Membrane Bioreactors (MBR) for Water Reclamation - Appendix A

Course No: C07-003

Credit: 7 PDH

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APPENDIX A
Tables and Figures

This Appendix contains the tables and figures referred to in the main report.

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Table 4-1: Specifications for the MBR Membranes

	Units	Kubota	US Filter	Zenon	Mitsubishi
Commercial Designation	----	Type 510	MemJet B10 R	ZW 500 D	Sterapore HF
Membrane Classification	----	MF	MF	UF	MF
Membrane Configuration		Vertical	Vertical	Vertical	Horizontal
Approx. Size of Element (LxWxH)	mm	490X6X1000	1850x100	1930X711X229	886X606X1483
Number of Sheets per membrane cassette	---	100	------	------	------
Number of Fibers per membrane cassette	-----	-----	~2000	~2700	~1820
Inside Diameter of Fiber	mm	-----	0.65	0.75	0.35
Outside Diameter of Fiber	mm	-----	1	1.9	0.54
Length of Fiber	m	-----	1.5	1.7	3.24
Active Membrane Area (MBR Pilot)	ft^2 (m^2)	1721 (160)	398 (37)	720 (67)	1076 (100)
[1] Flow Capacity (MBR Pilot)	gpm	17.6	4.0	7.5	9.2
Flow Direction	---	outside - in	outside - in	outside - in	outside - in
Nominal Membrane Pore Size	micron	0.4	0.08	0.04	0.4
Absolute Membrane Pore Size	micron	-----	0.2	0.1	0.5
Membrane Material/Construction	---	chlorinated polyethylene; flat sheet	PVDF/ hollow fiber	proprietary/ hollow fiber	polyethylene/ hollow fiber
Recommended Design Flux	gfd (L/h-m^2)	14.7 (24.9)	14.4 (24.4)	15 (25.4)	12.3 (20.8)
Standard Testing pH range	---	5.8 - 8.6	2-11	5-9.5	2-12
Vacuum Pressure for System	psi (bar)	<3 (<0.2)	<7.3 (<0.5)	<11.9 (<0.8)	<5.8(<0.4)

[1] Flow capacity based on recommend design flux and active membrane area supplied with the pilot unit.

Table 4-2: Specifications for the RO Membranes

	Units	Saehan	Hydranautics
Commercial Designation	---	RE 4040-BL	LFC3-4040
Active Membrane Area	ft^2 (m^2)	85 (7.9)	85 (7.9)
Membrane Material	---	Polyamide (thin film composite)	Polyamide (thin film composite)
Operating pH Range	---	3-10	3-10
Maximum Feedwater Turbidity	NTU	<1	<1
Maximum Feedwater SDI (15 minute)	---	<5	<5
Maximum Operating Temperature	^oF (^oC)	113 (45)	113 (45)
Free Chlorine Resistance	mg/L	<0.1	<0.1
Specific Flux @ 25 deg C	gfd/psi	0.20	0.10
Maximum Operating Pressure	psi (bar)	600 (40)	600 (40)

Table 4-3: Specifications for the Aquionics UV Pilot

	Units	Value
Characteristics		
Lamp Type	NA	Low pressure
Lamp Power	watts	150
Design Flow Rate	gpm	30
Operating Conditions		
Flow Rate	gpm	14.4
Feed Water UV Transmittance	%	70
Estimated UV Dose	mJ/cm^2	~42

Table 4-4: Analytical Methods / Detection Limits for measured Water Quality Parameters

Parameter	Units	Method Number and Type	Detection Limit
Total/Volatile Suspended Solids	mg/L	SM 2540D&E	1.6
Ammonia-N	mg/L	SM 4500 B&E	0.2
BOD5	mg/L	SM 5210B	2
COD	mg/L	SM5220D/EPA 410.4	22/5
Nitrate/Nitrite-N	mg/L	HACH 8171	0.1
Nitrite-N	mg/L	HACH 8507	0.005
Ortho-Phosphate-P	mg/L	HACH 8048	0.02
Total Hardness	mg/L as CaCO3	EPA 130.1/130.2	0.3
Alkalinity	mg/L as CaCO3	SM 2320 B	1.5
TKN	mg/L	EPA 351.3	0.5
TOC	mg/L	EPA 415.1	0.5
Total Coliform	MPN/100 mL	SM 9221E	<2 MPN/100 mL
Fecal Coliform	MPN/100 mL	SM 9221B	<2 MPN/100 mL
Coliphage	pfu/100 mL	[1]SM 9224F	<1PFU /100mL
HPC	CFU/mL	SM 9215B	1 CFU/mL

[1] 20th Edition Addendum.

Table 5-1: Raw Wastewater Quality Data during Phase I (Part 1)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	22	mg/L	27.3	30.2	22.4
Nitrate/Nitrite -N	24	mg/L	0.56	2.4	0.36
Nitrite -N	24	mg/L	0.005	0.05	0.001
TKN	14	mg/L	42.9	69.0	33.9
Ortho-Phosphate-P	24	mg/L	0.61	1.53	0.054
BOD_5	20	mg/L	213	274	88.3
COD	23	mg/L	463	783	211
TOC	16	mg/L	40	56	15
Total Hardness	9	mg/L	533	578	15
Calcium Hardness	9	mg/L	245	270	160
Magnesium Hardness	9	mg/L	285	315	192
Alkalinity	20	mg/L	264	286	233

Table 5-2: Advanced Primary Effluent Wastewater Quality Data during Phase I (Part 2)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	7	mg/L	26.6	29.4	24.1
Nitrate/Nitrite -N	5	mg/L	0.79	1.5	0.06
Nitrite -N	5	mg/L	0.026	0.16	0
TKN	1	mg/L	44.8	44.8	44.8
Ortho-Phosphate-P	5	mg/L	0.46	2.24	0.421
BOD_5	8	mg/L	97	110	57.8
COD	6	mg/L	216	245	147
TOC	1	mg/L	44	44	44
Total Hardness	6	mg/L	393	437	377
Calcium Hardness	6	mg/L	186	202	181
Magnesium Hardness	6	mg/L	208	235	193
Alkalinity	7	mg/L	247	257	238

Table 5-3: US Filter MBR Permeate Water Quality Data during Phase I (Part 1)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	14	mg/L	0.3	0.2	0
Nitrate/Nitrite -N	25	mg/L	22	39.9	5.34
Nitrite -N	23	mg/L	0.02	9	0
TKN	8	mg/L	8.45	13.2	2.62
TKN (CEL)	2	mg/L	0.7	0.7	0.7
Ortho-Phosphate-P	24	mg/L	0.357	0.635	0.119
BOD_5	21	mg/L	ND	6.27	ND
COD	23	mg/L	43	66	ND
TOC	16	mg/L	6.1	7.6	3.3
Total Hardness	9	mg/L	439	489	378
Calcium Hardness	9	mg/L	210	223	185
Magnesium Hardness	9	mg/L	222	266	193
Alkalinity	21	mg/L	64.3	108	30.1

Table 5-4: US Filter MBR Permeate Water Quality Data during Phase I (Part 2)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	3	mg/L	ND	ND	ND
Nitrate/Nitrite -N	3	mg/L	26.9	41.8	23.9
Nitrite -N	3	mg/L	0.045	0.077	0.042
TKN	2	mg/L	1.2	1.3	1.1
Ortho-Phosphate-P	3	mg/L	0.771	1.37	0.654
BOD_5	3	mg/L	ND	ND	ND
COD	3	mg/L	31	47	26
COD (CEL)	2	mg/L	10.05	15	5.1
TOC	2	mg/L	6.35	6.6	6.1
Total Hardness	1	mg/L	344	344	344
Calcium Hardness	1	mg/L	164	164	164
Magnesium Hardness	1	mg/L	180	180	180
Alkalinity	3	mg/L	65.1	83.4	48.4

Table 5-5: Kubota MBR Permeate Water Quality Data during Phase I (Part 1)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	22	mg/L	0.3	7.6	ND
Nitrate/Nitrite -N	18	mg/L	2.25	2.7	0.30
Nitrite -N	18	mg/L	0.012	0.19	0.005
TKN	8	mg/L	7.06	14.80	2.53
Ortho-Phosphate-P	18	mg/L	0.07	0.15	0.025
BOD_5	16	mg/L	ND	ND	ND
COD	18	mg/L	52	80	29
TOC	13	mg/L	7	8	3.5
Total Hardness	8	mg/L	449	495	410
Calcium Hardness	8	mg/L	216	241	196
Magnesium Hardness	8	mg/L	233	270	215
Alkalinity	16	mg/L	147	182	140

Table 5-6: Kubota MBR Permeate Water Quality Data during Phase I (Part 2)

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	8	mg/L	0.2	1.4	ND
Nitrate/Nitrite -N	9	mg/L	4.11	6.9	2.42
Nitrite -N	24	mg/L	0.165	2.71	0.006
TKN (CEL)	3	mg/L	0.2	0.8	0.12
Ortho-Phosphate-P	24	mg/L	3.80	7.46	0.045
BOD_5	21	mg/L	ND	2	ND
COD	5	mg/L	52	59	29
COD (CEL)	4	mg/L	16.5	23	5.1
TOC	5	mg/L	7	9	6.2
Total Hardness	8	mg/L	6	15	2.53
Calcium Hardness	9	mg/L	52	80	29
Magnesium Hardness	9	mg/L	0	0	0.009
Alkalinity	20	mg/L	280	495	14.2

Table 5-7: Saehan RO Permeate Water Quality Data during Phase I

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	18	mg/L	0.2	0.3	0.2
Nitrate/Nitrite –N	18	mg/L	0.45	1.9	0.10
Nitrite –N	19	mg/L	ND	0.05	ND
TKN (PL LAB)	7	mg/L	2.6	15.1	ND
TKN (CEL)	4	mg/L	ND	0.7	ND
Ortho-Phosphate-P	18	mg/L	0.02	0.04	0.02
COD	18	mg/L	ND	29	ND
COD (CEL)	4	mg/L	6.35	8	ND
TOC	12	mg/L	ND	ND	ND
Total Hardness	5	mg/L	12	18	7.68
Calcium Hardness	5	mg/L	10	11	6.8
Magnesium Hardness	5	mg/L	2	7	0.874
Alkalinity	17	mg/L	7	8.8	4.5

Table 5-8: Hydranautics RO Permeate Water Quality Data during Phase I

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	17	mg/L	0.2	0.3	0.2
Nitrate/Nitrite -N	17	mg/L	0.31	0.8	0.10
Nitrite -N	18	mg/L	ND	1.90	ND
TKN (PL LAB)	7	mg/L	ND	8.0	ND
TKN (CEL)	3	mg/L	ND	ND	ND
Ortho-Phosphate-P	18	mg/L	ND	0.04	ND
COD	18	mg/L	41.2	66.3	ND
COD (CEL)	3	mg/L	5.1	21	ND
TOC	0	mg/L	ND	ND	ND
Total Hardness	5	mg/L	0	0	0.056
Calcium Hardness	5	mg/L	22	22	22
Magnesium Hardness	5	mg/L	0	0	0.005
Alkalinity	17	mg/L	5	17.9	0.049

Table 6-1: Advanced Primary Effluent Wastewater Quality Data during Phase II

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	16	mg/L	25.5	28	23
Nitrate/Nitrite -N	16	mg/L	1.06	1.5	0.41
Nitrite -N	16	mg/L	0.01	0.02	0.005
TKN	8	mg/L	29	35.0	1.4
Ortho-Phosphate-P	16	mg/L	0.76	1.23	0.035
BOD_5	14	mg/L	112	165	83.8
COD	26	mg/L	237	285	149
COD (CEL)	7	mg/L	200	230	150
TOC	7	mg/L	44	50	37
[1]Total Hardness	6	mg/L	437	456	407
Alkalinity	16	mg/L	252	266	30

[1] Total hardness is presented as $CaCO_3$.

