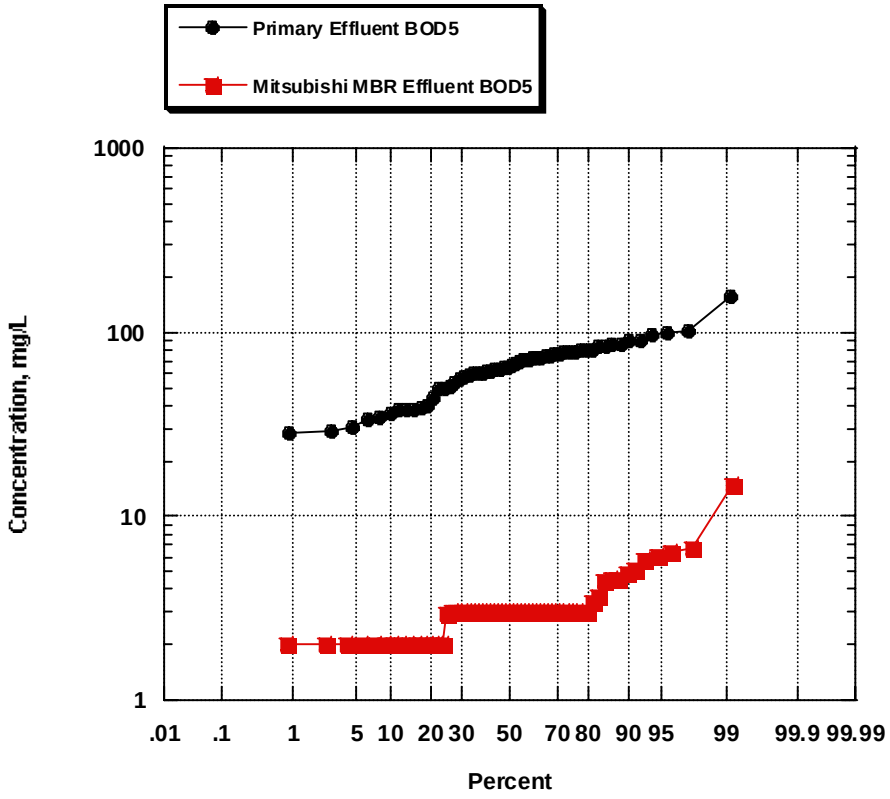



**Figure 3-3 Probability plot of $BOD_5$ removal by the Mitsubishi MBR**

### *3.2.4 Particulate Removal*

The Mitsubishi MBR pilot plant produced effluent turbidity values of <0.2 NTU in 99% of the samples, as shown in Figure 3-4. Primary effluent turbidity ranged from 11 NTU to 220 NTU.

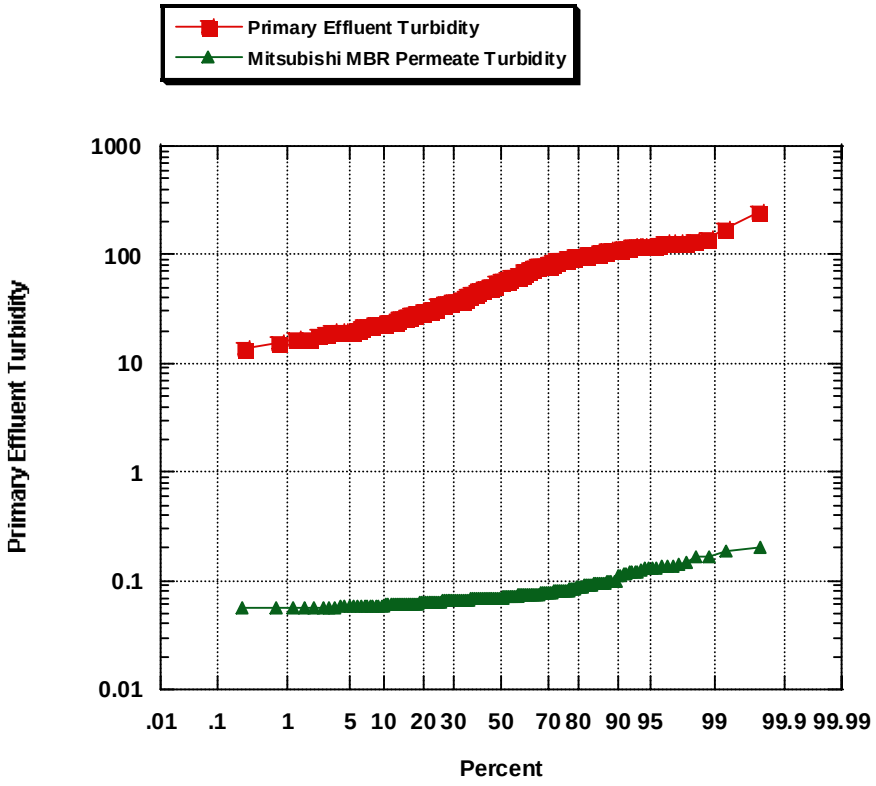



**Figure 3-4 Probability plot of turbidity removal by the Mitsubishi MBR**

### *3.2.5 Biological Nutrient Removal*

During Part 1 of the pilot testing, the Mitsubishi MBR produced effluent water with total inorganic nitrogen values of <12 mg-N/L in 50% of all samples (Figure 3-5). Even though nitrification and denitrification were not consistent during the testing, the MBR exhibited an ability to remove inorganic nitrogen. The aeration system and tank design were not sufficient to achieve high inorganic nitrogen removal, and this needs to be corrected in future work. The total inorganic nitrogen concentrations in the effluent during Part 1 were much lower than during Part 2. In Part 2, the effluent concentrations were <20 mg-N/L in 50 % of all samples (Figure 3-5). Primary effluent Ammonia-N values ranged from approximately 18 mg-N/L to 58 mg-N/L during Part 1 and from approximately 20 mg-N/L to 52 mg-N/L during Part 2.

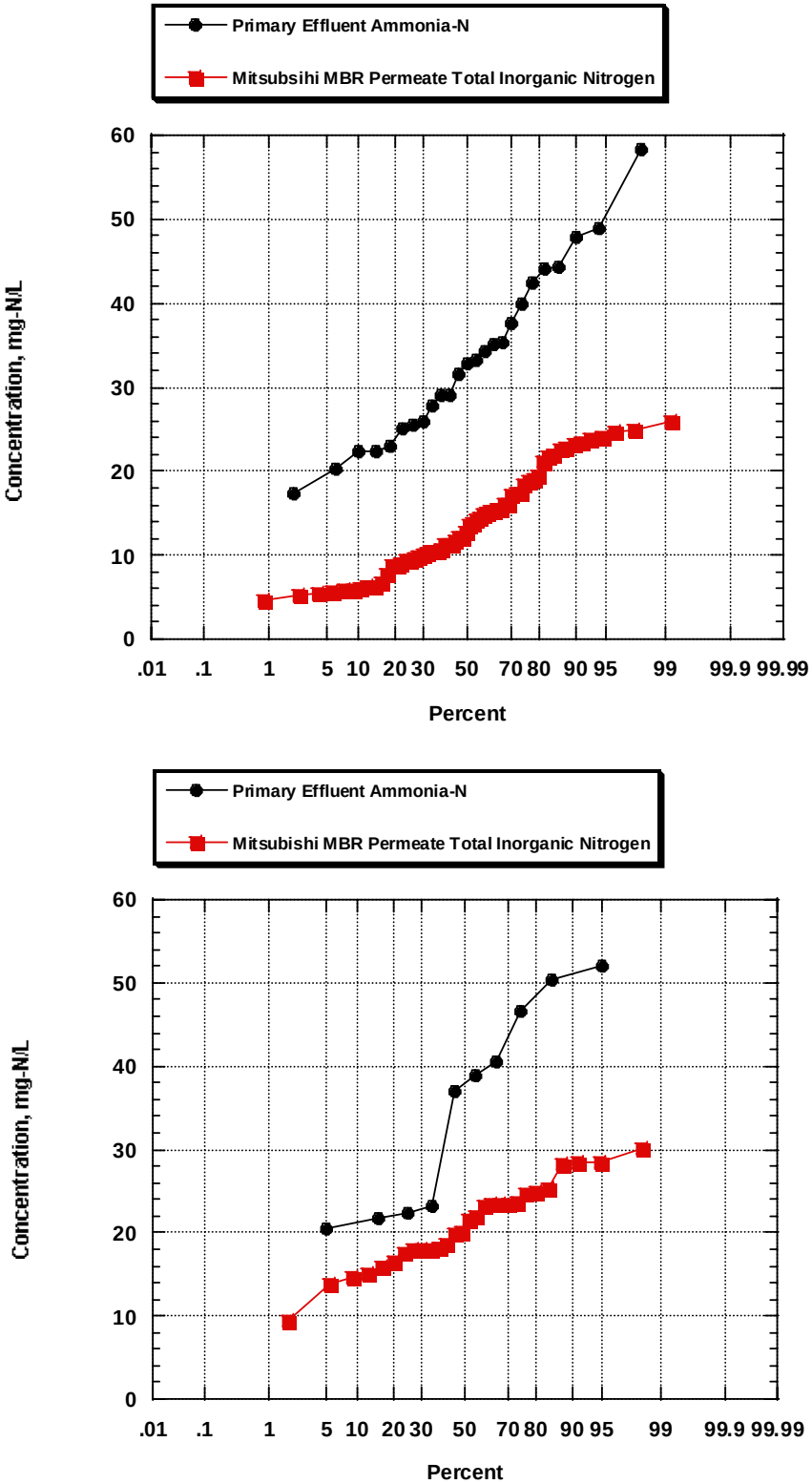



**Figure 3-5 Probability plots of the biological nutrient removal by the Mitsubishi MBR during Part 1(top) and Part 2 (bottom)**

### *3.2.6 Total Coliform, Fecal Coliform, Total Coliphage*

The microbial concentration (top figure) and log removals (bottom figure) of the Mitsubishi MBR can be seen in Figures 3-6, 3-7 and 3-8. The MBR pilot plant removed total and fecal coliforms throughout the pilot testing. The Mitsubishi MBR effluent total coliform concentration was ≤2 MPN/100 mL in 90% of all samples, achieving 6-log removal in 95% of all samples as can be seen in Figure 3-6. The primary effluent total coliform ranged from $2 \times 10^6$ MPN/100mL to $9 \times 10^7$ MPN/100mL.

The fecal coliform concentrations in the Mitsubishi MBR effluent were all ≤2 MPN/100. The Mitsubishi MBR pilot plant achieved a greater than 5-log removal of fecal coliforms in 95% of samples as shown in Figure 3-7. The primary effluent fecal coliform ranged from $3 \times 10^5$ MPN/100mL to $2 \times 10^8$ MPN/100mL.

The Mitsubishi MBR effluent total coliphage concentration was ≤1 PFU/100 mL in 80% of all samples. The Mitsubishi MBR achieved 3-log removal of coliphage in 95% of all samples as presented in Figure 3-7. The primary effluent coliphage ranged from 400 PFU/100mL to $3 \times 10^5$ PFU/100mL.

Additional details and discussion on the results from the pilot testing can be found in the Bureau of Reclamation study (Adham, 2000).

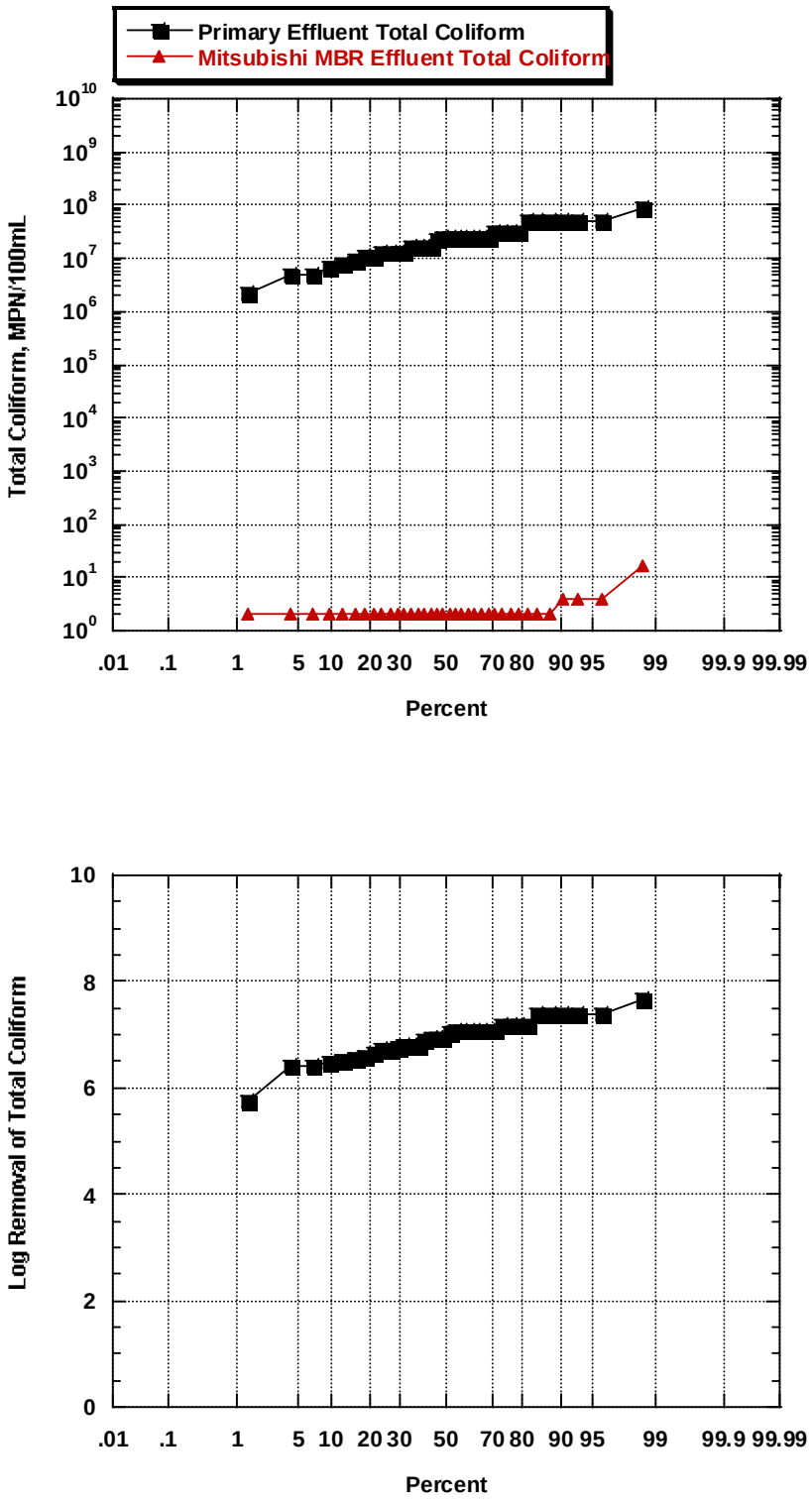



**Figure 3-6 Probability plots of Total Coliform for the Mitsubishi MBR**

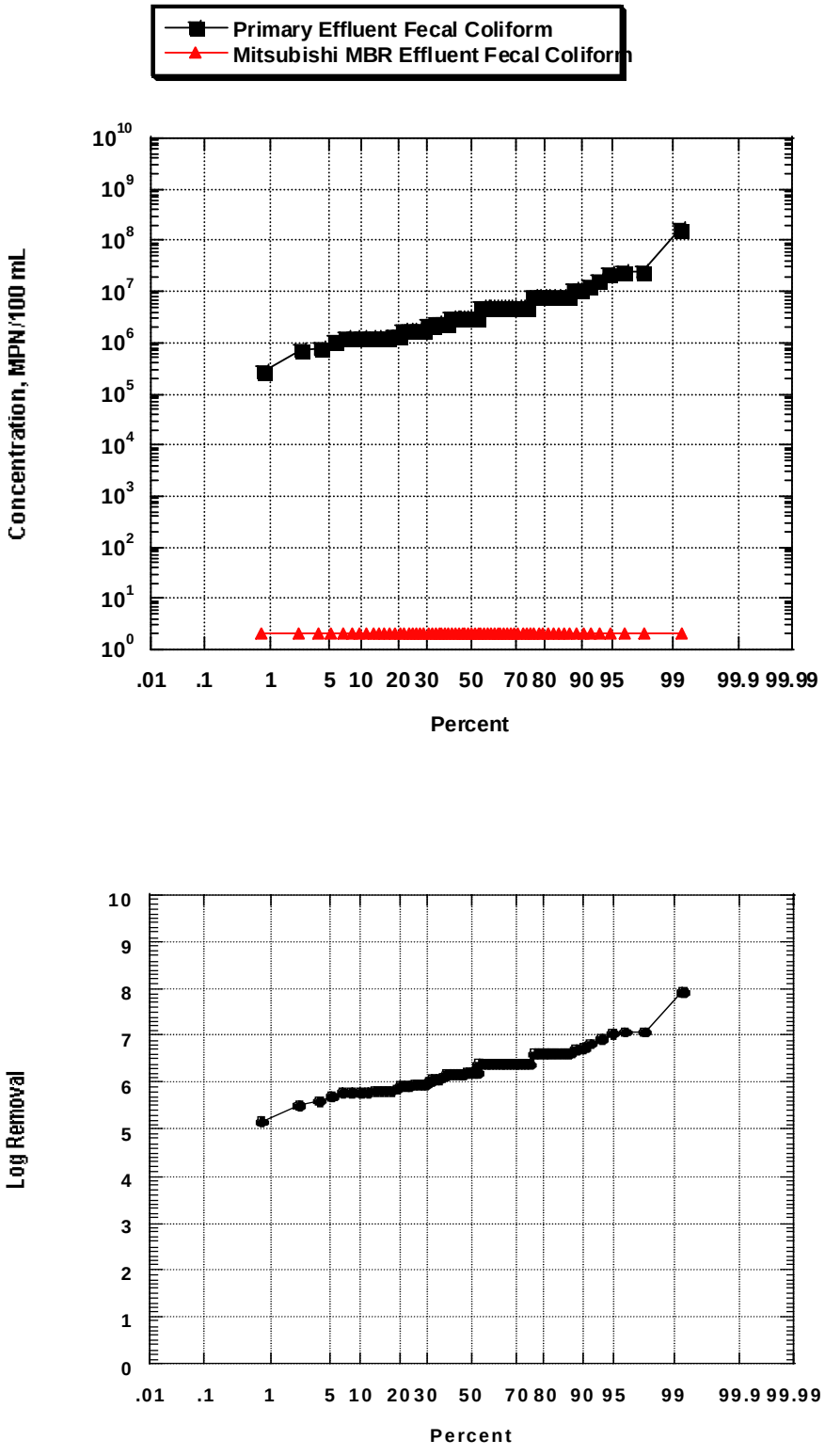



**Figure 3-7 Probability plots of Fecal Coliform for the Mitsubishi MBR**

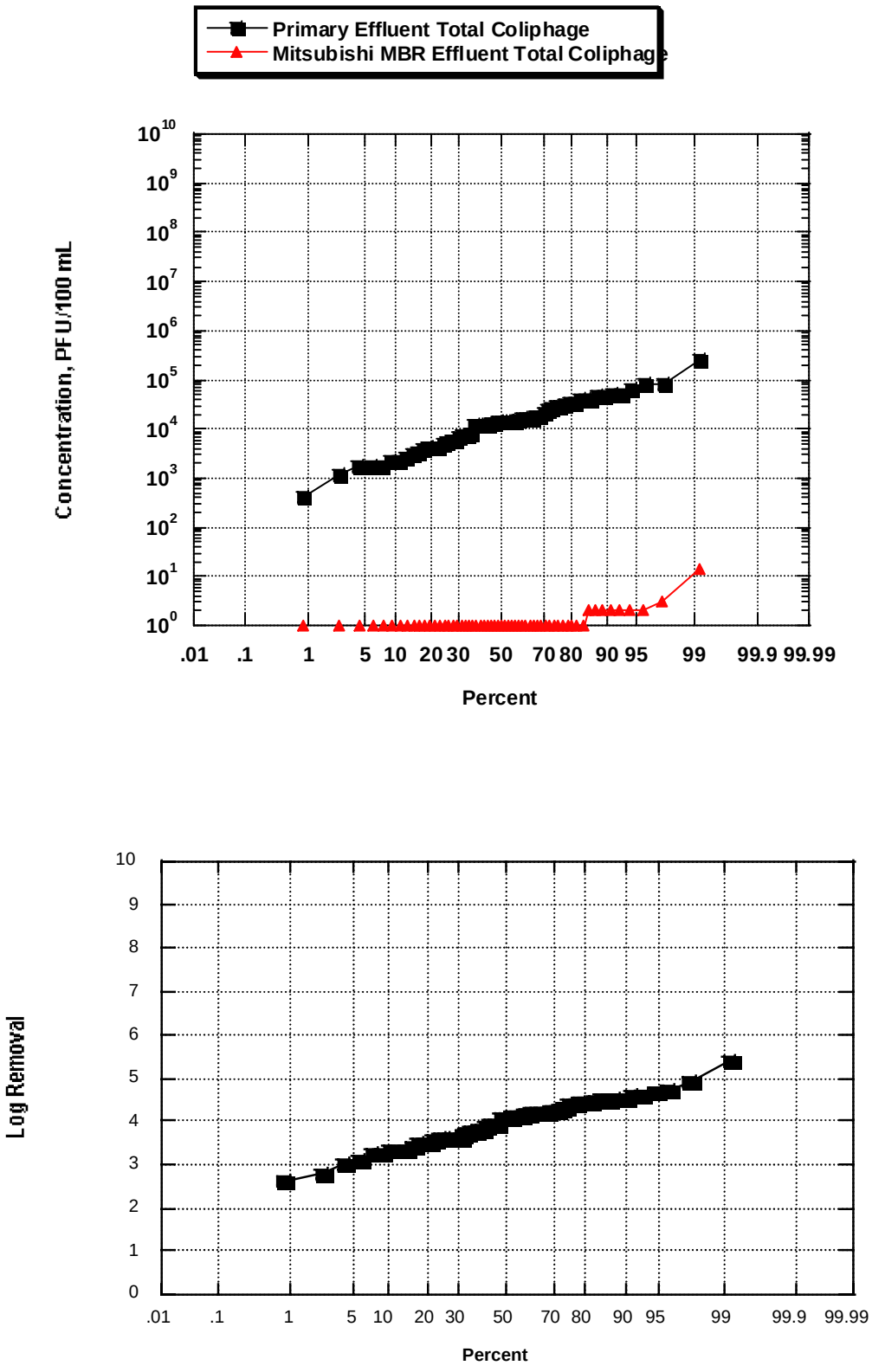



**Figure 3-8 Probability plots of Total Coliphage for the Mitsubishi MBR**

# SECTION 4

# Summary and Results of MBR Virus Seedings

## 4.1 VIRUS SEEDING PROTOCOL

### *4.1.1 Introduction*

As indicated previously, MWH conducted virus seeding experiments with the intent to further evaluate the potential for obtaining California DHS regulatory approval for the MBR process. The approach and method for evaluating the results were discussed during a meeting held with DHS staff. Table 4-1 summarizes the protocol that was followed during the virus seeding experiments. Appendix A presents the minutes from the March 1, 2000 meeting held with representatives from DHS. Virus seeding experiments were conducted using primary effluent as well as CRW. This section presents a description of the protocol used for the virus seeding experiments and the results that were observed.

**Table 4-1 Virus Seeding Test Sampling Protocols**

| Experiment | Number of Seed Solution Samples | Number of Samples | Replicates | Total Number of Samples per Experiment |
|---|---|---|---|---|
| Control | 2 | 2 | 2 | 6 |
| 1 | 2 | 3 feed/3 filtrate | 2 service cycles | 14 |
| 2 | 2 | 3 feed/3 filtrate | 2 service cycles | 14 |
| 3 | 2 | 3 feed/3filtrate | 2 service cycles | 14 |

### *4.1.2 Seedings Using Activated Sludge*

Four virus seedings were performed on the MBR pilot plant. These included two seedings at a low fouled condition, and additional seedings at medium and high fouled conditions. Two low-fouled virus seedings were performed after a chemical cleaning of the membrane. A description of the chemical cleanings performed is given in Appendix B. The membrane continued to foul

as the system was operated, and a virus seeding was performed at medium and high-fouled conditions.

An MS-2 bacteriophage solution was injected into the primary effluent feed stream of the MBR pilot plant over an 8-hour period. The bacteriophage solution was sampled at the beginning and end of each seeding and showed no significant change in concentration (Table 4-2). Samples were collected once per hour from the influent stream downstream of the virus injection and at the permeate of the membrane, 1 minute after the membrane relaxed. Prior to the study, literature review revealed that it was difficult to retrieve virus from samples collected containing activated sludge. After the first low-fouled virus seeding, however, samples were taken from the activated sludge and lab analyses showed good recovery of virus. Upon this discovery, samples were collected from the aeration basin for the remainder of the seedings.

**Table 4-2 Virus seeding solution concentration at the beginning and end of each seeding using activated sludge**

| Fouling Condition | Virus Solution Concentration, Initial (PFU/100 mL) | Virus Solution Concentration, Final (PFU/100 mL) | Concentration Change, Logarithmic |
|---|---|---|---|
| Low-1 | 3.50E+09 | 1.80E+09 | -0.29 |
| Low-2 | 3.00E+09 | 1.00E+09 | -0.48 |
| Medium | 2.30E+09 | 1.30E+09 | -0.25 |
| High | 2.50E+09 | 1.40E+09 | -0.25 |

### *4.1.3 Seedings Using Colorado River Water*

Like the testing conducted using the primary effluent wastewater, four virus seedings were also performed on the pilot plant using CRW. Two seedings were performed at low fouled condition, as well as at a medium and high fouled condition. The two low-fouled virus seedings were performed after a chemical cleaning of the membrane. The membrane continued to foul as the system was operated, and a virus seeding was performed at the medium and high-fouled condition

MS-2 bacteriophage was seeded directly into the reactor 2 minutes before the seeding experiment began. The reactor concentration was sampled at the beginning, middle and end of

two consecutive filtration cycles. The reactor concentration at the beginning and end of each seeding showed no significant change in concentration (Table 4-3). Samples were collected at the feed and permeate over two consecutive filtration cycles 1 minute before relax, 1 minute after relax, and at the middle of the cycle.