Table 6-2: Zenon MBR Permeate Water Quality Data during Phase II

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	12	mg/L	0.6	5	ND
Nitrate/Nitrite -N	15	mg/L	23.1	5	ND
Nitrite -N	15	mg/L	0.013	0.103	0.006
TKN	8	mg/L	0.98	1.7	0.7
Ortho-Phosphate-P	15	mg/L	0.49	1.24	0.309
BOD_5	14	mg/L	ND	ND	ND
COD	24	mg/L	41	67	ND
COD (CEL)	6	mg/L	18	28	8
TOC	7	mg/L	6.4	8.6	6.1
[1]Total Hardness	6	mg/L	400	434	380
Alkalinity	16	mg/L	66	111	7.35

[1] Total hardness is presented as $CaCO_3$.

Table 6-3: Mitsubishi MBR Permeate Water Quality Data during Phase II

	No. of Analyses	Units	Median	Maximum	Minimum
Ammonia-N	12	mg/L	0.3	16	0.3
Nitrate/Nitrite -N	13	mg/L	17.90	29.5	0.20
Nitrite –N	13	mg/L	0.057	5.19	0.006
TKN	6	mg/L	4.2	33.0	ND
Ortho-Phosphate-P	13	mg/L	0.59	1.47	0.185
BOD_5	12	mg/L	ND	ND	ND
COD	21	mg/L	44	61	ND
COD (CEL)	6	mg/L	21	31	18
TOC	7	mg/L	6.6	8.7	5.6
Conductivity	66	micromho	2,475	3,270	1,300
[1]Total Hardness	7	mg/L	8	31	0.3

[1] Total hardness is presented as $CaCO_3$.

Table 9-1: Capital Costs for Various Capacity MBR Systems Operating on Raw Wastewater

Item	Capital Costs, $K				
	0.2 MGD	0.5 MGD	1.0 MGD	5.0 MGD	10.0 MGD
Headworks	$250	$300	$450	$1,800	$3,100
Basins	$101	$222	$484	$2,101	$4,154
MBR System	$512-$1,375	$991-$1,688	$1,579-$2,347	$5,975-$6,614	$9,600-$12,200
Mechanical	$96	$176	$420	$2,438	$5,779
Blower and Pump building	$78	$152	$247	$861	$1,661
Chlorine Dosing System	$62	$123	$217	$1,083	$2,167
Subtotal	**$1,099-$1,962**	**$1,964-$2,660**	**$3,397-$4,165**	**$14,258-$14,897**	**$26,461-$29,061**
Electrical, 15%	$165-$294	$295-$399	$510-$625	$2,139-$2,235	$3,969-$4,359
Mechanical/ Plumbing/HVAC, 13%	$143-$255	$255-$346	$442-$541	$1,854-$1,937	$3,440-$3,778
Sitework, 9%	$99-$177	$177-$239	$306-$375	$1,283-$1,341	$2,381-$2,615
Subtotal	**$1,506-$2,688**	**$2,691-$3,644**	**$4,654-$5,706**	**$19,533-$20,409**	**$36,252-$39,814**
Contractor Overhead and Profit, 15%	$226-$403	$404-$547	$698-$856	$3,061-$2,930	$5,438-$5,972
Subtotal-Construction Cost	**$1,731-$3,091**	**$3,094-$4,191**	**$5,352-$6,562**	**$22,463-$23,470**	**$41,689-$45,786**
Land	$250	$500	$750	$1,750	$2,500
Contingency, 15%	$260-$464	$464-$629	$803-$984	$3,370-$3,521	$6,253-$6,868
Engineering/Legal/Administration, 15%	$260-$464	$464-$629	$803-$984	$3,370-$3,521	$6,253-$6,868
Total Capital Cost, $	**$2,500-$4,270**	**$4,520-$5,950**	**$7,710-$9,280**	**$30,950-$32,260**	**$56,700-$62,020**
Interest Rate	5%	5%	5%	5%	5%
Number of Years	30	30	30	30	30
P/A Factor	15.37	15.37	15.37	15.37	15.37
Amortized Capital Cost, $/yr	**$163-$278**	**$294-$387**	**$502-$604**	**$2,013-$2,099**	**$3,688-$4,034**

Table 9-2: O&M Costs for MBR Systems Operating on Raw Wastewater

Item	O & M Costs, $K/yr				
	0.2 MGD	0.5 MGD	1.0 MGD	5.0 MGD	10.0 MGD
Electrical Power for Process/Miscellaneous	$14	$35	$70	$350	$701
Equipment Repairs/Lubricants/Replacement	$6-$11	$10-$14	$16-$21	$70-$70	$144-$149
[1] Crane	$2.0	$3.0	--------	--------	---------
Chemical Cleaning	$1.6	$4.0	$8.0	$40.0	$80.0
Chemical Cost for Disinfection	$0.9	$2.3	$4.6	$22.8	$45.7
Diffuser Replacement	$0.5	$1.2	$2.4	$11.8	$23.5
[2] Membrane Replacement	$5-$15	$10-$40	$20-$80	$87-$400	$171-$800
Labor	$18	$25	$31	$88	$229
Total O&M Costs in First Year, $K	**$54-$58**	**$94-$120**	**$158-$212**	**$671-$983**	**$1,394-$2,028**
Interest Rate	5%	5%	5%	5%	5%
Number of Years	30	30	30	30	30
P/A Factor	15.37	15.37	15.37	15.37	15.37
Total Estimated O&M Costs, $K	**$830-$892**	**$1,445-$1,845**	**$2,429-$3,259**	**$10,315-$15,111**	**$21,429-$31,175**

[1] Crane cost for 1, 5, and 10 MGD included in capital costs. [2] Membrane replacement costs based on 8-yr life; annual cost shown would be used to fund account annually.

Table 9-3: Summary of Capital and O&M Costs MBR Operating on Raw Wastewater

Capacity (MGD)	Raw Wastewater		
	Capital Costs, $K	Total O&M Costs, $K	Present Worth Value, $K
0.2	$2,500-$4,270	$830-$892	$3,330-$5,162
0.5	$4,520-$5,950	$1,445-$1,845	$5,965-$7,795
1	$7,710-$9,280	$2,429-$3,259	$10,139-$12,539
5	$30,950-$32,260	$10,315-$15,111	$41,265-$47,371
10	$56,700-$62,020	$21,429-$31,175	$78,129-$93,195

Table 9-4: Summary of Costs, $/kgal MBR Operating on Raw Wastewater

Capacity (MGD)	Raw Wastewater			
	Amortized Capital Costs, $K/yr	O&M Costs, $K/yr	Total Cost $K/yr	Total Cost $/1000 gal
0.2	$163-$278	$54-$58	$217-$336	$2.97-$4.60
0.5	$294-$387	$94-$120	$388-$507	$2.13-$2.78
1	$502-$604	$158-$212	$660-$816	$1.81-$2.24
5	$2,013-$2,099	$671-$983	$2,684-$3,082	$1.47-$1.69
10	$3,688-$4,034	$1,394-$2,028	$5,082-$6,062	$1.39-$1.66

Table 9-5: Capital Costs 1&5 MGD MBR Operating on Advanced Primary Effluent

Item	Capital Costs, $K	
	1.0 MGD	5.0 MGD
[1]**Headworks**	$0	$0
Basins	$281	$1,099
MBR System	$1,579-$2,347	$5,975-$6,614
Mechanical	$395	$2,518
Blower and Pump Building	$166	$497
Chlorine Dosing System	$217	$1,083
Subtotal	**$2,638-$3,406**	**$11,812-$11,173**
Electrical, 15%	$396-$511	$1,676-$1,772
Mechanical/Plumbing/HVAC, 13%	$343-$443	$1,452-$1,536
Sitework, 9%	$237-$307	$1,006-$1,063
Subtotal	**$3,614-$4,667**	**$15,307-$16,183**
Contractor Overhead and Profit, 15%	$542-$700	$2,296-$2,427
Subtotal-Construction Cost	**$4,156-$5,367**	**$17,603-$18,610**
Land	$750	$1,750
Contingency, 15%	$623-$805	$2,640-$2,792
Engineering/Legal/Administration, 15%	$623-$805	$2,640-$2,792
Total Capital Cost, $	**$6,150-$7,730**	**$24,630-$25,940**
Interest rate	5%	5%
Number of Years	30	30
P/A Factor	15.37	15.37
Amortized Capital Cost, $/yr	**$400-$503**	**$1,602-$1,687**

[1] Excluded headworks cost assume facilities are built at existing advanced primary treatment plant.

Table 9-6: O&M Costs for MBR Operating on Advanced Primary Effluent

Item	O&M Costs, $/yr	
	1.0 MGD	**5.0 MGD**
Electrical Power for Process/Miscellaneous	$56	$280
Equipment Repairs/Lubricants/Replacement	$13-$18	$65-$65
Chemical Cleaning	$8	$40
Chemical Cost for Disinfection	$4.6	$22.8
Diffuser Replacement	$1.3	$6.4
[1]Membrane Replacement	$20-$80	$87-$400
Labor	$31	$88
Yearly O&M Costs, $/yr	**$139-$194**	**$590-$903**
Interest rate	5%	5%
Number of Years	30	30
P/A Factor	15.37	15.37
Total Estimated O&M Costs, $	**$2,137-$2,982**	**$9,070-$13,881**

[1] Membrane replacement costs based on 8-yr life; annual cost shown would be used to fund account annually.

Table 9-7: Summary of Capital and O&M Costs Operation on Advanced Primary Effluent

Capacity (MGD)	Advanced Primary Effluent		
	Capital Costs, $K	**Total O&M Costs, $K**	**Present Worth Value, $K**
1	$6,150-$7,730	$2,137-$2,982	$8,287-$10,712
5	$24,630-$25,940	$9,070-$13,881	$33,700-$39,821

Table 9-8: Summary of Costs, $/kgal Operation on Advanced Primary Effluent

Capacity (MGD)	Advanced Primary Effluent			
	Amortized Capital Costs, $K/yr	**O&M Costs, $K/yr**	**Total Cost $K/yr**	**Total Cost $/1000 gal**
1	$400-$503	$139-$194	$572-$729	$1.48-$1.91
5	$1,602-$1,687	$590-$903	$2,241-$2,614	$1.20-$1.42

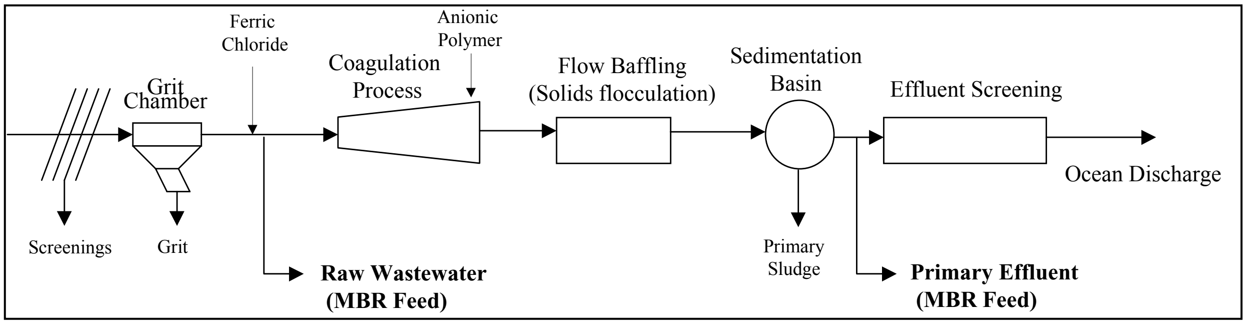


Figure 4-1: Schematic Diagram of the Point Loma Advanced Wastewater Treatment Plant