**Table 4-3 Reactor concentration at the beginning and end of each seeding using Colorado river water**

| Fouling Condition | Reactor Concentration, Initial (PFU/100 mL) | Reactor Concentration, Final (PFU/100 mL) | Concentration Change, Logarithmic |
|---|---|---|---|
| Low-1 | 2.60E+07 | 2.30E+07 | -0.05 |
| Low-2 | 7.00E+07 | 4.40E+07 | -0.20 |
| Medium | 6.50E+07 | 6.70E+07 | 0.01 |
| High | 4.40E+07 | 3.00E+07 | -0.17 |

## 4.2 RESULTS OF VIRUS SEEDINGS USING ACTIVATED SLUDGE

### *4.2.1 Operating Parameters*

The Mitsubishi MBR pilot plant was operated in a nitrification only mode during the virus seeding experiments. The Mitsubishi MBR was operated at an HRT of 3.8 hours and an average SRT of 8 days. The MLSS concentration was maintained at 8,000 mg/L. The membrane was agitated with continuous aeration using coarse air diffusers at a flowrate of 41 scfm. Table 4-4 shows the membrane operation during the virus seedings for the MBR pilot plant using activated sludge.

**Table 4-4 Operating conditons during virus seedings using activated sludge**

| Fouling Condition | Target Flux (gfd) | Vacuum Pressure (psi) | Specific Flux (gfd/psi) |
|---|---|---|---|
| Low-1 | 13 | 2.70 | 4.81 |
| Low-2 | 13 | 2.84 | 4.58 |
| Medium | 13 | 3.52 | 3.69 |
| High | 13 | 4.12 | 3.16 |

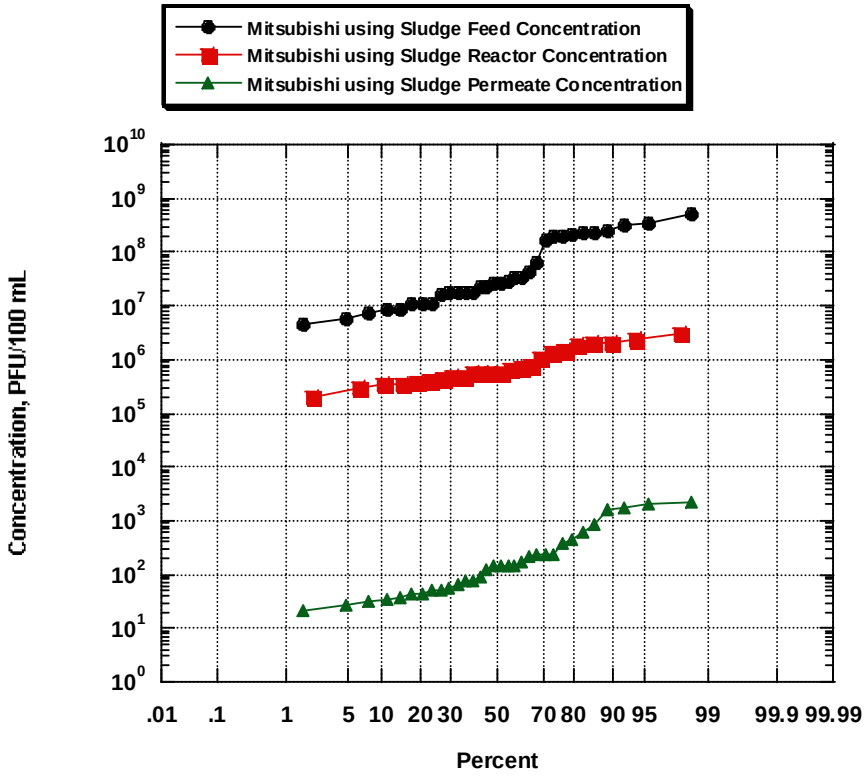
### *4.2.2 Seeding Results*

Table 4-5 shows the results of the virus seedings performed on the Mitsubishi MBR pilot plant using the primary effluent. A probability plot of the results of the virus seedings using activated sludge can be seen in Figure 4-1**.** The Mitsubishi MBR achieved greater than 5-log removal of viruses in 50% of samples from the feed to the permeate of the system. There was just under 4-log removal in 50% of all samples from the aeration basin to the effluent of the pilot plant.

**Table 4-5 Mitsubishi MBR virus seeding results using activated sludge**

| Time (h) | Fouling Condition | Feed Concentration (PFU/100 mL) | Sludge Concentration (PFU/100 mL) | Permeate Concentration (PFU/100 mL) | Log Removal (Feed to Permeate) | Log Removal (Sludge to Permeate) |
|---|---|---|---|---|---|---|
| 0 | Low-1 | 5.40E+08 | NA | 1.00E+02 | 6.73 | NA |
| 1 | Low-1 | 3.20E+08 | NA | 2.20E+03 | 5.16 | NA |
| 2 | Low-1 | 5.00E+08 | NA | 1.70E+03 | 5.47 | NA |
| 3 | Low-1 | 2.30E+08 | NA | 2.00E+03 | 5.06 | NA |
| 4 | Low-1 | 2.30E+08 | NA | 1.60E+03 | 5.16 | NA |
| 5 | Low-1 | 1.70E+08 | NA | 8.40E+02 | 5.31 | NA |
| 6 | Low-1 | 1.80E+07 | NA | 6.40E+02 | 4.45 | NA |
| 7 | Low-1 | 1.10E+07 | NA | 3.90E+02 | 4.45 | NA |
| 8 | Low-1 | 1.80E+07 | NA | 4.40E+02 | 4.61 | NA |
| 0 | Low-2 | 3.90E+07 | 1.90E+04 | 9.80E+01 | 5.60 | 2.29 |
| 1 | Low-2 | 6.30E+07 | 3.80E+05 | 2.30E+02 | 5.44 | 3.22 |
| 2 | Low-2 | 3.30E+07 | 5.50E+05 | 2.30E+02 | 5.16 | 3.38 |
| 3 | Low-2 | 2.80E+07 | 3.00E+05 | 2.10E+02 | 5.12 | 3.15 |
| 4 | Low-2 | 3.40E+07 | 5.50E+05 | 2.30E+02 | 5.17 | 3.38 |
| 5 | Low-2 | 4.40E+07 | 6.80E+05 | 1.50E+02 | 5.47 | 3.66 |
| 6 | Low-2 | 1.70E+07 | 1.50E+06 | 1.20E+02 | 5.15 | 4.10 |
| 7 | Low-2 | 1.80E+07 | 1.10E+06 | 1.50E+02 | 5.08 | 3.87 |
| 8 | Low-2 | 5.80E+06 | 7.90E+05 | 7.90E+01 | 4.87 | 4.00 |
| 0 | Medium | 5.70E+08 | 4.00E+04 | 1.30E+01 | 7.64 | 3.49 |
| 1 | Medium | 2.60E+08 | 3.50E+05 | 6.40E+01 | 6.61 | 3.74 |
| 2 | Medium | 2.10E+08 | 4.10E+05 | 9.30E+01 | 6.35 | 3.64 |
| 3 | Medium | 3.50E+08 | 5.80E+05 | 1.40E+02 | 6.40 | 3.62 |
| 4 | Medium | 2.00E+08 | 5.60E+05 | 1.70E+02 | 6.07 | 3.52 |
| 5 | Medium | 2.00E+08 | 4.90E+05 | 1.50E+02 | 6.12 | 3.51 |
| 6 | Medium | 8.70E+06 | 3.10E+06 | 7.60E+01 | 5.06 | 4.61 |
| 7 | Medium | 8.30E+06 | 1.40E+06 | 5.10E+01 | 5.21 | 4.44 |
| 8 | Medium | 4.70E+06 | 2.00E+06 | 5.20E+01 | 4.96 | 4.59 |
| 0 | High | 2.60E+07 | 5.90E+04 | 4.00E+00 | 6.81 | 4.17 |
| 1 | High | 2.30E+07 | 4.90E+05 | 3.60E+01 | 5.81 | 4.13 |
| 2 | High | 2.60E+07 | 6.90E+05 | 5.50E+01 | 5.67 | 4.10 |
| 3 | High | 2.30E+07 | 2.00E+05 | 3.20E+01 | 5.86 | 3.80 |
| 4 | High | 2.60E+07 | 3.60E+05 | 4.20E+01 | 5.79 | 3.93 |
| 5 | High | 1.80E+07 | 4.40E+05 | 4.20E+01 | 5.63 | 4.02 |
| 6 | High | 1.10E+07 | 1.90E+06 | 2.10E+01 | 5.72 | 4.96 |
| 7 | High | 1.10E+07 | 2.10E+06 | 2.80E+01 | 5.59 | 4.88 |
| 8 | High | 7.40E+06 | 2.40E+06 | 3.40E+01 | 5.34 | 4.85 |

NA Not Analyzed



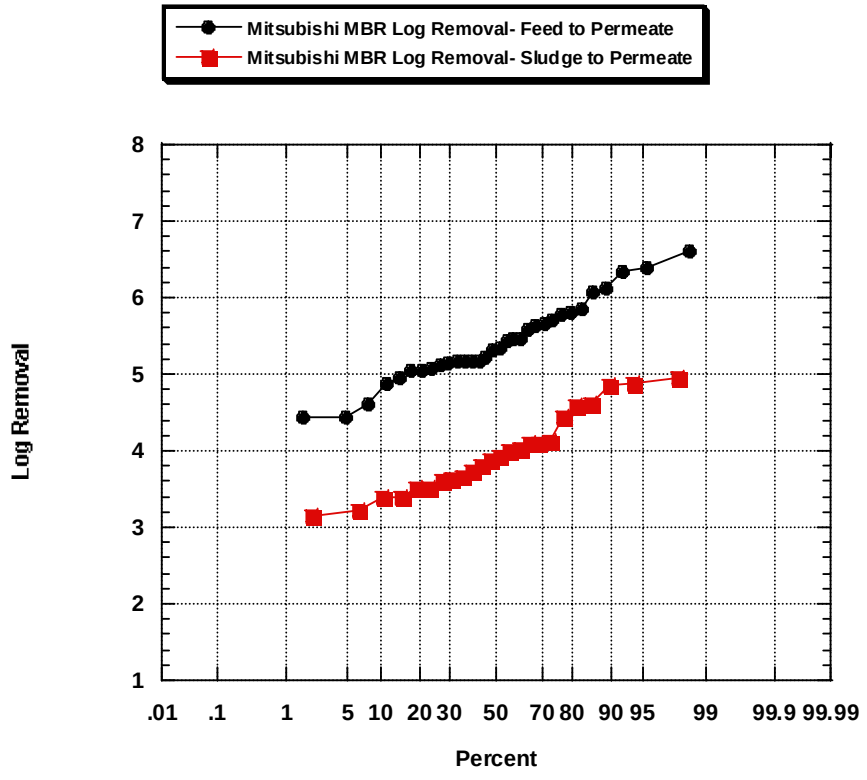




**Figure 4-1 Probability plots of virus seedings of Mitsubishi MBR using activated sludge**

## 4.3 VIRUS SEEDINGS USING COLORADO RIVER WATER

### *4.3.1 Operating Parameters*

The Mitsubishi MBR pilot plant was retrofitted to operate using CRW. The membrane was operated in the same manner as before. The pilot plant was operated in a dead-end fashion during all virus seedings, meaning a waste stream was not used. The membrane was agitated with continuous aeration using coarse air diffusers at a flowrate of 41 scfm. Table 4-6 shows the membrane operation during the virus seedings for the MBR pilot plant.