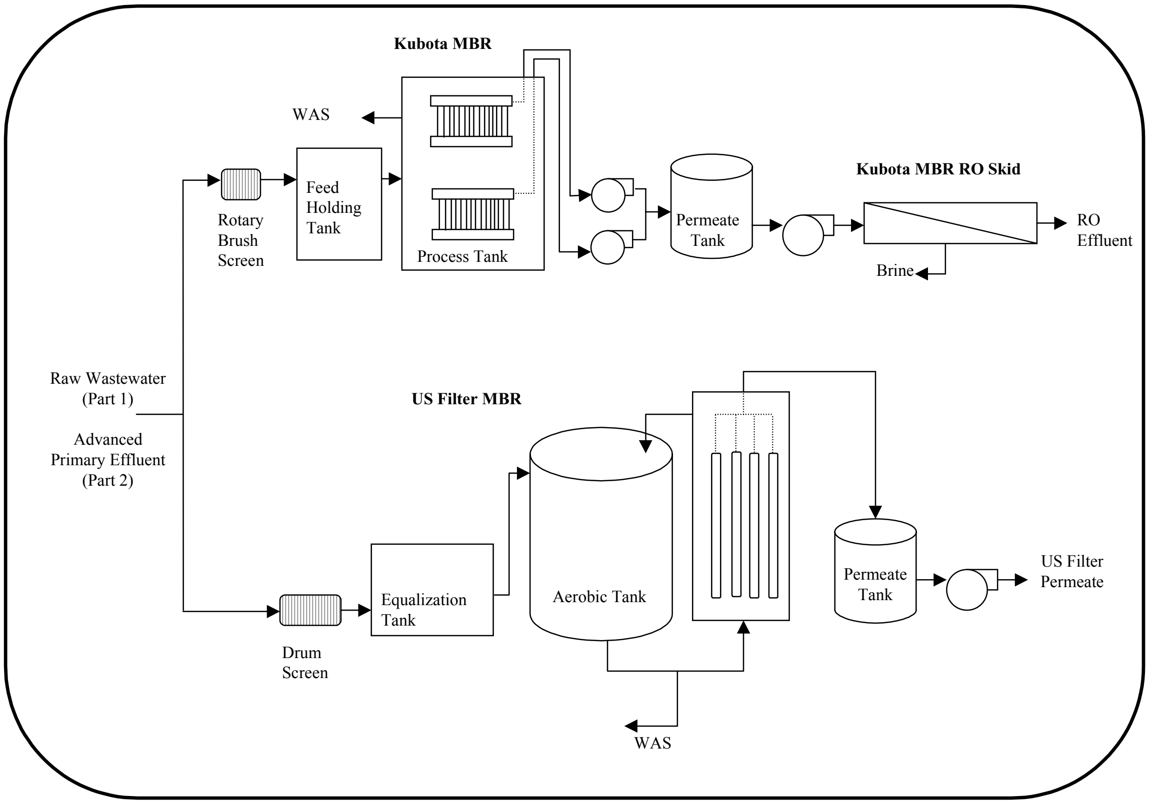


Figure 4-2: Schematic Diagram of Pilot Treatment Train during Phase I (Part 1 & Part 2)

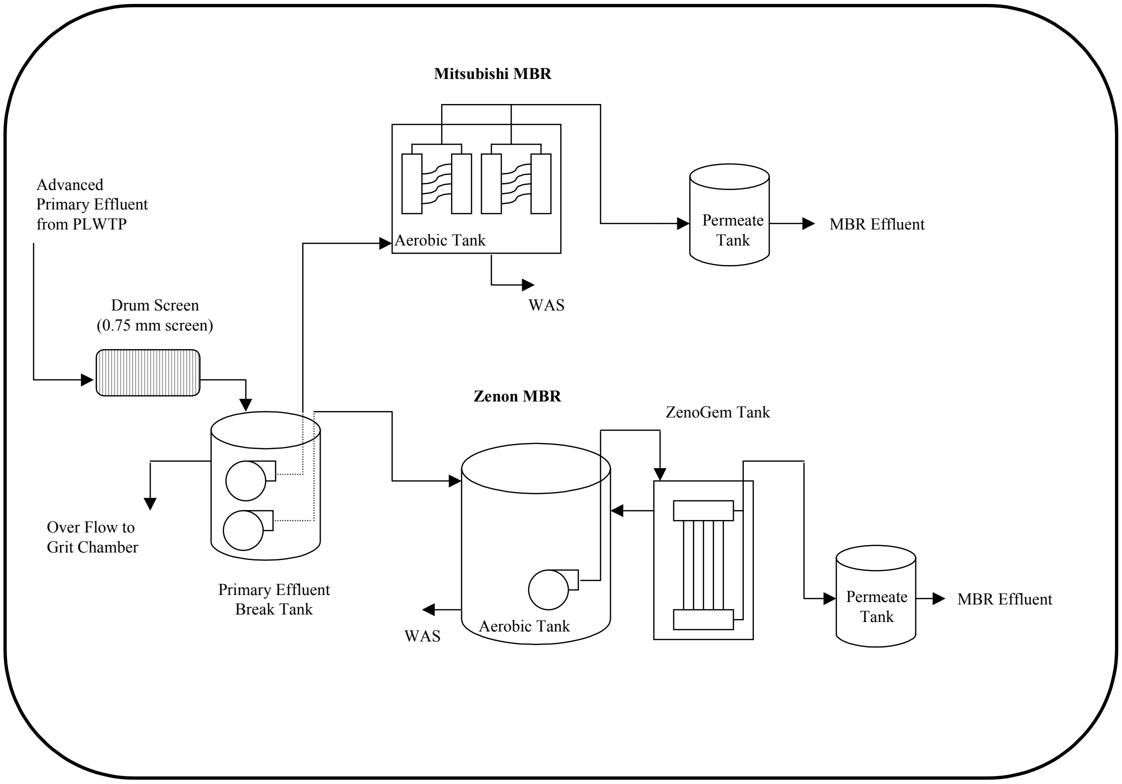


Figure 4-3: Schematic Diagram of Pilot Treatment Train during Phase II

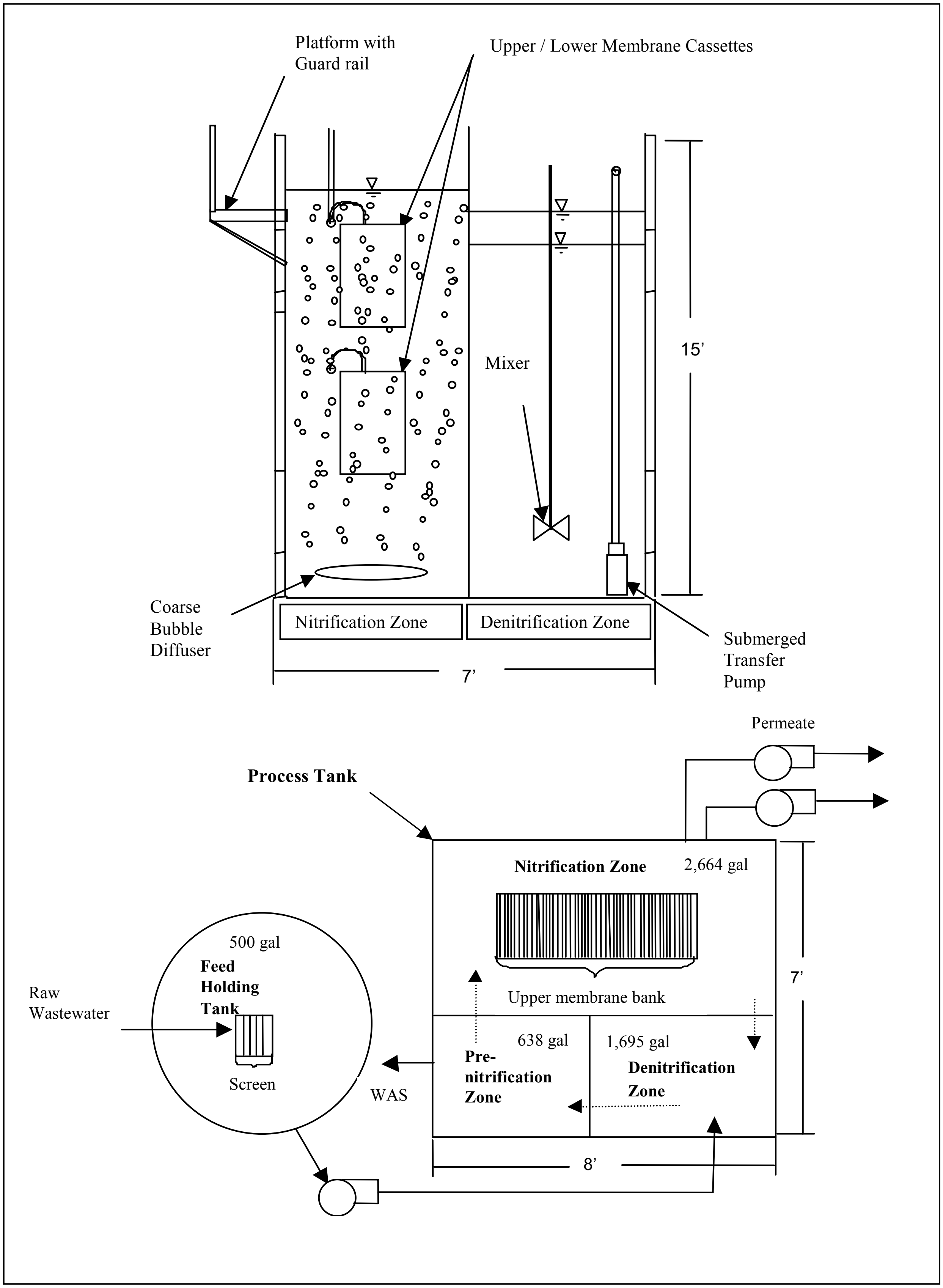


Figure 4-4: Kubota MBR: Side View (Top); Plan View (Bottom)