**Table 4-6 Operating Conditions during virus seedings using Colorado River Water**

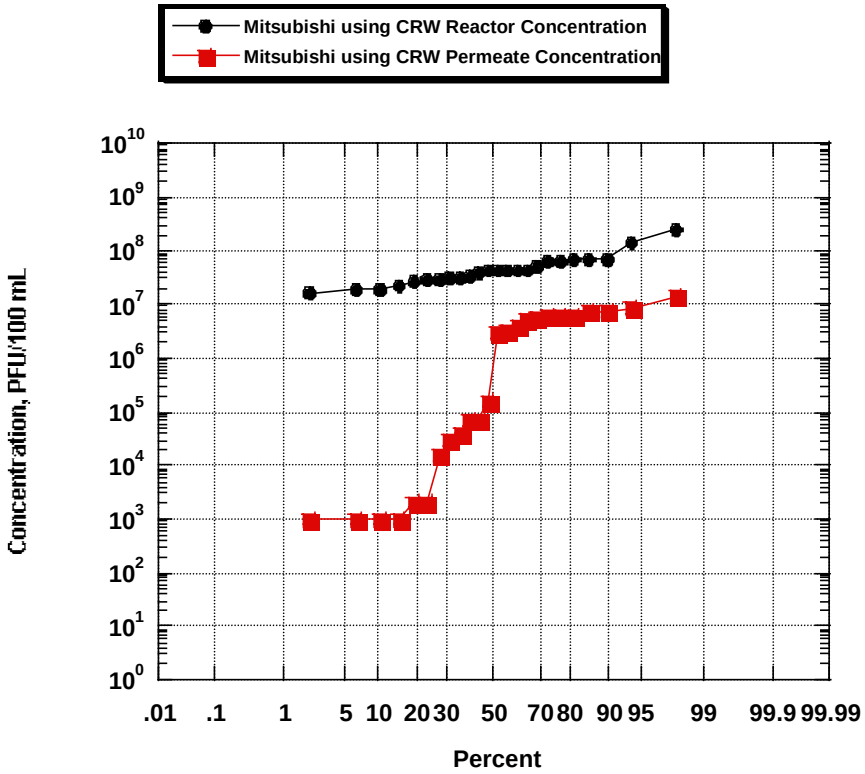
| Fouling Condition | Target Flux (gfd) | Vacuum Pressure (psi) | Specific Flux (gfd/psi) |
|---|---|---|---|
| Low-1 | 13 | 1.17 | 11.11 |
| Low-2 | 13 | 1.39 | 9.35 |
| Medium | 13 | 1.88 | 6.91 |
| High | 13 | 2.95 | 4.41 |

### *4.3.2 Seeding Results*

Table 4-7 shows the results of the virus seedings performed on the Mitsubishi MBR pilot plant using CRW. A probability plot of the results of the virus seedings using activated sludge can be seen in Figure 4-2**.** The Mitsubishi MBR achieved 2-log removal in 50% of samples of virus from the reactor to the permeate of the system.

**Table 4-7 Results of virus seedings using Colorado River Water**

| Time (min) | Fouling Condition | Reactor Concentration (PFU/100 mL) | Permeate Concentration (PFU/100 mL) | Log Removal |
|---|---|---|---|---|
| 1 | Low-1 | 2.60E+07 | 1.40E+07 | 0.27 |
| 6 | Low-1 | 2.80E+07 | 8.40E+06 | 0.52 |
| 11 | Low-1 | 2.00E+07 | 7.20E+06 | 0.44 |
| 1 | Low-1 | 3.00E+07 | 6.50E+06 | 0.66 |
| 6 | Low-1 | 1.60E+07 | 7.20E+06 | 0.35 |
| 11 | Low-1 | 2.30E+07 | 5.20E+06 | 0.65 |
| | | | | |
| 1 | Low-2 | 7.00E+07 | 3.00E+06 | 1.37 |
| 6 | Low-2 | 1.40E+08 | 6.50E+06 | 1.33 |
| 11 | Low-2 | 2.60E+08 | 3.80E+06 | 1.84 |
| 1 | Low-2 | 7.20E+07 | 6.50E+06 | 1.04 |
| 6 | Low-2 | 4.20E+07 | 3.40E+06 | 1.09 |
| 11 | Low-2 | 4.40E+07 | 5.70E+06 | 0.89 |
| | | | | |
| 1 | Medium | 6.50E+07 | 4.00E+04 | 3.21 |
| 6 | Medium | 4.30E+07 | 7.00E+04 | 2.79 |
| 11 | Medium | 5.10E+07 | 1.50E+04 | 3.53 |
| 1 | Medium | 6.60E+07 | 1.50E+05 | 2.64 |
| 6 | Medium | 4.30E+07 | 7.00E+04 | 2.79 |
| 11 | Medium | 6.70E+07 | 3.00E+04 | 3.35 |
| | | | | |
| 1 | High | 4.40E+07 | 1.00E+03 | 4.64 |
| 6 | High | 3.50E+07 | 1.00E+03 | 4.54 |
| 11 | High | 4.00E+07 | 2.00E+03 | 4.30 |
| 1 | High | 2.00E+07 | 1.00E+03 | 4.30 |
| 6 | High | 2.90E+07 | 1.00E+03 | 4.46 |
| 11 | High | 3.00E+07 | 2.00E+03 | 4.18 |



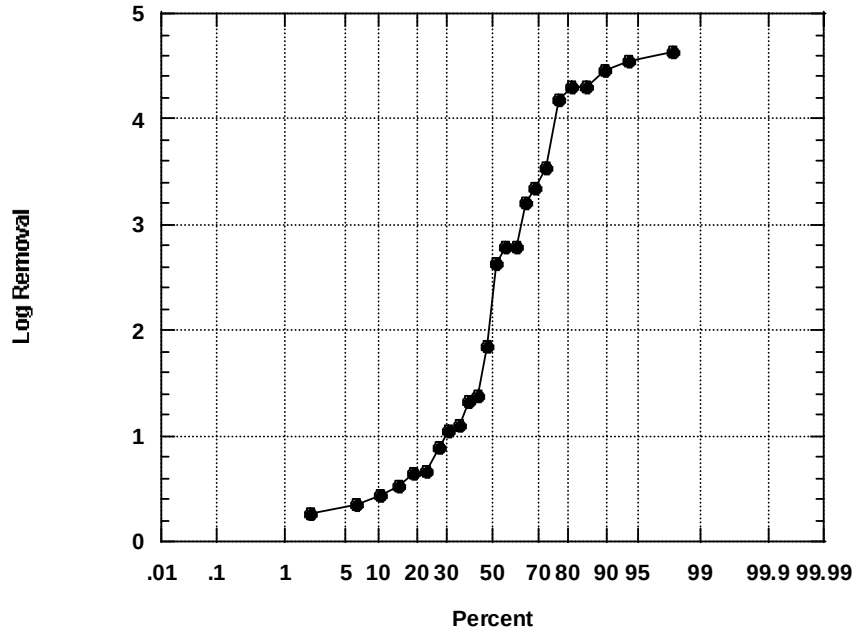




**Figure 4-2 Probability Plots of Mitsubishi MBR using Colorado river water**

# SECTION 5

# Regulatory Approval

## 5.1 INTRODUCTION

Representatives from California and 5 additional State Regulatory Agencies were contacted and sent preliminary versions of this report. The representatives were requested to review the results presented in the report and respond in writing with regard to the ability of the MBR technology to meet applicable State wastewater recycling criteria. This section presents the results of this regulatory approval task.

## 5.2 CALIFORNIA REGULATORY APPROVAL PROCESS

In California, the latest version of the Water Recycling Criteria[1], presents the following criteria for a filtered wastewater:

> "Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed any of the following:
>
> (1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and
> (2) 0.5 NTU at any time."[2]

[1] Water Recycling Criteria. Proposed Regulations Water Recycling. R-13-95. Marked up version of the State criteria that is stamped "Received October 13, 1998: Drinking Water Program Santa Rosa District." Title 22, Chapter 3, Article 1.

[2] In addition, the latest version of the State Water Recycling Criteria defines a disinfected tertiary recycled water as a filtered and subsequently disinfected wastewater that meets the following criteria:

(a) The filtered wastewater has been disinfected by either:
(1) A chlorine disinfection process following conventional treatment or its equivalent that provides a CT (the product of total chlorine residual and modal contact time measured at the same point) value of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 mintues, based on peak dry weather design flow: or
(2) A disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus in the

On March 1, 2000 MWH project team members and City of San Diego representatives met with representatives of the California DHS. In addition to presenting results from the MBR study to DHS staff, the goal of the meeting was to discuss specific data needed and the process to be followed to obtain DHS approval for using MBR process for meeting the Title 22 Water Recycling Criteria.

DHS staff indicated that to obtain formal approval, Title 22 requires a membrane process to achieve 0.2 NTU effluent 95% of the time within any 24-hour period (never to exceed 0.5 NTU) combined with disinfection to achieve a total of 5 log removal of virus. In addition, DHS indicated that to obtain their approval, the MBR process would need to achieve a 1-log removal of virus (DHS indicated they would consider basing this virus credit on the 50$^{th}$ percentile of virus rejection). The minutes of this meeting are presented in Appendix A.

A letter was sent to Mr. Jeff Stone of the California DHS requesting conditional approval for use of the MBR under Title 22 water recycling criteria. In addition Mr. Stone received preliminary copies of this report. On April 23, 2001, Mr. Stone responded with a letter to Mr. Lei Ge of Mitsubishi, granting conditional approval for the use of their MBR for water recycling under Title 22. Copies of the request and acceptance letters are provided in Appendix C. The acceptance letter states:

> "The demonstration studies conducted using the Mitsubishi MBR have sufficiently demonstrated the ability to produce an oxidized wastewater and the membranes ability to comply with the above stated turbidity performance requirements. In addition, virus-seeding experiments demonstrated the process ability to achieve a 1-log virus reduction at the 50$^{th}$ percentile. Therefore, the

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wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration.

(b) The medium concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30 day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 milliliters."

> Department of Health Services accepts the use of this membrane, identified as the Mitsubishi MBR Sterapore hollow fiber membrane, as a filtration technology for use in compliance with the Water Recycling Criteria. Based on performance data, the membrane filtration units will be limited to a maximum flux of 13 gfd and a maximum vacuum pressure of –5.8 psi."

In addition, the approval letter indicated that the DHS would review all projects on a case by case basis to determine full compliance with all treatment and reliability requirements.

## 5.3 ADDITIONAL CANDIDATE STATES

After formally contacting DHS and requesting approval for use of MBR as an alternative to filtration to meet the Title 22 Wastewater Recycling Criteria, MWH contacted 5 additional states to seek regulatory approval or at least to obtain feedback from the State regulatory authority's as to the use of MBR technology to meet their wastewater recycling criteria.

Table 5-1 presents preliminary information obtained from contacting the selected States and reviewing their regulations, standards and criteria documents. The contacts at each State regulatory agency were sent a copy of a preliminary version of this report. In addition, they received a copy of the California DHS approval letter. A cover letter requested a review of the enclosed materials and a written response with respect to the ability of the Mitsubishi MBR technology to meet the State's regulatory requirements. The letters sent to State Regulators are presented in Appendix D. The responses received from the five States are provided as Appendix E and summarized below.

### *5.3.1 Arizona*

A response was received from Gregory H. Brown, P.E, Wastewater Design Review Unit Manager for the Arizona Department of Environmental Quality (ADEQ) in a letter dated August 21, 2001. The letter states "the Mitsubishi MBR appears to meet the effluent requirements for Class A reclaimed water in accordance with AAC R18-9-303 and the treatment performance requirements found in AAC R19-9-B204." It also states that "the Mitsubishi MBR does not

appear to meet the total nitrogen criteria of 10 mg/L found in AAC R18-9-B204." The letter states that the ADEQ does not provide individual product review approvals, but only provides technical review of technology when it is included as a component in an entire system designed for installation. The letter also states that "the ADEQ does not provide product review approvals," but rather "provides technical review when it is included as a component of an entire designed system."

## Table 5-1 Overview of State Wastewater Reuse Information

| | Contact | Agency Name | Reuse Regulations | Criteria (most stringent) |
|---|---|---|---|---|
| Arizona | Natasha Mu | Department of Environmental Quality | Title 18: Environmental Quality, Article 7 Regulations for Reuse of Wastewater | Food Consumed Raw (fecal coliform 2.2/100 mL, geo mean, no single sample >25/100 mL; 1 NTU, 1 virus per 40 L, no detectable entamoeba, giardia, ascaris, tapeworm) |
| Florida | David York, Ph.D. | Department of Environmental Protection | Chapter 62-610, Reuse of Reclaimed Water and Land Application | [Discharge to Class 1 surface water used for potable supply] No detectable fecal coliform/100 mL, 5 mg/L TSS, 20 mg/L CBOD, 10 mg/L NO3 (as N). Meet primary and secondary drinking water standards. |
| Texas | Louis Herrin | Texas Natural Resource Conservation Commission | Chapter 210, 210.1-210.9 | Type 1 Reclaimed Water Use (BOD5 or COD5 at 5 mg/L, turbidity of 3 NTU, fecal <20/100 mL (geo. mean); fecal <75/100 mL (single grab sample) |
| Oregon | Walt West | Department of Environmental Quality | Division 55, Regulations Pertaining to the Use of Reclaimed Water (Treated Effluent) from Sewage Treatment Plants | 2.2/100 mL 7-day median total coliforms, 23/100 mL maximum coliform, 2 NTU, 24 hour max 5 NTU, 5% of time during 24 hours |
| Washington | Kathy Cupps | Department of Ecology | Water Reclamation and Reuse Standards | Direct recharge into potable gw aquifer (oxidation, filtration, RO, disinfection) drinking water MCLs, turbidity <0.1 NTU, nitrogen <10 mg/L, TOC <1.0 mg/L, turbidity <2 NTU, total coliforms 1/100 mL median of previous 7 days, 5/100 mL maximum. |

### *5.3.2 Florida*

A response was received from David W. York, Ph.D. P.E, reuse coordinator for the Florida State Department of Environmental Protection in a letter dated July 3, 2001. The letter listed the reclaimed water requirements for Florida and indicated that the State does not approve specific products, but instead reviews processes on a case-by-case basis during the Department's review of permit applications. The letter went on to state that "the performance of the Mitsubishi system was encouraging" and that "the well-conceived study yielded a wealth of valuable information". The system met turbidity requirements, would most likely met TSS requirements based on the low turbidity, (TSS was not measured), had no detectable fecal coliforms in 99 percent of samples and exceed 6 logs removal of fecal coliforms in about 70 percent of samples, and achieved a $50^{th}$ percentile of 3.8 logs removal of MS2 virus.

### *5.3.3 Texas*

The Texas Natural Resource Conversation Commission did not respond to the approval request letter, after repeated requests.

### *5.3.4 Oregon*

The Oregon Department of Environmental Quality informed us in an email dated July 28, 2001 that they would not be providing comments on the Mitsubishi MBR process due to work loads and time restrictions.

### *5.3.5 Washington*

A response was received from Kathy Cupps, P.E, Ecology Water Reclamation Lead Engineer for the Washington State Department of Ecology in a letter dated July 3, 2001. The letter stated the following:

- The Ecology Department does not approve proprietary technologies, but rather each individual reclamation facility design is reviewed in accordance with the specific application.

- When the Ecology Department has not established standards for new technology, it looks for justification from other State experiences. In Ms. Cupps opinion, the membrane standards of California State Title 22 could be considered as appropriately conservative for the filtration step in Washington State Class A reclaimed water.
- In Ms. Cupps opinion, the NWRI study would satisfy the requirements of a Class A equivalent filtration technology for water reclamation facilities that would propose to use of MBR technology.
- This approval would be contingent on membrane and wastewater characteristics at the proposed facility that do not deviate substantially from the membrane and wastewater characteristics for the NWRI study.
- The NWRI study does not fully demonstrate Ecology's requirement for nitrogen reduction when reclamation facilities discharge to ground water via surface percolation. The total nitrogen as N maximum is 10 mg/L in this case.
- Ms. Cupps would like to see more information on operations and maintenance costs, ease of cleaning procedure, required level of operator skill, and long-term operating viability. She states that perhaps the experience at the Arapahoe, Colorado facility would provide this.

A second reviewer at Washington State was Craig Riley, P.E. In addition to reiterating many of Ms. Cupps observations, Mr. Riley indicated that MBR could result in a reduction in the disinfection step required for Class A reclaimed water. The details of this reduction are presented in Mr. Riley's written response titled "DOH comments July, 2001, Membrane Bioreactor Recognition – Mitsubishi and Zenon," presented in Appendix E.

# SECTION 6

# Summary and Conclusions

## 6.1 BUREAU OF RECLAMATION STUDY

In October 1998 the City of San Diego was awarded a grant from the Bureau of Reclamation to evaluate the MBR process and its potential application to wastewater reclamation. During Part 1 of the study the system was operated in a nitrification/denitrification mode using an auxiliary anoxic tank. During Part 2, the pilot plant was operated in a nitrification only mode. The primary objectives of the Bureau of Reclamation project were to obtain long-term operational and performance data for the MBR process in treating primary wastewater effluent.

The Bureau of Reclamation study demonstrated the following:

- The MBR pilot system was capable of producing a good quality effluent water suitable for use by an RO system.
- Run times between chemical cleanings were reasonable.
- Very high removal of total and fecal coliforms and total coliphage was achieved.
- Excellent organic removal was achieved.
- The Mitsubishi MBR pilot system achieved complete nitrification and partial denitrification during Part 1, and complete nitrification during Part 2.

In a meeting with California DHS personnel in March 2000, DHS indicated that in order for California to consider the MBR process for a formal approval from the State that virus seeding studies would also be needed. In addition, the DHS indicated that approval would in part be based on the MBR's ability to demonstrate at least a 1-log removal of MS-2 virus at the $50^{th}$ percentile.

## 6.2 VIRUS SEEDING STUDY

As requested by DHS, virus-seeding studies were conducted using both primary effluent wastewater and Colorado River Water as the feed to the MBR. Four seedings were conducted

using each feed water. Two of the seedings were conducted at low fouled conditions, one at medium fouled condition and one at a high fouled condition. Samples were taken from the MBR permeate, the MBR feed water and the activated sludge. Sludge concentrations were approximately 1 log lower than feed water concentrations because of lower recovery of the organism from sludge samples. Log removals of virus were calculated based on both feed water and sludge concentrations. The $50^{th}$ percentile log removal of MS-2 exceeded 2 logs in all cases, thus exceeding the DHS requirement of l log removal

## 6.3 REGULATORY APPROVAL

State regulators from California and 5 other States were requested to review the MBR operational and virus seeding results presented in a preliminary version of this report and provide a written response with regard to the MBR ability to meet State wastewater reclamation criteria. The individual responses are summarized below.

### *6.3.1 California*

Mr. Jeff Stone, Chief of the Water Recycling Unit at the California DHS was sent a letter requesting approval of the Mitsubishi MBR process as an acceptable filtration technology under California Title 22. In a letter dated April 23, 2001, Mitsubishi received notification from the California DHS that the studies conducted sufficiently demonstrated the Mitsubishi MBR ability to comply with State Recycling Criteria as a filtration technology under Title 22. The MBR permeate met all turbidity requirements and demonstrated greater than 1-log removal of seeded MS2 virus. Further the DHS stipulated that the acceptance was granted specifically for the Sterapore 0.4 micron pore size membrane, operating at a flux no greater than 13 gfd and a maximum vacuum pressure of –5.8 psi.

### *6.3.2 Arizona*

The Arizona response letter states "the Mitsubishi MBR appears to meet the effluent requirements for Class A reclaimed water in accordance with AAC R18-9-303 and the treatment performance requirements found in AAC R19-9-B204." It also states that "the Mitsubishi MBR does not appear to meet the toal nitrogen criteria of 10 mg/L found in AAC R18-9-B204."

### *6.3.3 Florida*

The Florida response letter states that "the performance of the Mitsubishi system was encouraging" and that "the well-conceived study yielded a wealth of valuable information". The system met turbidity requirements, would most likely met TSS requirements based on the low turbidity, (TSS was not measured), had no detectable fecal coliforms in 99 percent of samples and exceed 6 logs removal of fecal coliforms in about 70 percent of samples, and achieved a $50^{th}$ percentile of 3.8 logs removal of MS2 virus.

### *6.3.4 Texas*

No response was received from Texas.

### *6.3.5 Washington*

The Washington response letter indicated the following.

- The membrane standards of California State Title 22 could be considered as appropriately conservative for the filtration step in Washington State Class A reclaimed water.
- The NWRI report would satisfy the requirements of a Class A equivalent filtration technology for water reclamation facilities that would propose to use of MBR technology.
- The NWRI report does not fully demonstrate Ecology's requirement for nitrogen reduction when reclamation facilities discharge to ground water via surface percolation. The total nitrogen as N maximum is 10 mg/L in this case.
- The State would like to see more information on operations and maintenance costs, ease of cleaning procedure, required level of operator skill, and long-term operating viability.

Regulators from every State but California indicated they do not approve proprietary technologies. All States indicated they would review individual reclamation facility designs in accordance with their ability to meet the requirements of a specific application.

The responses received from California and the additional states are encouraging. The information exchanged with these states could provide a strong foundation for greater acceptance, approval and use of the MBR technology in these and other states across the country.

# SECTION 7

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# APPENDIX A

# MEETING MINUTES

# MEMORANDUM

Aqua 2000

Aqua 2000 Research Center
14103 Highland Valley Road
Escondido, California 92025

**Date:** 3/2/00

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**To:** Samer Adham, PhD

**From:** Rion Merlo and Shane Trussell

**Subject:** Meeting Minutes

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Subject: California Department of Health Services visit to the Aqua 2000 Research Center to discuss the results from the MBR pilot testing and MBR process compliance with Title 22.

Attendees:

| | |
|---|---|
| Samer Adham | (MWH) |
| Daniel Askenaizer | (MWH) |
| Brian Bernados | (California Department of Health Services) |
| Paul Gagliardo | (City of San Diego) |
| Edward Hitti | (California Department of Health Services) |
| Rion Merlo | (MWH) |
| Toby Roy | (California Department of Health Services) |
| Rick Sakaji | (California Department of Health Services) |
| Jeff Stone | (California Department of Health Services) |
| Rhodes Trussell | (MWH) |
| R. Shane Trussell | (MWH) |
| Jeff Williams | (City of San Diego) |

WELCOME AND INTRODUCTIONS:

Paul Gagliardo: The purpose of this MBR testing has been to investigate the operation and cost-effectiveness of the MBR process and to investigate the feasibility of getting Title 22 approval for the MBR process to use the product water as reclaimed water. The Metro Waste Water Department is close to making a decision about replacing the existing treatment system at San Pasqual with an MBR process.

PRESENTATION OF BUREAU OF RECLAMATION RESULTS:

Samer Adham presented data from the Bureau of Reclamation funded project, "Membrane Bioreactors for Water Reclamation." The issue of coliform breakthrough in the Zenon MBR was discussed. Possibilities of permanent pore blocking and possible contamination of the piping were discussed, however the point was continually highlighted that the process is still getting

much better removals than a tertiary filtration step. Samer indicated that the testing of the MBR process would be shut down by the end of March 2000.

With regard to the coliform results the project team indicated that the membrane is not an absolute barrier. However, from the data, it appears that when the UF was installed the high total coliforms are only residual growth in the line from the previous run with the MF membrane.

DHS agreed with this observation. From the data, the fecal coliforms dropped to non-detect immediately after the installation of the UF (OCP) membrane. It appears that the total coliforms are only residual.

The project team observed that there is only a slight chance that the total coliform are due to residual growth because they made a concerted effort to eliminate all contamination issues. The permeate line was chlorinated twice per week with 200 ppm of free chlorine for an hour, not counting the full chemical cleans. In fact, a micro sample was collected immediately after the membrane, before going through any piping. Possibly, there's a dead spot in the line where the coliform could still grow, but it is highly unlikely that it did not get disinfected.

During the discussion that followed, the project team indicated that they have reason to believe that the Zenon membrane used in wastewater is made from the same material as the drinking water membrane, but it does not have the same pore distribution as the drinking water membrane. The manufacturer has indicated that they are the same membrane.

The DHS indicated that if that were the case, then it is not the same membrane. DHS indicated a concern with regard to manufacturing issues that were discussed, and stated that their position is to be very strict on manufacturing issues.

The project team observed that this raises an important issue regarding how to regulate membrane manufacturing, and that currently there is no such process in place.

The discussion moved to obtaining Title 22 approval. DHS indicated that Title 22 requires a 0.2 NTU effluent turbidity combined with disinfection to achieve a total of 5 log removal of virus. To get DHS approval, the MBR would need to achieve a 1-log removal of virus.

The project team suggested that we could test the MBRs by feeding poliovirus to the systems and adding a disinfection unit (chlorine contacter or UV disinfection) after the MBR. We could monitor the influent and effluent for poliovirus in order to determine if the system could achieve 5-log removal of virus. We could also spike the influent with MS-2 phage and see if we can recover any from the primary effluent. Another suggestion was that the testing could use Colorado aqueduct water spiked with phage. This would represent a "worst-case" testing scenario for the MBR process.

The project team, however, also observed that such testing will be unfair to the "MBR process". The Mitsubishi MF will not provide one log removal of virus (based upon the $95^{th}$ percentile) when challenged in a "solids-free" environment. If this is the case and the Mitsubishi MBR does not achieve the required virus reduction for Title 22 approval, this could leave only one potential manufacturer for the full-scale bid.

The DHS indicated that could consider basing virus credit on the 50$^{th}$ percentile of virus rejection.

The project team indicated that during the remainder of the month of March, they will conduct testing for the purposes of obtaining Title 22 approval for the MBR.

DHS discussed the process for submitting the proposal to obtain Title 22 approval to the Water Reclamation Committee (proposals could either be submitted in writing with supporting documentation, or a presentation could be made to the committee.)

At the end of the meeting, DHS requested information on the status of the n-Nitrosodimethylamine (NDMA) testing? Previously, the project team indicated that there would be sampling for NDMA conducted as part of this project. The project team indicated that MWH Laboratories has resolved issues with regard to the analytical method and that samples for NDMA will be collected this week. The current action level has been set at 20 ppt (initially the action level had been set at 2 ppt, but was recently raised by DHS as part of an investigation as to whether or not NDMA is a disinfection byproduct).

As an additional action item, DHS requested that Zenon must provide a written statement that the wastewater/water OCP membranes are identical.

ACTION ITEMS

1. MWH will contact Zenon, and request that they provide a written statement to Jeff Stone, DHS, indicating that the water OCP membrane and the wastewater OCP membrane are the same membrane and are manufactured using the same procedures.
2. MWH will conduct testing with the goal of obtaining virus reduction results for Title 22 approval.