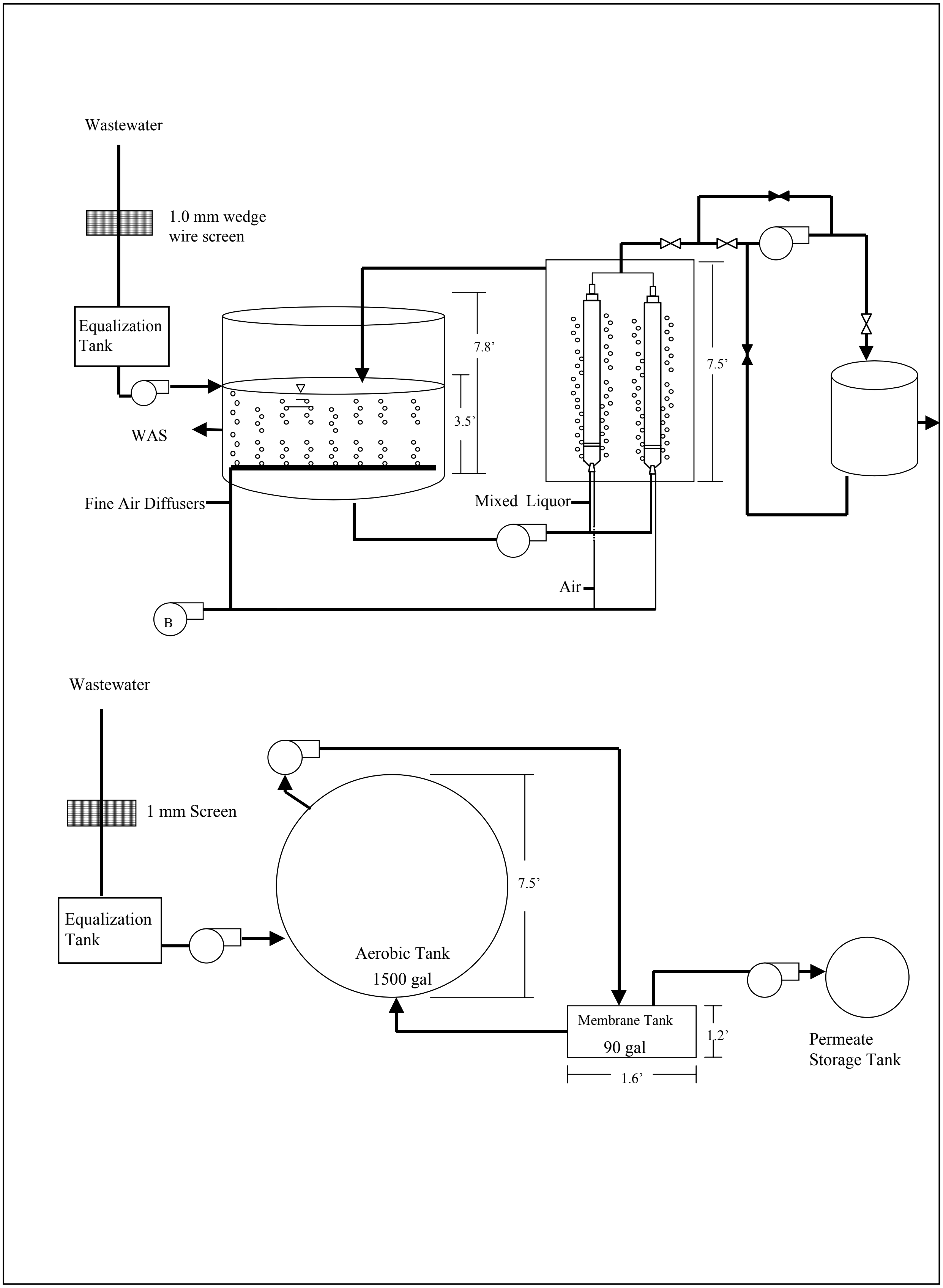


Figure 4-5: US Filter MBR: Side View (Top); Plan View (Bottom)

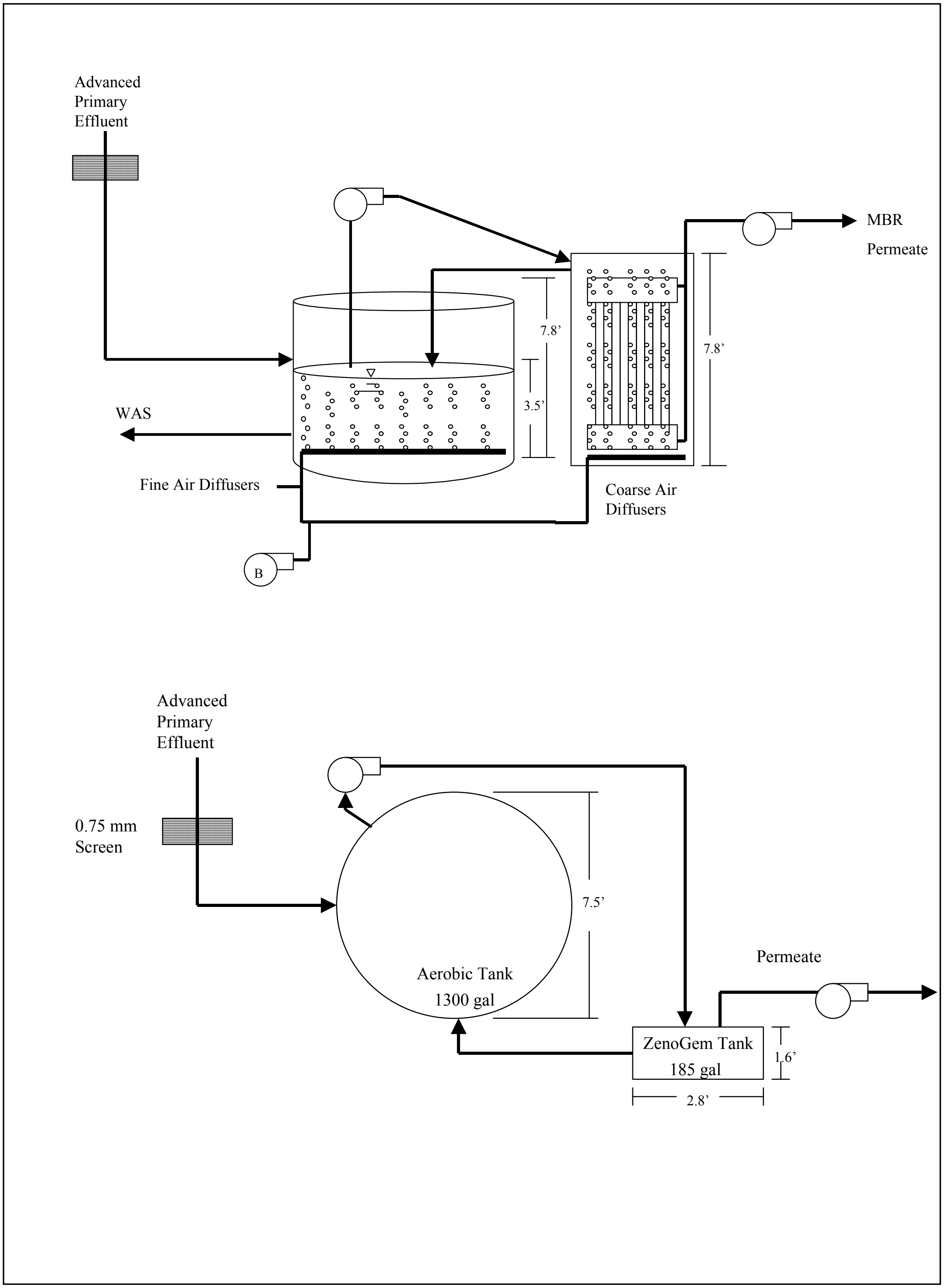


Figure 4-6: Zenon MBR: Side View (Top); Plan View (Bottom)

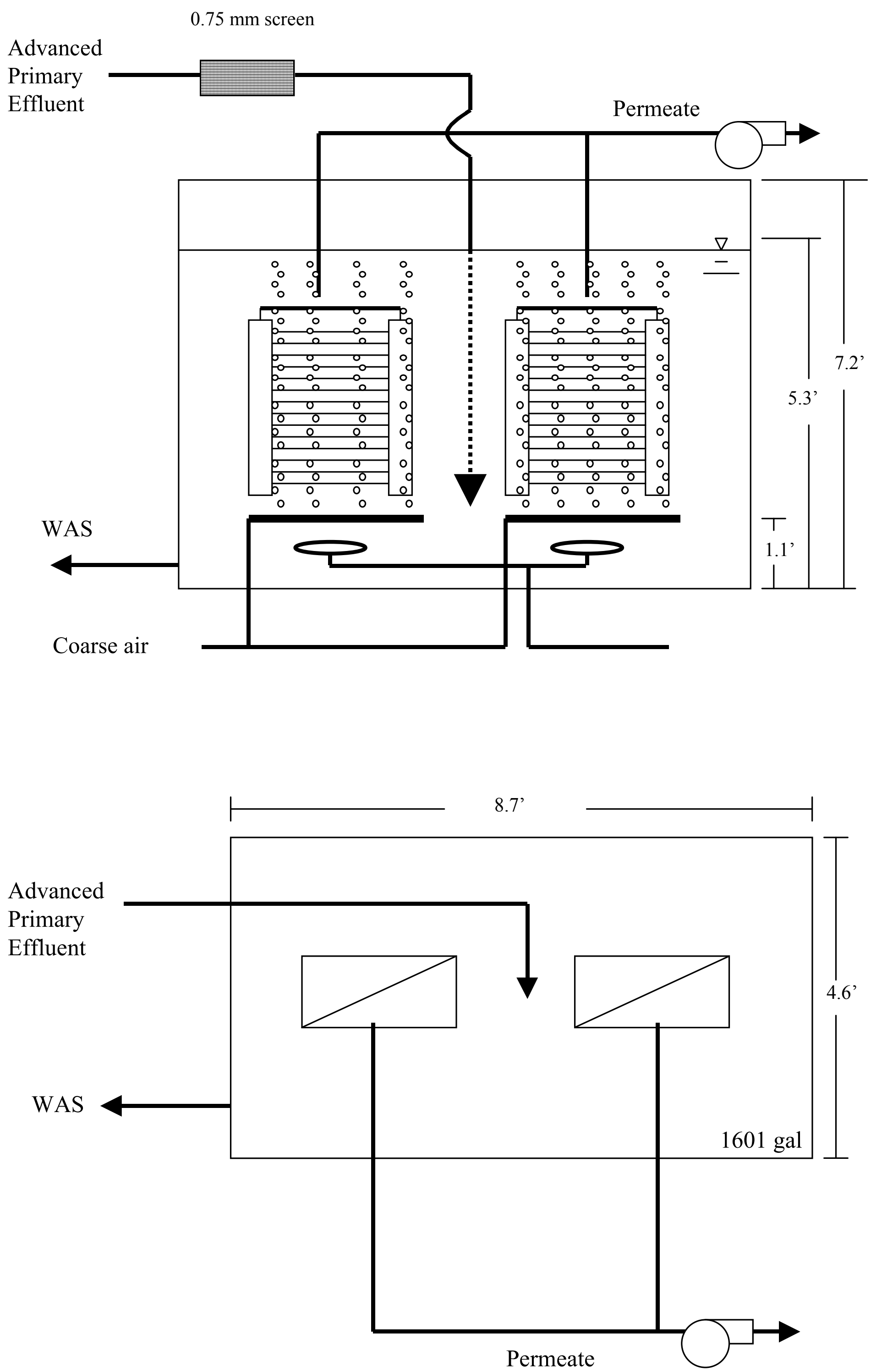
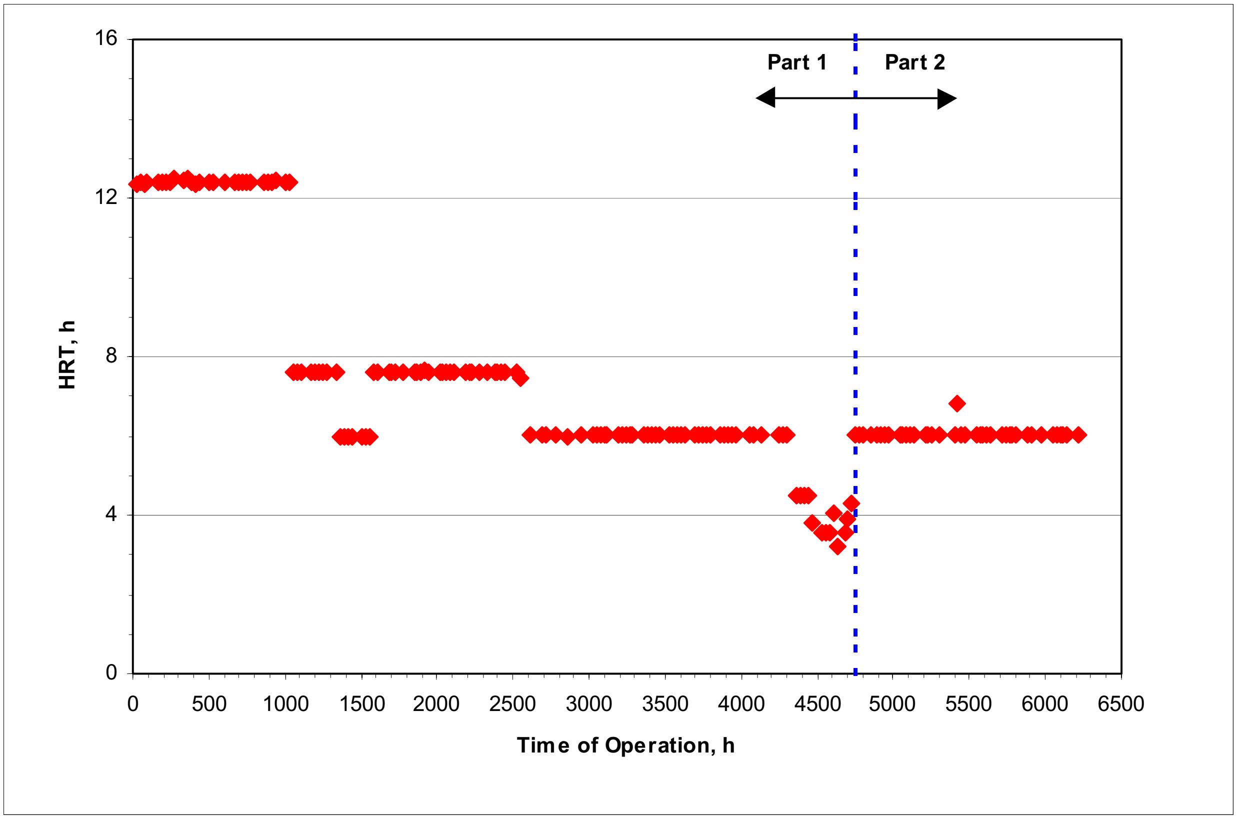