# APPENDIX B

# CHEMICAL CLEANING PROCEDURE

**Mitsubishi MBR In-Line Chemical Cleaning Protocol**

Chemical Reagent: NaOCl (effective chlorine concentration: 3,700 mg/L)
Volume of Chemical Reagent: 0.186 L/ft$^2$ of membrane area

1. Stop the vacuum pump
2. Place the chemical tank 1 m above the membrane injection port
3. Connect the chemical tank to the chemical injection port
4. Open the valve of the chemical tank and chemical injection port, and operate the vacuum pump for 30 s
5. Stop the vacuum pump
6. Inject 30 L reagent for 10 min (this was changed to 45 L for 15 min for all cleanings after the initial cleaning)
7. Inject 70 L reagent for 2 h (this was changed to 105 L for 3 h for all cleanings after the initial cleaning)
8. Place the system in normal operation

# APPENDIX C

# CALIFORNIA REQUEST AND ACCEPTANCE LETTERS

**MONTGOMERY WATSON**
Applied Research Department



March 21, 2001

Jeff Stone
California Department of Health Services
1180 Eugenia Place, Suite 205
Carpinteria, CA 93010-2000

Re: Request for Mitsubishi MBR Approval under Title 22 Water Recycling Criteria

Dear Mr. Stone:

Please find enclosed a copy of the final report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." As discussed earlier, Montgomery Watson is requesting California Department of Health Services (CDHS) approval of the Mitsubishi Membrane Bioreactor (MBR), employing the Sterapore HF microfiltration membrane, as acceptable treatment technology for compliance with the California Wastewater Reclamation Criteria (Title 22).

This final report addresses comments received from you and the membrane manufacturer. The comments were addressed as follows:

1. All references to "Draft" report have been changed to "Final" report.
2. The typographical error in Table 2-3 listing the membrane nominal pore size as 0.4 mm instead of 0.4 um has been corrected.
3. The category "Design Flux" in Table 2-3 has been further specified as "Recommended Design Flux",
4. The category "Approval Study Test Flux" has been added to Table 2-3.
5. "Sterapore" is the trade name for a product category of Mitsubishi membranes. Specifically, the membrane tested and the membrane for which approval is being requested is the "**Mitsubishi Sterapore HF**" membrane.
6. The manufacturer's recommended design flux is 9.9 gfd. The approval study was conducted at a test flux of 13 gfd to demonstrate to the CDHS that the membrane was capable of meeting operational and microbial performance objectives at a flux greater than the recommended design flux. The CDHS issues approval of membrane products for use in full-scale drinking water applications up to a maximum flux. This maximum flux is defined by the CDHS as the test flux at which microbial challenge studies were conducted, and is typically well above the manufacturers recommended design flux. The higher approval flux allows full-scale plants employing that specific membrane technology the flexibility to operate their plants beyond the recommended design flux when feasible.

7. Dissolved oxygen concentrations in the aerobic and anoxic tank for Part 1 of testing and the anoxic tank for Part 2 of testing have been added to the report as Section 3.2.2.

Please let me know if we can provide you with any additional information. Thank you in advance for your consideration of this request.

If you have any questions, please feel free to call me at (626) 568-6751.

Sincerely yours,

- Samer -

Samer Adham, Ph.D.

cc: Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Daniel Askenaizer (MW)

Enclosures

STATE OF CALIFORNIA—HEALTH AND HUMAN SERVICES AGENCY
GRAY DAVIS, Governor

DEPARTMENT OF HEALTH SERVICES
DIVISION OF DRINKING WATER AND ENVIRONMENTAL MANAGEMENT
TECHNICAL OPERATIONS SECTION
RECYCLED WATER UNIT
1180 Eugenia Place, Suite 200
Carpinteria, CA 93013
(805) 566-9787
FAX (805) 566-4790

April 23, 2001

Mr. Lei Ge
Mitsubishi International Corporation
333 South Hope Street West, Suite 2500
Los Angeles, CA 90071

Subject: Use of the Mitsubishi MBR to comply with California Water Recycling Criteria

Dear Mr. Ge:

By letter dated March 21, 2001, Montgomery Watson requested Departmental approval of the Mitsubishi Membrane Bioreactor (MBR) filtration treatment unit as an acceptable filtration technology for compliance with the State of California Water Recycling Criteria (Title 22). Accompanying this request was a report prepared by Montgomery Watson entitled "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon, Ltd.)", dated March 2001. The report was prepared for the National Water Research Institute. The Department has reviewed this report and offers the following comments.

The Mitsubishi MBR filtration system evaluated utilizes the Sterapore hollow fiber polyethylene membrane with a nominal pore size of 0.4 micron. The membranes are submerged and operated in the feed-and-bleed mode under vacuum pressure with a test flux of 13 gallons per square foot per day (gfd).

The California Water Recycling Criteria recognize membrane filtration as an acceptable filtration technology provided prescribed performance requirements (i.e. turbidity) are reliably met. The turbidity performance criteria require that the filtered wastewater not exceed any of the following:

1. 0.2 NTU more than 5 percent of the time within a 24-hour period; and

2. 0.5 NTU at any time.

The demonstration studies conducted using the Mitsubishi MBR have sufficiently demonstrated the ability to produce an oxidized wastewater and the membranes ability to comply with the above stated turbidity performance requirements. In addition, virus seeding experiments demonstrated the processes ability to achieve a 1-log virus reduction at the 50$^{th}$ percentile. Therefore, the Department of Health Services accepts the use of this membrane, identified as Mitsubishi MBR Sterapore hollow fiber membrane, as a filtration technology for use in compliance with the Water Recycling Criteria. Based on the performance data, the membrane filtration units will be limited to a maximum loading rate of 13 gfd and a maximum operating vacuum pressure of -5.8 psi.

The acceptance of your technology is specific to the Mitsubishi Sterapore hollow fiber polypropylene membrane having a nominal pore size of 0.4 mm. Any proposed changes made in the physical attributes or character of this membrane shall be reviewed in advance by the Department to determine whether the modifications will require additional testing.

The Department will continue to review all proposed projects on a case-by-case basis to determine full compliance with all applicable treatment and reliability features required by the Water Recycling Criteria. This will include the collective review of all treatment unit processes, operational controls (e.g. loading rates, TMP, frequency of integrity tests), 'O&M' procedures, etc.

If you have any questions concerning this letter, please contact the undersigned at (805) 566-9767.

Sincerely,

Jeffrey L. Stone, Chief
Recycled Water Unit
Division of Drinking Water

cc: Montgomery Watson – Samer Adham
National Water Research Institute – Ron Linsky
City of San Diego – Paul Gagliardo
Recycled Water Committee

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# APPENDIX D

# ADDITIONAL STATE REVIEW REQUESTS

# Arizona

**MONTGOMERY WATSON**
Applied Research Department

FILE
Client #:
File #:
Job #:

June 18, 2001

Mr. Greg Brown
Wastewater Design Unit Manager
Arizona Department of Environmental Quality
3033 North Central Ave
Phoenix, AZ 85012

**Re: Request for Mitsubishi MBR Recognition Under AAC Section R18-11-303**

Dear Mr. Brown,

On June 13, 2001 you spoke with Dr. Dan Askenaizer of Montgomery Watson regarding the issue of State recognition of membrane bioreactor technology as capable of producing an effluent meeting specific reclamation criteria contained in the Arizona Administrative Code. This letter is being sent to you as a followup to that discussion.

Earlier this year California's Department of Health Services (DHS) recognized in a letter that the Mitsubishi MBR technology (as tested) can produce an effluent meeting the requirements of the State's water reclamation criteria. DHS was careful, however, to indicate that they will continue to review the application of the MBR technology on a case-by-case, project-by-project basis. The National Water Research Institute (NWRI) is interested in purposing similar types of feedback from State regulatory agencies around the US. NWRI thus funded this effort which is being managed by Montgomery Watson. NWRI has funded numerous studies with the goal of promoting the use of water reclamation technology.

After a discussion with Marcie Mullins of the Arizona DEQ, the same information that was sent to the California DHS for their review was sent to Mr. Asif Majeed (cover letter dated May 10, 2001). Per your request we are sending the same information as sent to Mr. Majeed to your attention. If possible, we would like to receive a formal response from the State of Arizona (like what was provided by California DHS) regarding the ability of the MBR technology to meet specified effluent criteria. If that is not possible, we would appreciate any guidance you could provide as to how and under what procedures the State would review the application of such technology.

What follows below is the text of the letter to Mr. Majeed. Thank you in advance for your consideration and any response that you can provide.

## Introduction

Please find enclosed a copy of the report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." In October 1998 the City of San Diego and Montgomery Watson were awarded a grant from the Bureau of Reclamation to evaluate the Membrane Bioreactor (MBR) and its potential application to wastewater reclamation. This report includes a summary of the results and observations from the study conducted using the Mitsubishi MBR. A second, smaller study, funded by the National Water Research Institute, is building upon the efforts of the Bureau of Reclamation study to conduct a more in-depth evaluation of state regulatory issues associated with the MBR process. Part of this effort includes contacting individual State regulatory agencies and requesting their review of the enclosed material.

## California DHS Review

During the Bureau of Reclamation funded study initial contacts were made with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process. During those discussions, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus seeding experiments were conducted to provide that needed information. The virus seeding studies are described in the enclosed report. The enclosed report was submitted to the California DHS with the request for approval of the MBR technology as meeting the State's water reclamation criteria for filtration.

After reviewing the enclosed information the California DHS has written a letter recognizing that the MBR technology is an acceptable filtration technology for use in meeting the State's Water Recycling Criteria. A copy of the letter from Mr. Jeff Stone of the California Department of Health Services (DHS) is also enclosed. Mr. Stone can be reached at (805) 566-9767.

## Request for ADEQ Review

Montgomery Watson is requesting a review and response from the Arizona Department of Environmental Quality (ADEQ) that the Mitsubishi MBR filtration is an acceptable "alternative treatment method" for compliance with Arizona Administrative Code, Section R18-11-303 Class A+ Reclaimed Water (Section R18-11-303(A)-R18-11-303(C)).

According to Section R18-11-303(B)-(C), a Class A+ reclaimed water must meet the following requirements:

1. The turbidity of the reclaimed water effluent prior to disinfection must meet a 24-hour turbidity of 2 NTU or less, never to exceed 5 NTU.
2. After disinfection the effluent must have no detectable fecal coliforms in 4 of the last 7 daily samples and the single maximum must be below 23/100 mL.

3. If an alternative process is used, there must be no detectable enteric virus in 4 of the last 7 monthly samples.
4. The 5-sample geometric mean concentration of total nitrogen in a reclaimed water is less than 10 mg/L.
5. Alternative treatment may be used (other than secondary treatment, filtration, nitrogen removal and disinfection) provided there is a demonstration through pilot plant testing, water quality data or other means that the reclaimed water effluent meets the disinfection criteria and the total nitrogen criteria.

Based on the results obtained during the Bureau of Reclamation funded study, and the additional virus removal challenge studies that are presented in the enclosed report, we believe the Mitsubishi Rayon Co., Ltd. MBR process met the turbidity performance criteria, the disinfection performance criteria, the nitrogen performance criteria as well as the virus reduction performance criteria.

If you believe this enclosed information is adequate, Montgomery Watson and the NWRI would like to request a formal response from ADEQ recognizing that MBR is capable of producing a Class A+ reclaimed water as described in Arizona Administrative Code Section R18-11-303. We recognize that any approved use of the MBR technology on a given reclamation project within the State must go through a formal review and approval process to determine compliance with all applicable treatment and reliability requirements.

Please let me know if we can provide you with any additional information. I can be reached at (626) 568-6751. Thank you in advance for your consideration of this request.

Sincerely,

Samer

Samer Adham, Ph.D.
Montgomery Watson

cc w/o enclosures
Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Dan Askenaizer (Montgomery Watson)

Enclosures

# Florida

MONTGOMERY WATSON
Applied Research Department

May 10, 2001

Dr. David York
Reuse Coordinator
Florida Department of Environmental Protection
Tallahassee, FL 32399-2400

**Re: Request for Recognition of MBR Performance Per State Reclamation Criteria**

Dear Dr. York,

Please find enclosed a copy of the report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." In October 1998 the City of San Diego and Montgomery Watson were awarded a grant from the Bureau of Reclamation to evaluate the Membrane Bioreactor (MBR) and its potential application to wastewater reclamation. This report includes a summary of the results and observations from the study conducted using the Mitsubishi MBR. A second, smaller study, funded by the National Water Research Institute, is building upon the efforts of the Bureau of Reclamation study to conduct a more in-depth evaluation of state regulatory issues associated with the MBR process. Part of this effort includes contacting individual State regulatory agencies and requesting their review of the enclosed material.

**California DHS Approval of MBR Technology**

During the Bureau of Reclamation funded study initial contacts were made with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process. During those discussions, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus seeding experiments were conducted to provide that needed information. The virus seeding studies are described in the enclosed report. The enclosed report was submitted to the California DHS with the request for approval of the MBR technology as meeting the State's water reclamation criteria for filtration.

After reviewing the enclosed information the California DHS has written a letter recognizing that the MBR technology is an acceptable filtration technology for use in meeting the State's Water Recycling Criteria. A copy of the letter from Mr. Jeff Stone of the California DHS is also enclosed. Mr. Stone can be reached at (805) 566-9767.

**Request for Florida DEP Review of MBR Results**

Montgomery Watson is requesting a formal response from the Florida Department of Environmental Protection (DEP) that the Mitsubishi MBR filtration is capable of producing an effluent water that meets the quality criteria specified in the Florida

Administrative Code Section 62-610.460 Waste Treatment and Disinfection and Section 62-600.440(5) on high-level disinfection.