Figure 4-7: Mitsubishi MBR: Side View (Top); Plan View (Bottom)



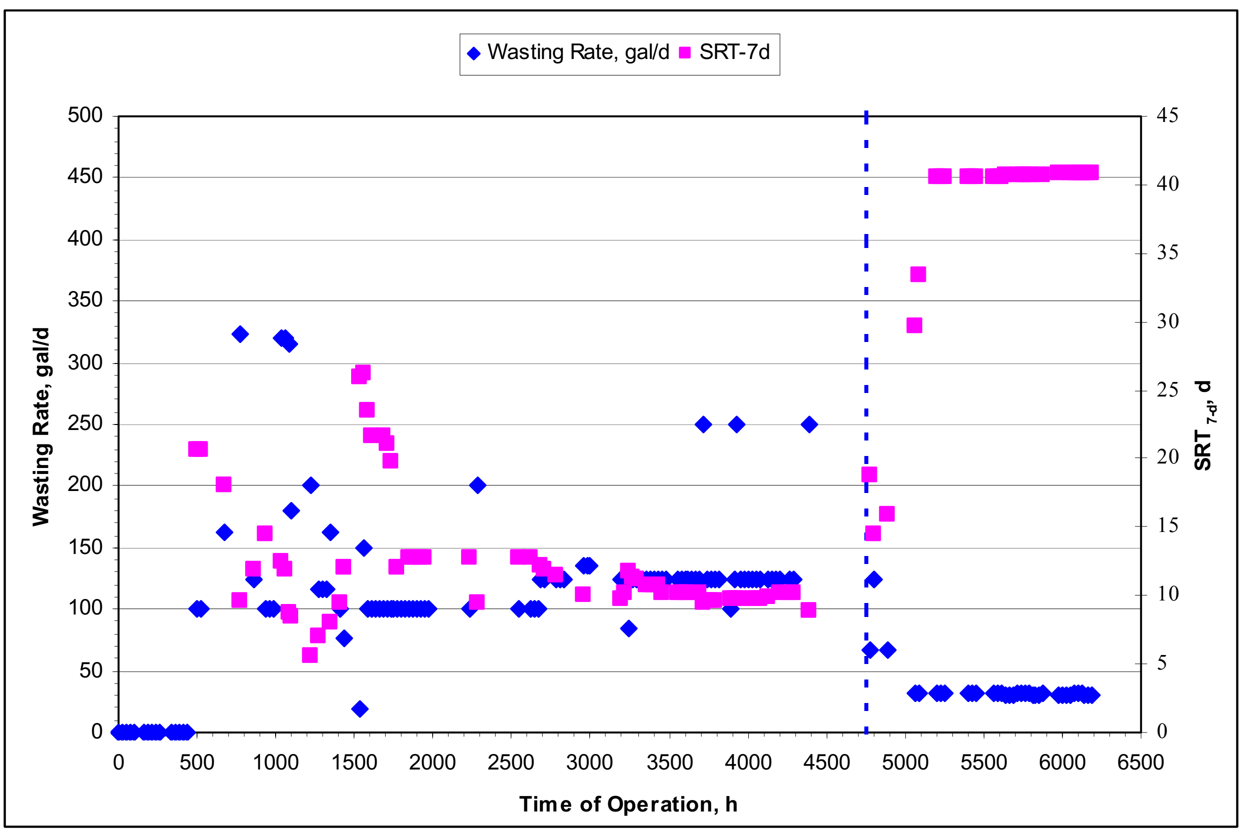
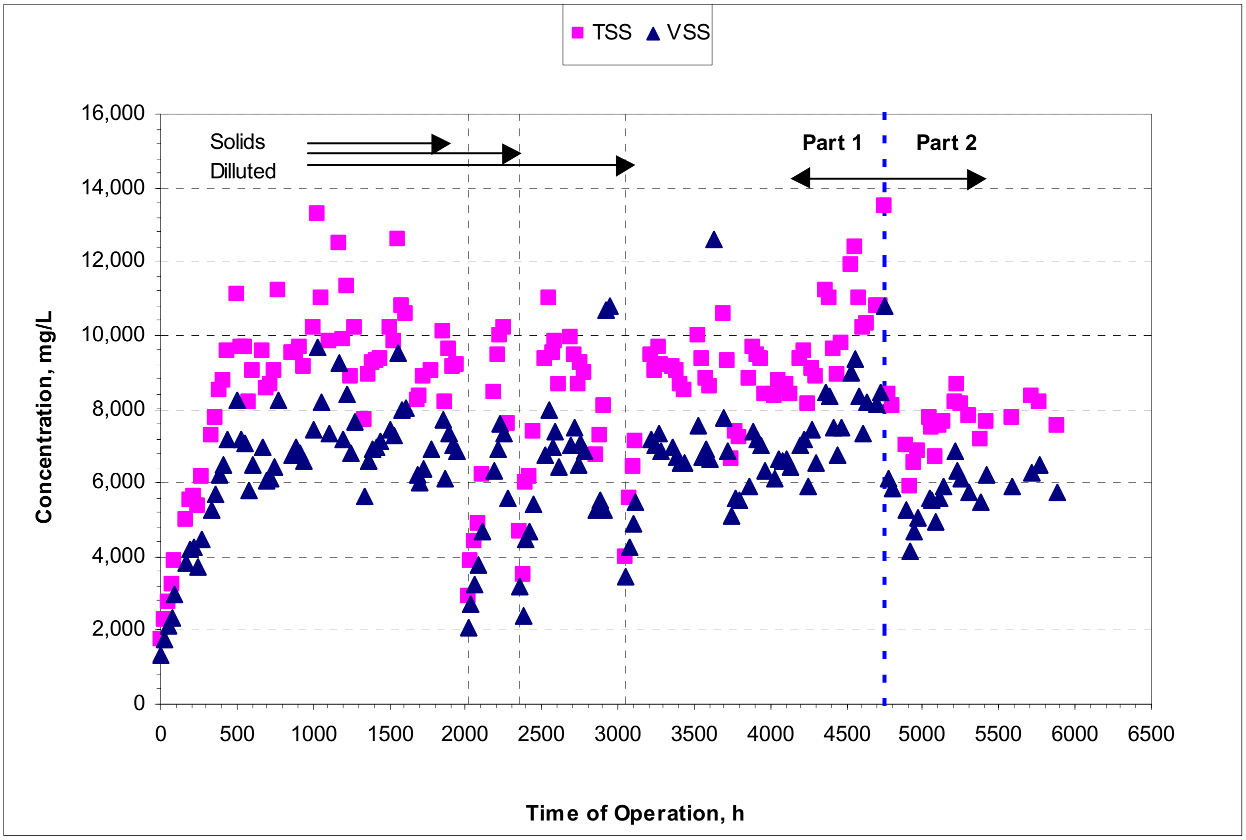


Figure 5-1: HRT and SRT $_{7\text{-d}}$ for the US Filter MBR



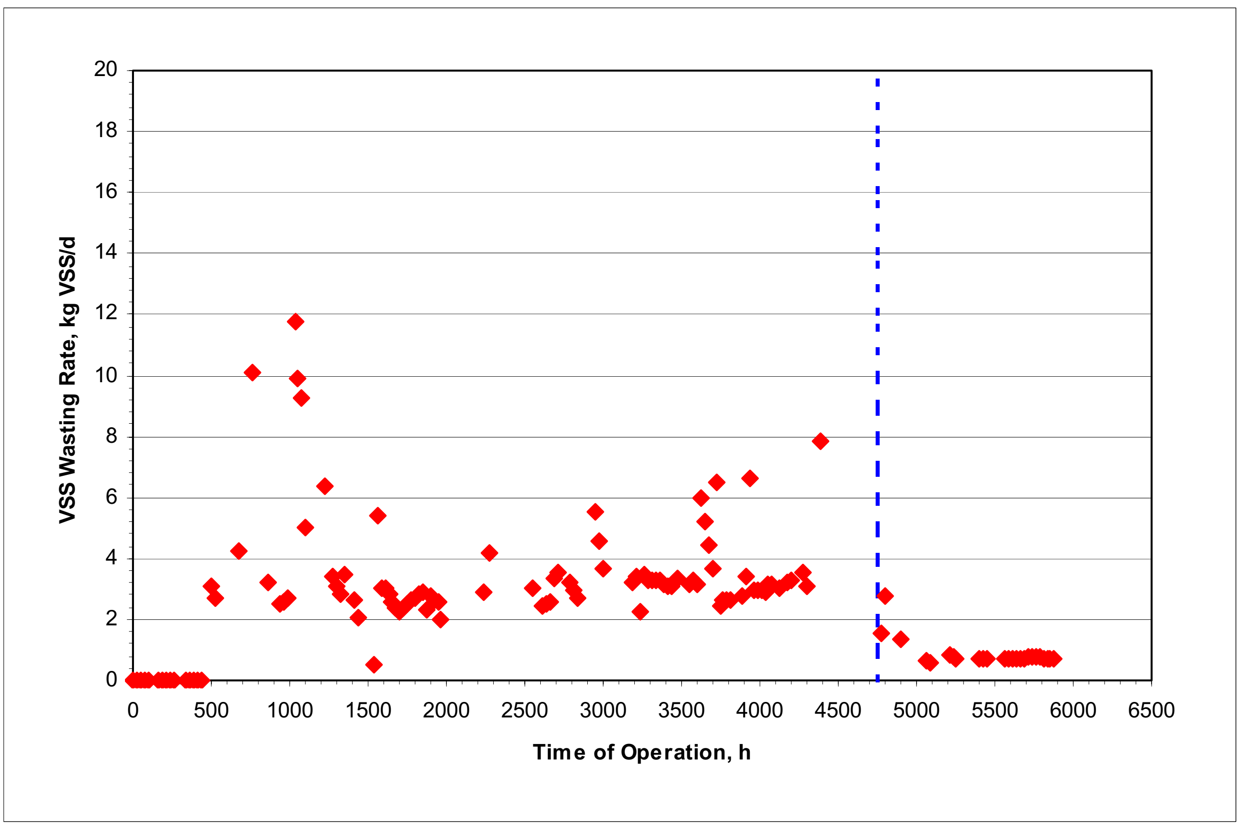


Figure 5-2: Mixed Liquor Solids for the US Filter MBR

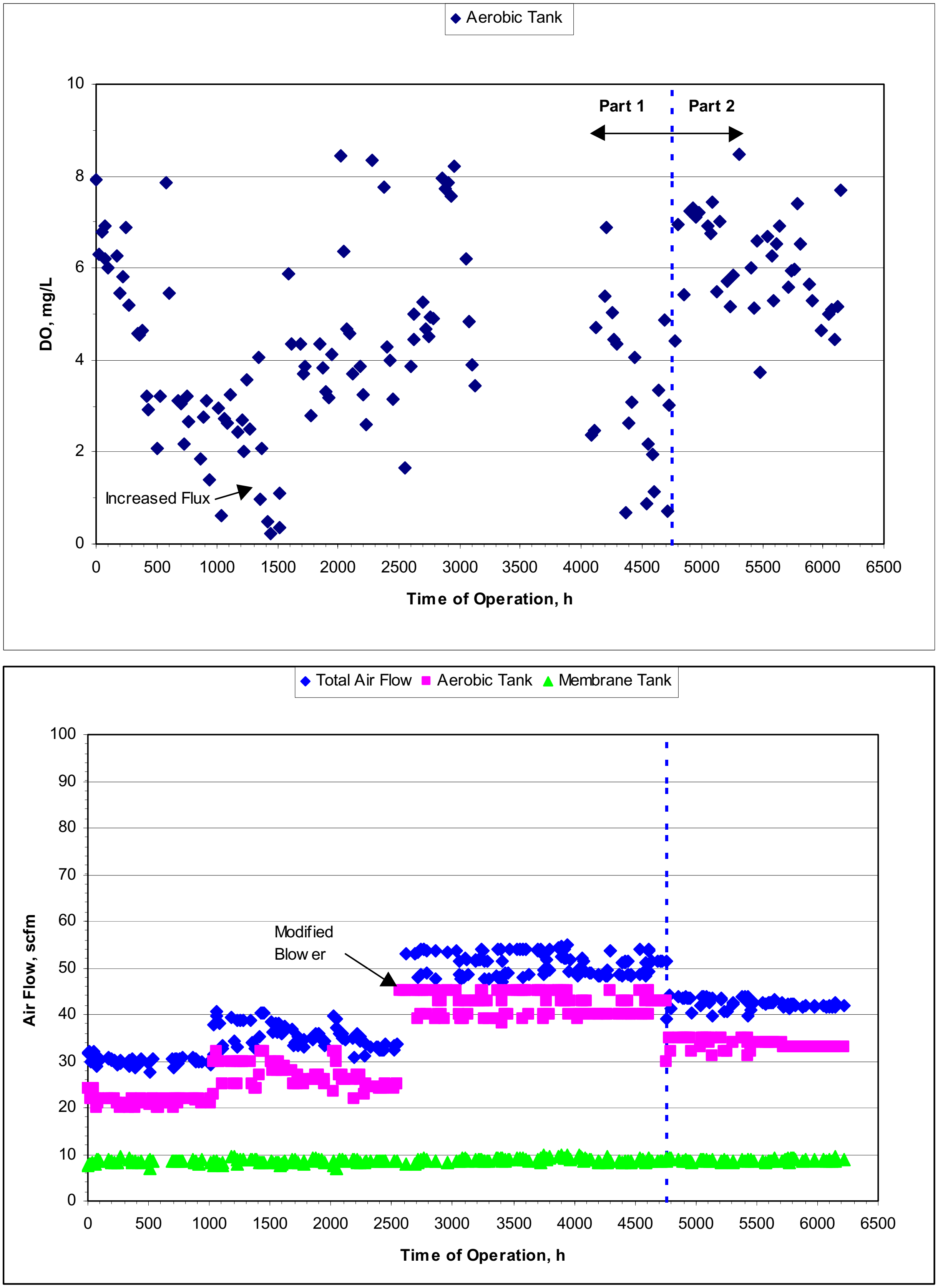
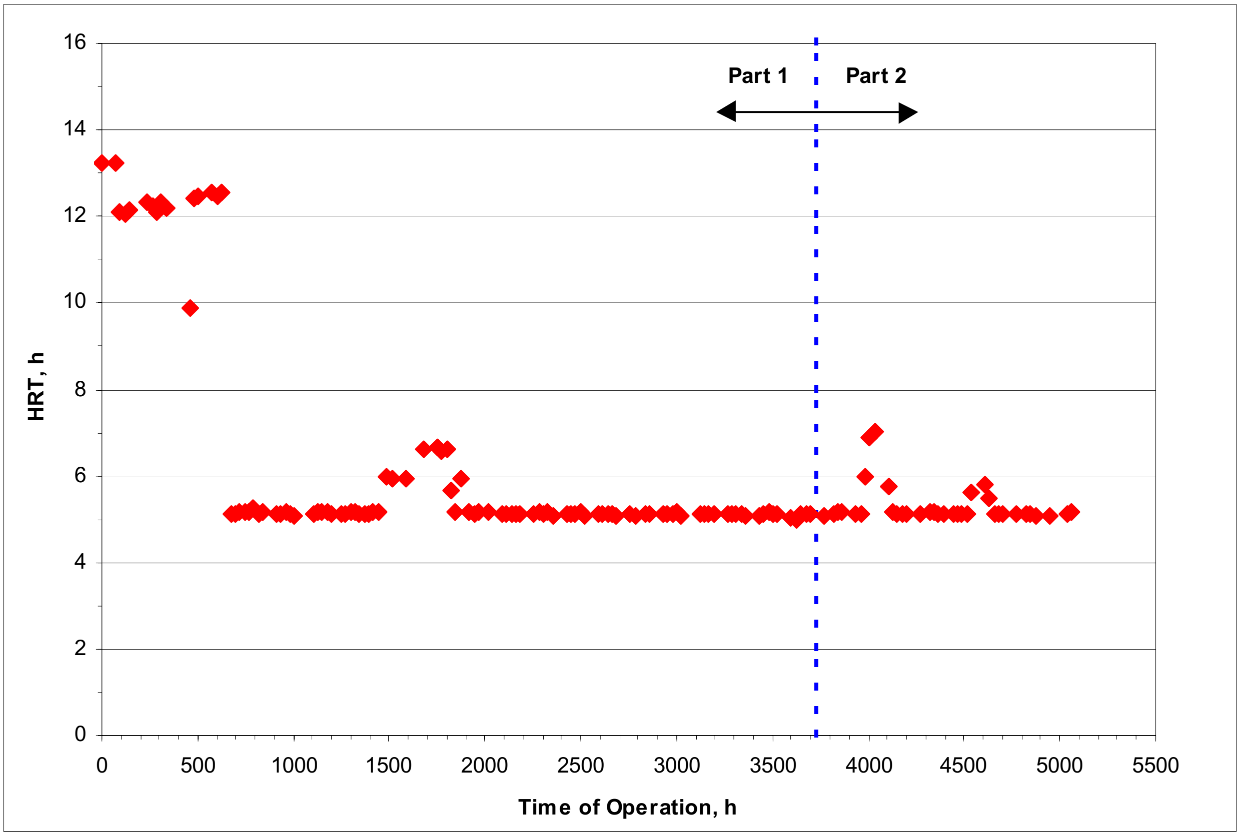