According to Section 62-610.460 the reclaimed water effluent shall contain less than 5 mg/L of suspended solids. The section goes on to state that "Filtration shall be provided for TSS control. Chemical feed facilities for coagulant, coagulant aids, or polyelectrolytes shall be provided. Such chemical feed facilities may be idle if the TSS limitation is being achieved without chemical additional.....Filtration also serves as the primary barrier for removal of protozoan pathogens (Cryptosporidium, Giardia and others)."

According to Section 62-600.440(5) facilities should provide additional TSS control (beyond secondary treatment levels) and shall be designed to result in a reclaimed water in which fecal coliform values are below detectable limits.

If you believe this enclosed information is adequate, Montgomery Watson and the NWRI would like to request a formal response from Florida DEP recognizing that MBR is capable of producing a reclaimed water meeting the requirements contained in Sections 62-610.460 and 62-600.440(5). We recognize that any approved use of the MBR technology on a given reclamation project within the State must go through a formal review and approval process to determine compliance with all applicable treatment and reliability requirements.

Please let me know if we can provide you with any additional information. I can be reached at (626) 568-6751. Thank you in advance for your consideration of this request.

Sincerely,

Samer

Samer Adham, Ph.D.
Montgomery Watson

cc w/o enclosures
Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Dan Askenaizer (Montgomery Watson)

Enclosures

# Oregon

MONTGOMERY WATSON
Applied Research Department

May 17, 2001

Ms. Judy Johndohl
Municipal Wastewater Specialist
Oregon Department of Environmental Quality
811 SW 6th Street
Portland, OR 97204

**Re: Request for Mitsubishi MBR Recognition**

Dear Ms. Johndohl,

I regret that recently you and Dan Askenaizer have been unable to talk prior to my sending you this letter. Given the short timeframe for our project with the National Water Resources Institute (NWRI) I have decided to go ahead and send you this information and request. We are sending this information to a number of states across the country.

Please find enclosed a copy of the report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." In October 1998 the City of San Diego was awarded a grant from the Bureau of Reclamation to evaluate the Membrane Bioreactor (MBR) and its potential application to wastewater reclamation. This report includes a summary of the results and observations from the study conducted using the Mitsubishi MBR. A second, smaller study, funded by the National Water Research Institute, is building upon the efforts of the Bureau of Reclamation study to conduct a more in-depth evaluation of state regulatory issues associated with the MBR process. Part of this effort includes contacting Individual State regulatory agencies and requesting their review of the enclosed material.

**California DHS Review**

During the Bureau of Reclamation funded study initial contacts were made with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process. During those discussions, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus seeding experiments were conducted to provide that needed information. The virus seeding studies are described in the enclosed report. The enclosed report was submitted to the California DHS with the request for approval of the MBR technology as meeting the State's water reclamation criteria for filtration.

After reviewing the enclosed information the California DHS has written a letter recognizing that the MBR technology is an acceptable filtration technology for use in

meeting the State's Water Recycling Criteria. A copy of the letter from Mr. Jeff Stone of the California Department of Health Services (DHS) is also enclosed. Mr. Stone can be reached at (805) 566-9767.

**Request for Oregon DEQ Review**

Montgomery Watson is requesting a review and response from the Oregon Department of Environmental Quality that the Mitsubishi MBR technology is an acceptable filtration technology to meet the intent of section 340-055-0015 (4)(a) of Division 55 (Regulations Pertaining to the Use of Reclaimed Water (treated Effluent) from Sewage Treatment Plants) wherein it states the following:

"Where Table 1, for specified uses, requires that reclaimed water receive biological, coagulation, clarification, filtration treatment plus disinfection, the Department will consider treatment processes that do not utilize coagulation provided that equivalent effluent quality to that achieved with coagulation can be demonstrated. (emphasis added) The Department shall consult with the Oregon Health Division when considering alternative treatment processes allowed for under this section."

Based on the results obtained during the Bureau of Reclamation funded study and the additional virus removal challenge studies that are presented in the enclosed report we believe the Mitsubishi Rayon Co., Ltd. MBR process met the turbidity performance criteria (contained in section 340-055-0010(14) definition of filtration), and the coliform limits described in Table 1 in Division 55 (Regulations Pertaining to the Use of Reclaimed Water (Treated Effluent) from Sewage Treatment Plants).

If you believe this enclosed information is adequate, Montgomery Watson and the NWRI would like to request a formal response from Oregon Department of Environmental Quality recognizing that MBR is capable of producing effluent quality equivalent to the requirements for filtration technology using coagulation as described in the Oregon Administrative Code. We recognize that any approved use of the MBR technology on a given reclamation project within the State must go through a formal review and approval process to determine compliance with all applicable treatment and reliability requirements.

Please let me know if we can provide you with any additional information. I can be reached at (626) 568-6751. Thank you in advance for your consideration of this request.

Sincerely,

Samer

Samer Adham, Ph.D.
Montgomery Watson

cc w/o enclosures
Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Dan Askenaizer (Montgomery Watson)

Enclosures

# Texas

MONTGOMERY WATSON
Applied Research Department

May 10, 2001

Mr. Louis Herrin
TNRCC, MC-148
P.O. Box 13087
Austin, TX 78711

Texas Natural Resource Conservation Commission

**Re: Request for Mitsubishi MBR Recognition Under AAC Section R18-11-303**

Dear Mr. Herrin,

Please find enclosed a copy of the report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." In October 1998 the City of San Diego and Montgomery Watson were awarded a grant from the Bureau of Reclamation to evaluate the Membrane Bioreactor (MBR) and its potential application to wastewater reclamation. This report includes a summary of the results and observations from the study conducted using the Mitsubishi MBR. A second, smaller study, funded by the National Water Research Institute, is building upon the efforts of the Bureau of Reclamation study to conduct a more in-depth evaluation of state regulatory issues associated with the MBR process. Part of this effort includes contacting individual State regulatory agencies and requesting their review of the enclosed material.

**California DHS Review**

In addition a copy of the letter received from Mr. Jeff Stone of the California Department of Health Services (DHS) is also enclosed. During initial contacts with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus seeding experiments were conducted to provide that needed information and are described in the enclosed report. The letter from Mr. Stone of DHS to Mr. Lei Ge of Mitsubishi grants the Mitsubishi MBR conditional approval for use in California. Mr. Stone can be reached at (805) 566-9767.

**Request for TNRCC Review**

Montgomery Watson is requesting a formal response from the Texas Natural Resource Conservation Commission (TNRCC) that the Mitsubishi MBR filtration can produce an effluent water that meets the quality criteria specified in Chapter 210-Use of Reclaimed

Water, Subchapter C, Section 210.33 (1) Quality Standards for Using Reclaimed Water in the Texas Administrative Code.

According to Section 210.33 (1) Quality Standards for Using Reclaimed Water reclaimed water must meet the following requirements for a Type I reclaimed water use (based on a 30-day average):

1. BOD5 or CBOD5 of 5 mg/L
2. Turbidity of 3 NTU,
3. Fecal Coliform of 20 cfu/100 mL (geometric mean)
4. Fecal Coliform (not to exceed) 75 cfu/100 mL (single grab sample)

Based on the results obtained during the Bureau of Reclamation funded study and presented in the enclosed report the Mitsubishi Rayon Co., Ltd. MBR process met the turbidity performance criteria, the disinfection performance criteria, the nitrogen performance criteria as well as the virus reduction performance criteria.

Please let me know if we can provide you with any additional information. I can be reached at (626) 568-6751. Thank you in advance for your consideration of this request.

Sincerely,

Samer

Samer Adham, Ph.D.
Montgomery Watson

cc w/o enclosures
Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Dan Askenaizer (Montgomery Watson)

Enclosures

# Washington

MONTGOMERY WATSON
Applied Research Department

May 10, 2001

Ms. Kathy Cuppe, P.E.
Water Reclamation and Reuse Lead
Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

**Re: Request for Mitsubishi MBR Recognition**

Dear Ms. Cuppe,

Please find enclosed a copy of the report "Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)." In October 1998 the City of San Diego and Montgomery Watson were awarded a grant from the Bureau of Reclamation to evaluate the Membrane Bioreactor (MBR) and its potential application to wastewater reclamation. This report includes a summary of the results and observations from the study conducted using the Mitsubishi MBR. A second, smaller study, funded by the National Water Research Institute, is building upon the efforts of the Bureau of Reclamation study to conduct a more in-depth evaluation of state regulatory issues associated with the MBR process. Part of this effort includes contacting individual State regulatory agencies and requesting their review of the enclosed material.

**California DHS Approval of MBR Technology**

During the Bureau of Reclamation funded study initial contacts were made with representatives of the California Department of Health Services (DHS) on regulatory requirements for the MBR process. During those discussions, DHS staff requested additional data showing the ability of the MBR process to remove viruses. As part of the NWRI study, therefore, virus seeding experiments were conducted to provide that needed information. The virus seeding studies are described in the enclosed report. The enclosed report was submitted to the California DHS with the request for approval of the MBR technology as meeting the State's water reclamation criteria for filtration.

After reviewing the enclosed information the California DHS has written a letter recognizing that the MBR technology is an acceptable filtration technology for use in meeting the State's Water Recycling Criteria. A copy of the letter from Mr. Jeff Stone of the California DHS is also enclosed. Mr. Stone can be reached at (805) 566-9767.

**Request for Review by Washington Department of Ecology**

Montgomery Watson is requesting a formal response from the Washington Department of Ecology that the Mitsubishi MBR filtration is capable of producing an effluent water that meets the language provided in the Water Reclamation and Reuse Standards (September 1997) for a Class A reclaimed water.

Specifically, the Washington State Water Reclamation and Reuse Standards provides the following definitions:

Class A Reclaimed Water – means reclaimed water that, at a minimum, is at all times an oxidized, coagulated, filtered, disinfected wastewater. The wastewater shall be considered adequately disinfected if the median number of total coliform organisms in the wastewater after disinfection does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed, and the number of total coliform organisms does not exceed 23 per 100 milliliters in any sample.

The requirements of a Class A reclaimed water is addressed in the additional definitions presented below that are contained within the Water Reclamation and Reuse Standards:

Coagulated Wastewater – means an oxidized wastewater in which colloidal and finely divided suspended matter have been destabilized and agglomerated prior to filtration by the addition of chemicals or by an equally effective method.

Disinfected wastewater means wastewater in which pathogenic organisms have been destroyed by chemical, physical or biological means.

Filtered Wastewater – means an oxidized, coagulated wastewater which has been passed through natural undisturbed soils or filter media, such as sand or anthracite, so that the turbidity as determined by an approved laboratory method does not exceed an average operating turbidity of 2 nephelometric turbidity units (NTU), determined monthly, and does not exceed 5 NTU at any time.

Oxidized Wastewater means wastewater in which organic matter has been stabilized such that the biochemical oxygen demand (BOD) does not exceed 30 mng/L and the total suspended solids (TSS) do not exceed 30 mg/L, is nonpotrscible, and contains dissolved oxygen.

Based on the results obtained during the Bureau of Reclamation funded study and the virus seeding study presented in the enclosed report on the Mitsubishi MBR, we believe the effluent from the MBR process would meet the definition of a Class A reclaimed water.

If you believe this enclosed information is adequate, Montgomery Watson and the NWRI would like to request a formal response from Washington Department of Ecology recognizing that MBR is capable of producing a Class A reclaimed water as described in the state's Water Reclamation and Reuse Standards . We recognize that any approved use of the MBR technology on a given reclamation project within the State must go through a formal review and approval process to determine compliance with all applicable treatment and reliability requirements.

Please let me know if we can provide you with any additional information. I can be reached at (626) 568-6751. Thank you in advance for your consideration of this request.

Sincerely,

Samer

Samer Adham, Ph.D.
Montgomery Watson

cc w/o enclosures
Ron Linsky (NWRI)
Lei Ge (Mitsubishi)
Dan Askenaizer (Montgomery Watson)

Enclosures

# APPENDIX E

# ADDITIONAL STATE RESPONSES

# Arizona

Jane Dee Hull
Governor

# ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

1110 West Washington Street • Phoenix, Arizona 85007-2935
(602) 207-2300 • www.adeq.state.az.us

Jacqueline E. Schafer
Director

August 21, 2001

Samer Adham, Ph.D.
Montgomery Watson
250 N. Madison Ave
Pasadena, CA 91101

RE: Mitsubishi Membrane Bioreactor (MBR)

Dear Mr. Adham:

The Arizona Department of Environmental Quality (ADEQ) has received your request, dated June 18, 2001, for Mitsubishi MBR recognition under Arizona Administrative Code R18-9-303 for Class A+ reclaimed water. Attached to the request was a report prepared by Montgomery Watson entitled *Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd)*, March 2001. The report was prepared for the National Water Research Institute.

ADEQ does not provide product review approvals. ADEQ only provides technical review of technology when it is included as a component of an entire system designed for installation at a specific site under an aquifer protection permit in accordance with Arizona Administrative Code (AAC), Title 18, Chapter 9. However, review of the information presented in the report indicates that the Mitsubishi MBR appears to meet the effluent requirements for Class A reclaimed water in accordance with AAC R18-9-303 and the treatment performance requirements found in AAC R18-9-B204. The Mitsubishi MBR does not appear to meet the total nitrogen criteria of 10 mg/l found in AAC R18-9-B204.