Figure 5-3: DO Concentration in the US Filter MBR



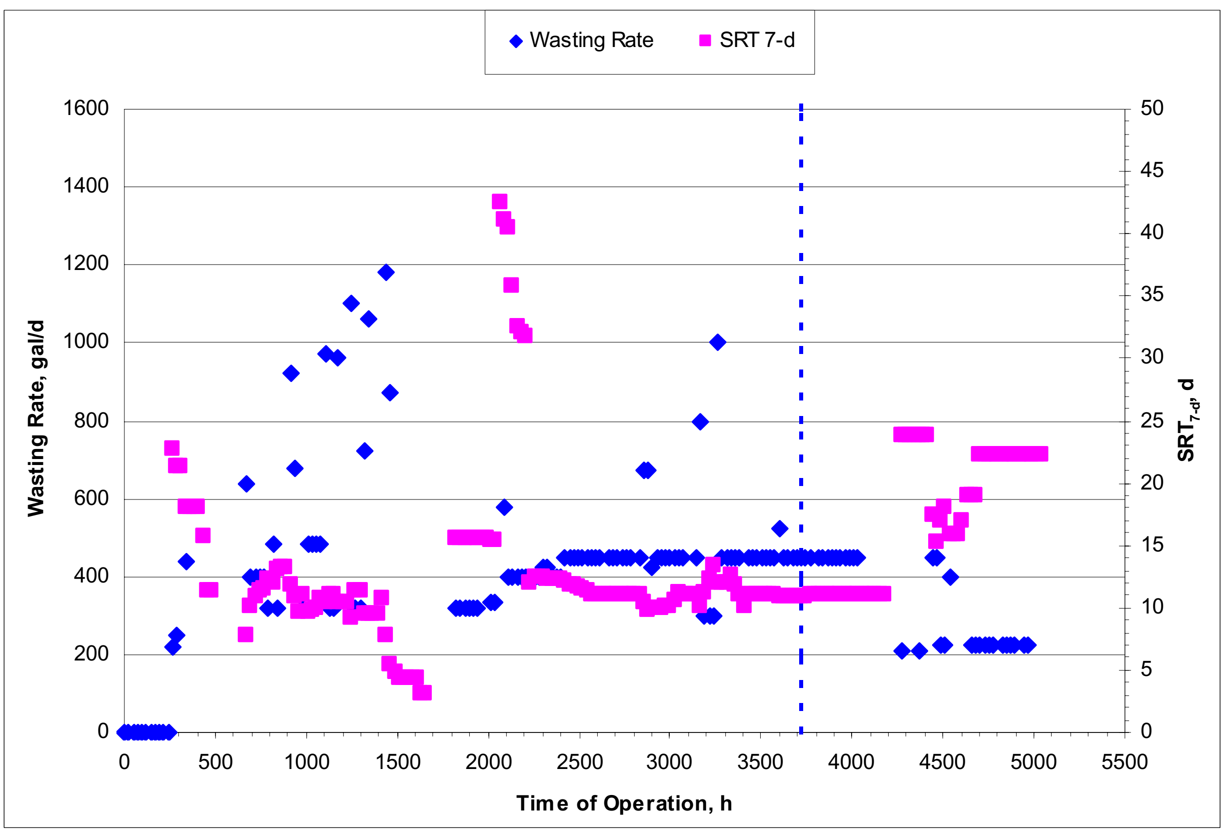


Figure 5-4: HRT and SRT $_{7\text{-d}}$ for the Kubota MBR

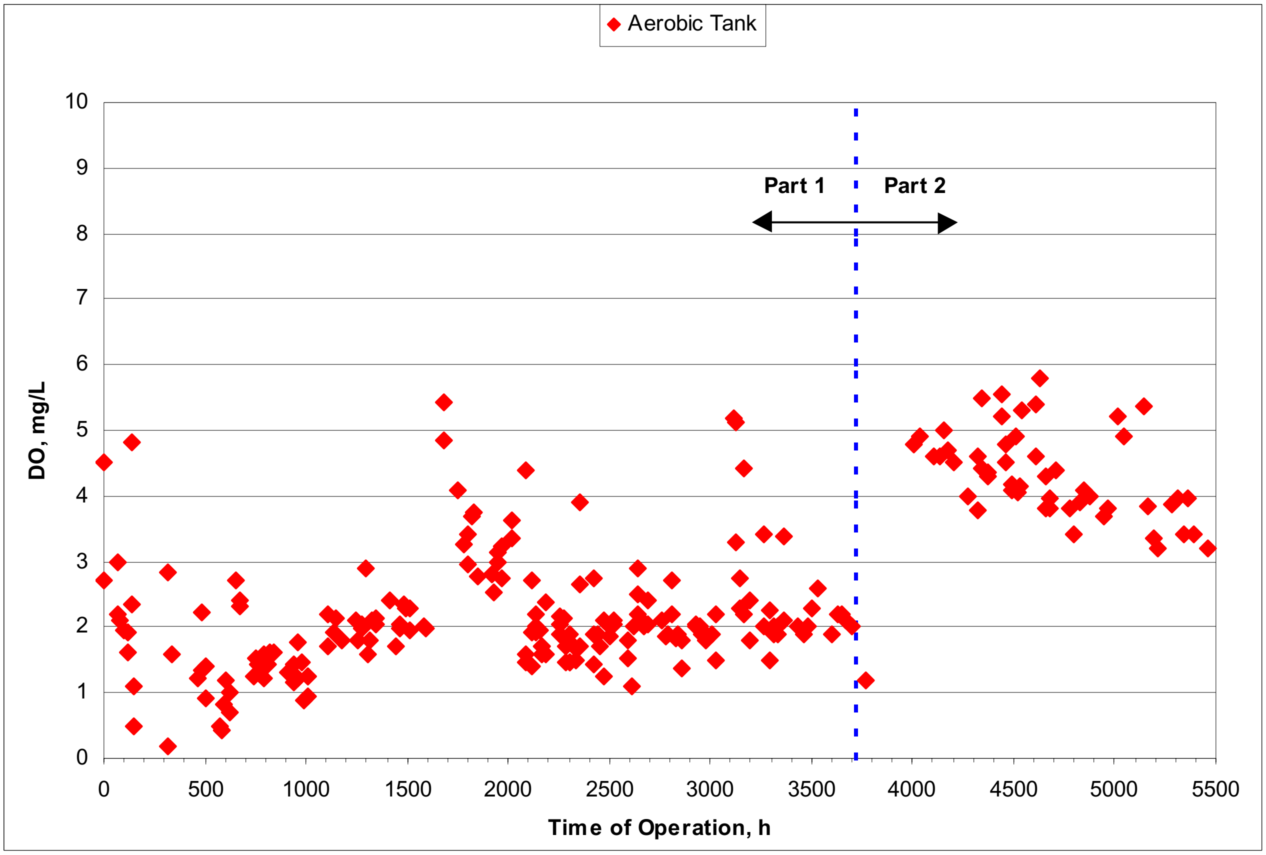
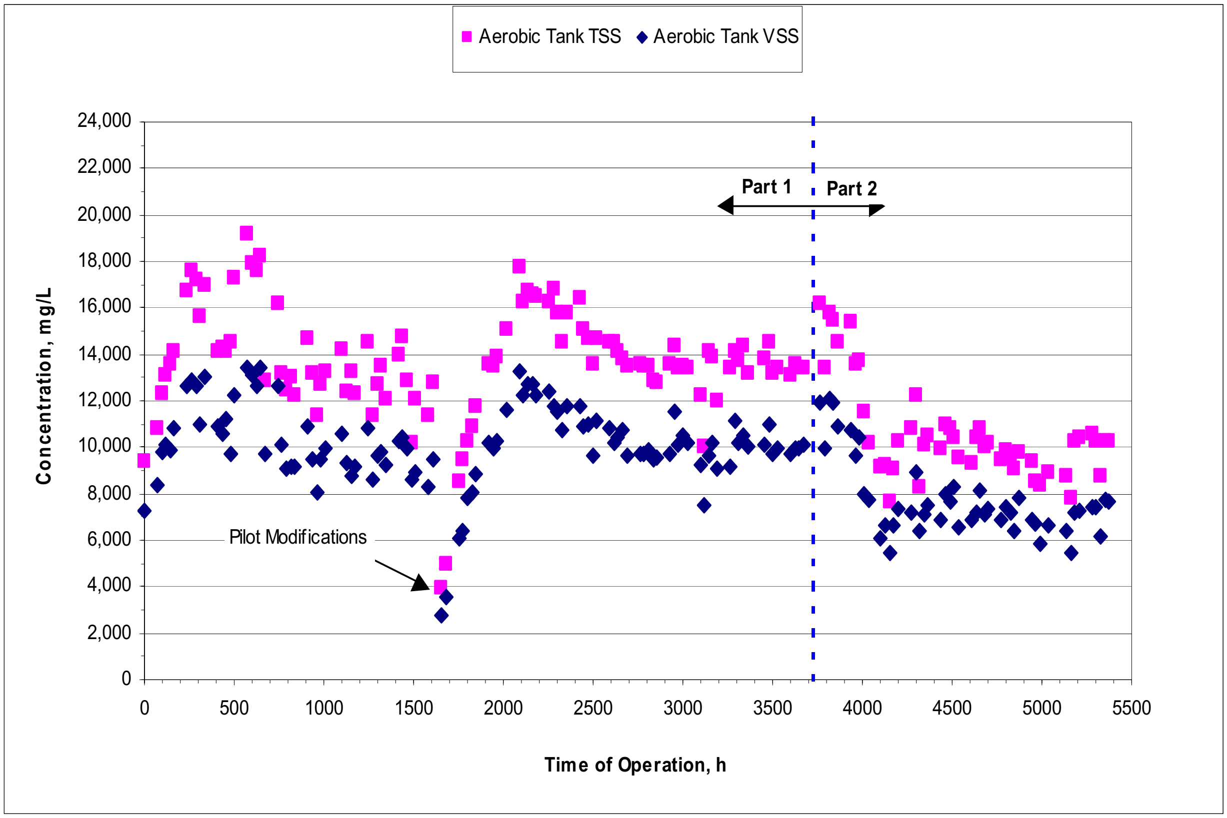