If you have any questions or comments, please call me at 602-207-4697, or toll free in Arizona at 800-234-5677, extension 4697.

Sincerely,

Gregory H. Brown, P.E.
Wastewater Design Review Unit Manager
Water Permits Section
Water Quality Division

**EHP:01-2202**

Northern Regional Office
1515 East Cedar Avenue • Suite F • Flagstaff, AZ 86004
(520) 779-4214

Southern Regional Office
400 West Congress Street • Suite 433 • Tucson, AZ 85701
(520) 628-6733

# Florida

# Department of Environmental Protection

Jeb Bush
Governor

Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

David B. Struhs
Secretary


July 3, 2001

Dr. Samer S. Adham
Montgomery Watson
250 N Madison Avenue
Pasadena, CA 91101

Dear Dr. Adham:

Per your request, I reviewed the March 2001 report ***Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)***. The Mitsubishi membrane bioreactor (MBR) uses submerged membranes having nominal pore size of 0.4 microns. My comments follow:

On page 30, the report notes that Florida's most stringent reclaimed water limits are for discharges to Class I surface waters. Actually, the most stringent criteria are applied to ground water recharge projects that feature injection of reclaimed water to ground water having total dissolved solids (TDS) of 3,000 mg/L or less. This type of reuse system is regulated under Rule 62-610.560, Florida Administrative Code (F.A.C.). For this class of injection, the reclaimed water must meet the full treatment and disinfection requirements contained in Rule 62-610.563(3), F.A.C. A copy of Chapter 62-610, F.A.C., is enclosed for your reference. Reclaimed water must meet the primary and secondary drinking water standards (except for asbestos), a total nitrogen limit, and limits on total organic carbon and total organic halogen. Multiple barriers are required for control of organics and pathogens. We require that total suspended solids (TSS) be reduced by filtration below 5.0 mg/L as a single sample maximum before disinfection. We use total coliforms as our bacteriological indicator and require that no more than one sample be positive for total coliforms during a month and that no sample shall exceed 4 per 100 mL.

Part III of Chapter 62-610, F.A.C., regulates reclaimed water used to irrigate residential properties, public access areas, and edible crops. Filtration and high-level disinfection is required. High-level disinfection is defined in Rule 62-600.440(5), F.A.C. Filtration is required to reduce TSS below 5.0 mg/L as a single sample maximum before disinfection. Fecal coliforms are used as our indicator organism. At least 75 percent of observations of fecal coliforms must be below detection and no sample may exceed 25 per 100 mL.

Florida does not approve or endorse specific products or processes for wastewater treatment or water reclamation. Proposed projects and the unit processes involved are reviewed on a case-by-case basis during the Department of Environmental Protection's

review of permit applications. Hence, my comments on the Mitsubishi MBR do not constitute any form of state approval or endorsement.

This well-conceived study yielded a wealth of valuable information on the Mitsubishi MBR system. The performance of the Mitsubishi system was encouraging.

$BOD_5$ was reduced to less than 3 mg/L in 80 percent of the samples taken.

Turbidity was reduced to less than 0.1 NTU in 90 percent of the observations. The 99-percentile value was about 0.2 NTU. Unfortunately, TSS data were not included in the report. Hence, the ability of the process to meet Florida's 5.0-mg/L TSS limit cannot be directly addressed. However, given the excellent performance related to turbidity, it is likely that this system would be able to meet the single sample maximum TSS limit of 5.0 mg/L.

Removals of fecal coliforms also were excellent. About 99 percent of fecal coliform observations were less than 2 per 100 mL and log removals of fecal coliforms exceeded 6 logs in about 70 percent of observations. Virus removals (based on seeded trials using MS-2 bacteriophage) were good. The membranes removed 3.5 logs or less of MS-2 (reactor to permeate) in 20 percent of the observations. The 50-percentile log removal was about 3.8 logs. Removals exceeded 4.5 logs in about 20 percent of the observations. In general, virus removals increased somewhat as the degree of fouling increased. No data were presented on removal of the protozoan pathogens (notably Giardia and Cryptosporidium). As noted in our rules, there is growing interest in the protozoan pathogens in Florida. Proposals for implementation of alternative disinfection systems probably would need to be supported with virus and protozoan data in addition to documentation of the process' ability to meet Florida's coliform limits.

If you would like to discuss my comments or Florida's reuse criteria further, please call me at 850/922-2034. I can also be reached by e-mail at david.york@dep.state.fl.us.

Sincerely,

David W. York, Ph.D., P.E.
Reuse Coordinator

Enclosures

cc: Ron Linsky – NWRI
Sharon Sawicki – DEP
Elsa Potts – DEP

# Oregon

**WEST.Walt@deq.state.or.us on 07/28/2001 12:37:08 AM**

To: Daniel.askenaizer@mw.com
cc:

Subject:

Daniel, The Oregon DEQ will not be providing comments on the membrane activated sludge process that was submitted on your behalf. Due to work loads and time restrictions we are limited to reviewing these processes as they are proposed on a case by case basis.

Thank You,
Walt West, P.E.
ER -Bend Office
Bend, Oregon

# Texas

# Washington

WASHINGTON STATE DEPARTMENT OF ECOLOGY

# DEPARTMENT OF ECOLOGY ENGINEERING/TECHNICAL REVIEW COMMENTS

| | |
|---|---|
| **Date:** | **July 3, 2001** |
| **To:** | **Samer Adham, Ph.D.<br>Montgomery Watson** |
| **cc:** | **Craig Riley, P.E. Washington Department of Health<br>Water Reclamation Lead Engineer** |
| **From:** | **Kathy Cupps, P.E.<br>Ecology Water Reclamation Lead Engineer** |
| **Project:** | **Membrane Bioreactor Equivalency Determination** |
| **Prepared For:** | **National Water Research Institute Study** |

Craig Riley and I have received and reviewed the following reports which were submitted to my attention in May, 2001.

1. Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Mitsubishi Rayon Co., Ltd.)
2. Assessing the Ability of Membrane Bioreactor to Meet Existing Water Reuse Criteria (Zenon Environmental Inc.)

We also received copies of the review conducted by the California Department of Heath Services and your request to make a Class A equivalency determination for the membrane bioreactor technology. A copy of Mr. Riley's comments is attached. My comments are noted below.

1. Ecology does not approve proprietary technologies, per se. Each individual design is reviewed by the assigned engineer in accordance with the specific application. Ecology review includes engineering reports, plans and specifications and operation and maintenance manuals for reclaimed water facilities.

2. Ecology establishes or adopts minimum design criteria for technologies within our Criteria for Sewage Works Design, Publication No. 98-37 WQ (CSWD). Where criteria have not been established, Ecology looks for justification in standard engineering references. The CSWD discusses membrane technologies briefly in Chapter T4-2.6.1. Although specific design criteria for membrane treatment systems are not established in the CSWD, the following factors are required to be considered in evaluating membrane design.

   a. Flux rate
   b. Reject rate or recovery rate
   c. Transmembrane operating pressure
   d. Fouling rate
   e. Backwashing or chemical cleaning capabilities
   f. Overall operating costs including membrane replacement, power, chemicals for cleaning and labor

3. By definition, any technology which has not been incorporated into the CSWD is considered a new technology. The first step of the approval process is full-scale or representative pilot installations. To the extent that the NWRI data and test results meet the CSWD objectives noted below , the information can be considered as the submittal to satisfy Ecology's data submission requirements for membrane reactor technology.

   a. All procedures used in validating the process are conducted under the supervision of a registered professional engineer experienced in sanitary engineering.

   b. Sample data must demonstrate effectiveness and efficiency under minimum and maximum design conditions and over extended periods of time for the planned facility.

   c. The data must be from continuous operation of a full-scale or pilot operation treating the type and strength of sewage to be handled.

   d. Total flow and other process control measurements must be taken and recorded daily or at a frequency required to verify operation of the technology.

   e. All analyses are made in accordance with the latest version of the EPA guidelines, 40 CFR 136 or " Standard Methods for the Examination of Water and Wastewater" by an accredited laboratory unless specifically approved by Ecology.

4. Upon completion of the engineering review for the specific project, Ecology grants an provisional approval for construction and a subsequent evaluation period between 12 and 18 months. Additional monitoring and testing may be required to adequately demonstrate performance. Upon successful completion of the provisional period, Ecology will grant full approval for operation. If operation is not successful, Ecology will require corrective action to assure the permit requirements are consistently achieved.

5. When standards are not established by Ecology, our agency looks for justification from other states experiences. Our standards were modeled in part after California standards. The membrane standards in Title 22 could be considered as appropriately conservative for the filtration step in our Class A reclaimed water.

6. It is my opinion, that the NWRI study would satisfy the requirements as a Class A equivalent filtration technology for water reclamation facilities that would propose use of the membrane bioreactor technology. It is important to note that the data provided is specific to the membranes and wastewater characteristics used in the study and cannot not be generalized to membranes with different specifications or wastewaters that deviate substantially from the pilot.

7. One important criteria that was not fully demonstrated is Ecology's requirement for nitrogen reduction when reclamation facilities discharge to ground water via surface percolation or land apply at levels above agronomic rates. In these cases, the total nitrogen as N (sum of organic N, ammonia, nitrite and nitrate) is limited to a maximum of 10 mg/L. Since the pilot was not designed to removal nitrogen below ten, this could possibly be satisfied with the use of appropriate selector technology or a stripping tower.

8. My immediate concerns are with operation and maintenance and the overall O&M costs of these facilities. Specifically, I am concerned with membrane fouling, ease of cleaning

procedures and the level of operator skill that may be required. Furthermore, the relatively short-term experiences of the pilot cannot answer the longer-term operating viability. Perhaps this can be supplemented by the experience of other facilities such as the Arapahoe facility in Colorado.

9. Mr. Riley's review for the Department of Health proposes a possible reduction to our CT requirement for chlorine disinfection. Ecology would defer to Health on the issue of appropriate disinfection for public health protection.

# DOH comments July, 2001

# Membrane Bioreactor Recognition - Mitsubishi & Zeon

As requested, I have reviewed both of the documents submitted to the State of California for recognition that these two MBR products conform to California Title 22 requirements for membrane filtration. Based on the information provided, it would appear to me that membrane filtration provides treatment that is basically equivalent to the filtration portion required of Class A Reclaimed Water, and could result in a reduction in the disinfection step required for Class A reclaimed water. Based on these challenge studies, I would propose that additional disinfection to provide a minimum of an additional four -log virus inactivation, which would make this approach equivalent to the California standards requiring 99.999 % inactivation of viruses.

Based on the USEPA Surface Water Treatment Rule Guidance Manual, Appendix E, four-log virus inactivation by free chlorine in a pH range of 6 to 9 would require the following CT's:

| Temperature °C | CT Required, mg-min/L | Time at C = 1.0 ppm, minutes | Time at C = 0.5 ppm, minutes |
|---|---|---|---|
| 0.5 | 12 | 12 | 24 |
| 5 | 8 | 8 | 16 |
| 10 | 6 | 6 | 12 |
| 15 | 4 | 4 | 8 |
| 20 | 3 | 3 | 6 |
| 25 | 2 | 2 | 4 |

This would in effect reduce the thirty-minute detention time identified in the standards in Section 1, Article 9, Section 5, to eight to 12 minutes under extreme cold conditions, while providing an equivalent level of disinfection. The contact time in the USEPA SWTRGM is based on the effective detention time as being identified as the $T_{10}$ time based on a tracer study, which is not equivalent to the modal time determined by a tracer study, but could be related. The requirement to use a 90 minute contact time based on the modal time from the tracer study would seem to be much more conservative than providing 8 to 12 minutes based on $T_{10}$ contact time.

The California compliance letters also continue review of proposed projects on a case-by-case basis to assure compliance with applicability and treatment reliability.

Technologically, it appears that membrane filtration will provide treatment equivalent to Class A reclaimed water standards, based on the assessment of turbidity and microbiologic reduction. The applicability of this process for nitrogen reduction is not considered. Nitrogen reduction is a concern in surface percolation, as the standards require nitrate less than 10 ppm, nitrogen reduction and compliance with non-degradation standards for groundwater quality. This must be determined by Department of Ecology, which has the expertise for this.

Approval for a proposal should require the MBR be accompanied by additional disinfection. To be conservative, the additional disinfection should comply with California Standards until an assessment of the basis for this standard is completed. At that time, the final determination

should go to the Technical Advisory Committee for review if the assessment supports CT's that are lower than the California standard.

Compliance statements issued by California also limit the design flux rate and establish a nominal pore size in the compliance acceptance. Other parameters that appear to be of interest include the specific flux rate, air scour rate, and the production / backwash cycle periods. Any case-by-case approval should address these issues, and require that at least the design flux rate for a nominal pore size be consistent with the California compliance protocol.

Finally, the case-by-case approvals in California will address operational controls such as loading rates, TMP, frequency of integrity tests and O&M procedures. Research and experience with these issues is necessary for adequate review and approval.