Figure 5-5: DO Concentration in the Kubota MBR



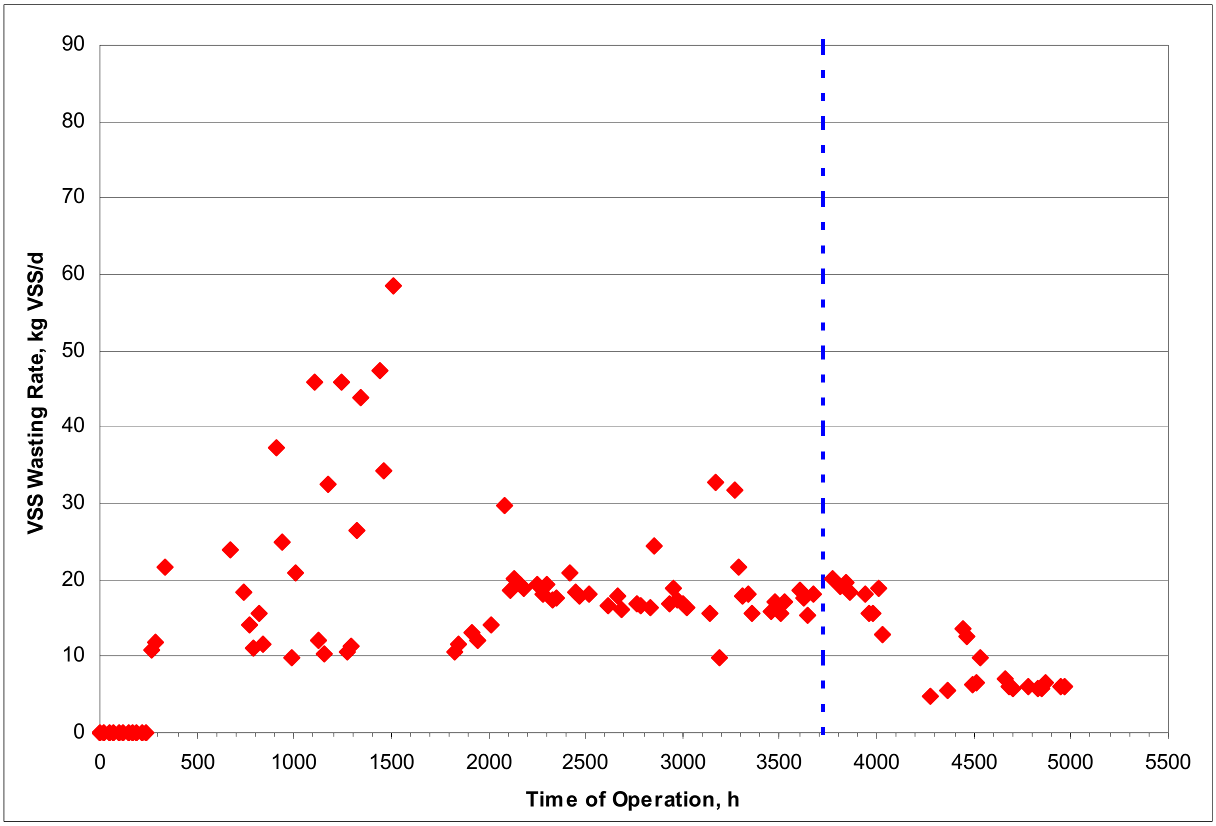


Figure 5-6: Mixed Liquor Solids for the Kubota MBR

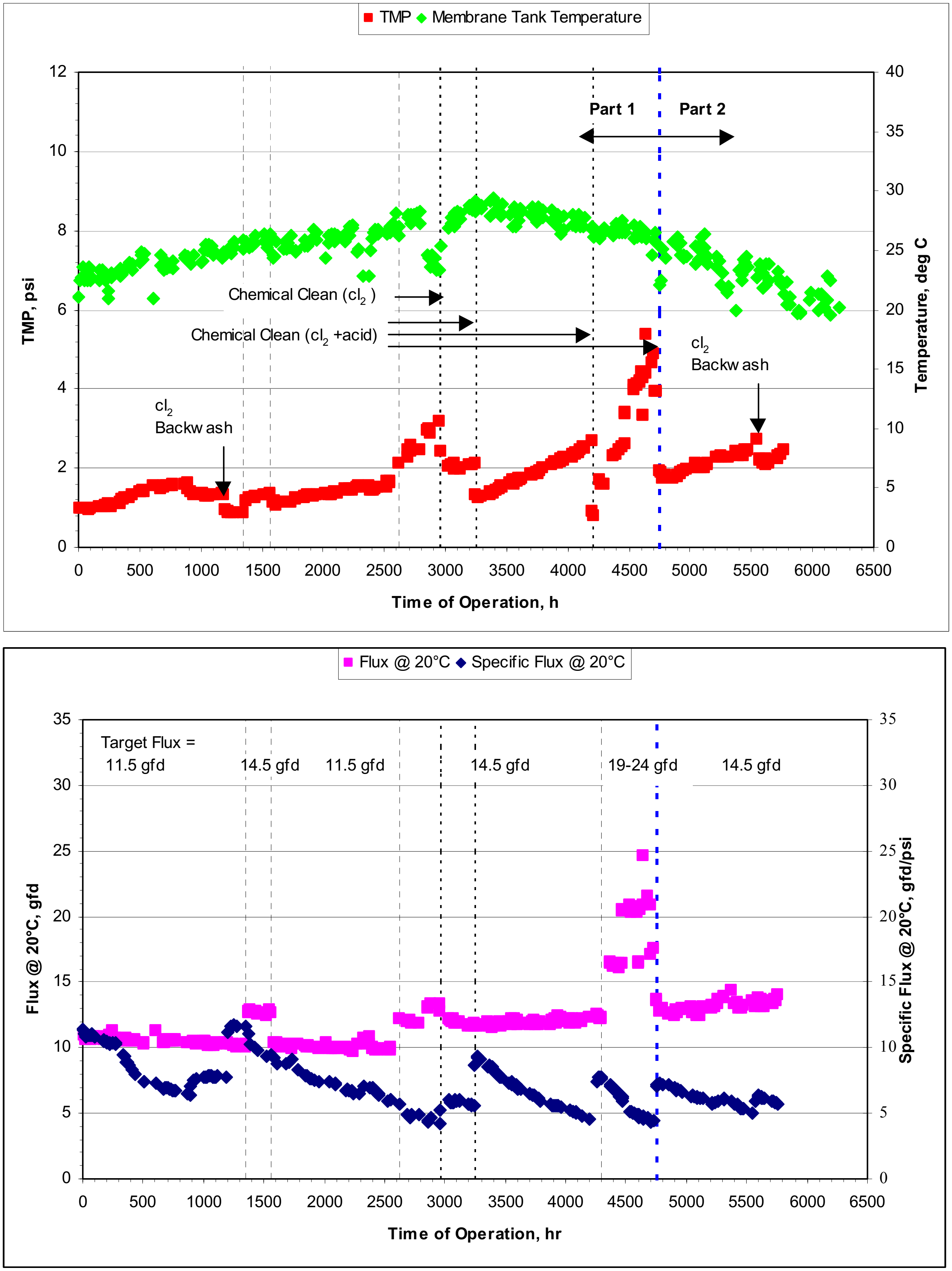
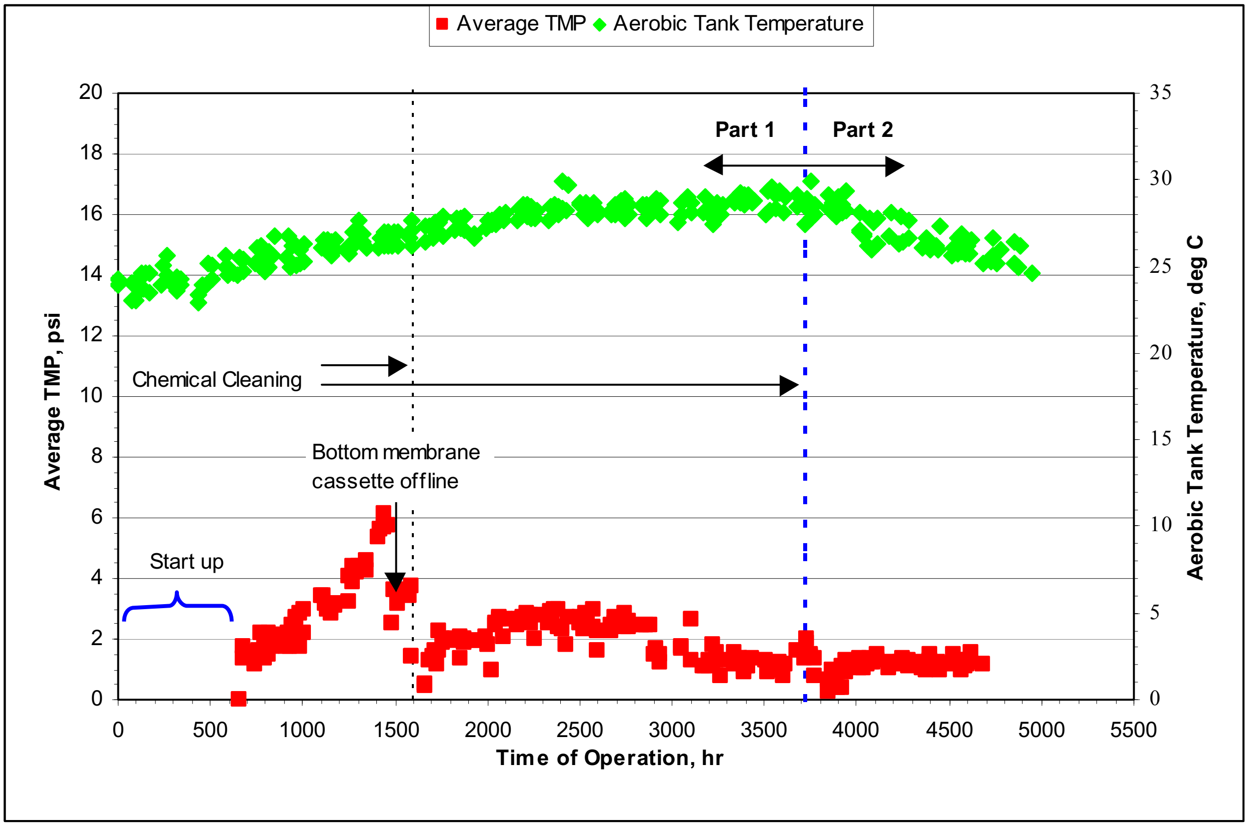


Figure 5-7: Membrane Performance of the US Filter MBR



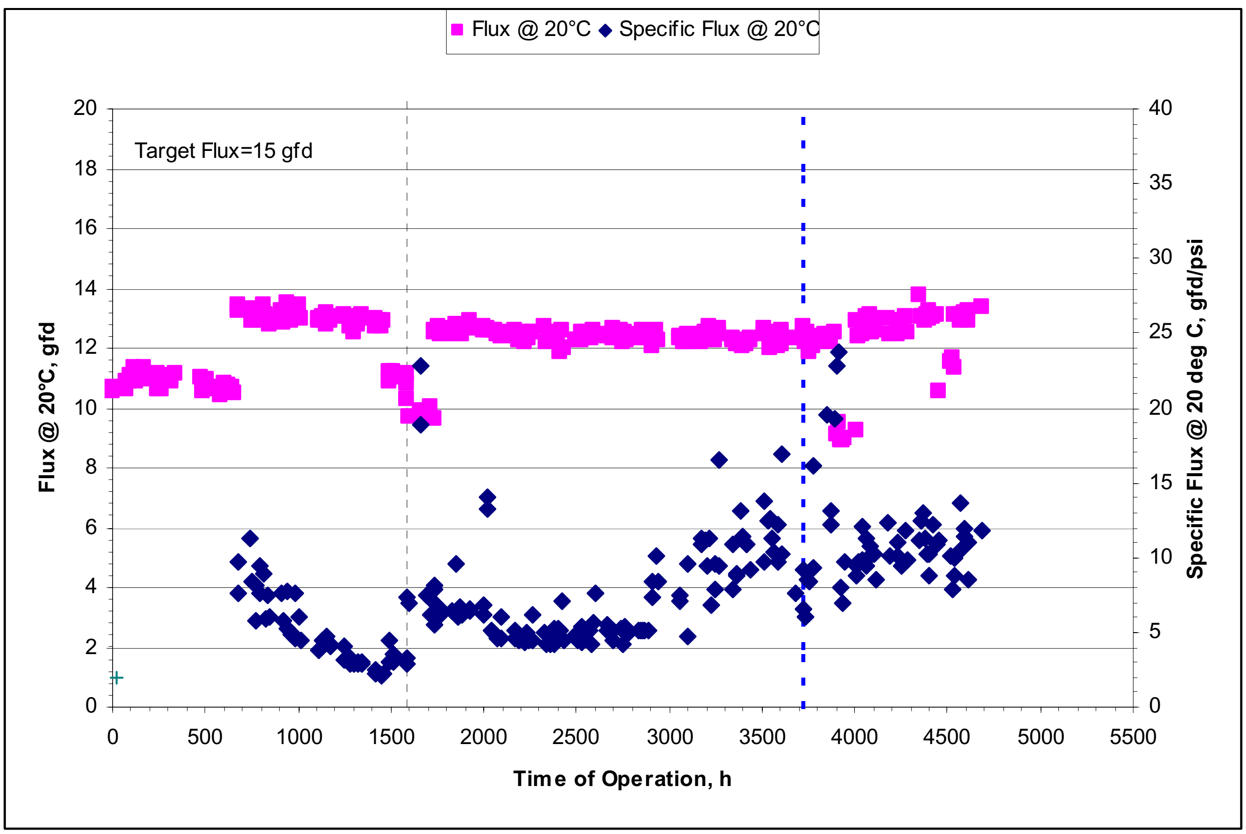


Figure 5-8: Membrane Performance of the Kubota MBR

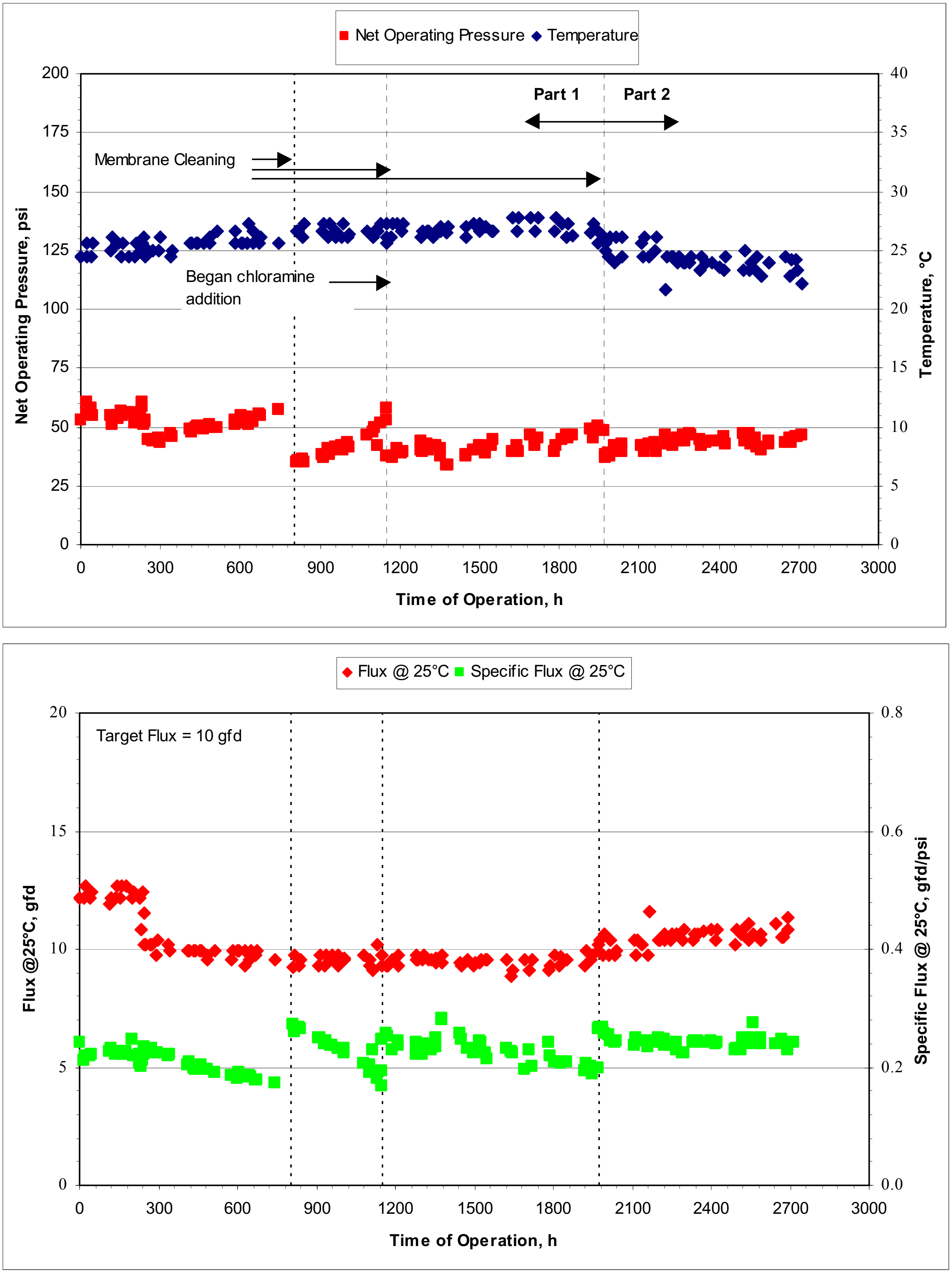
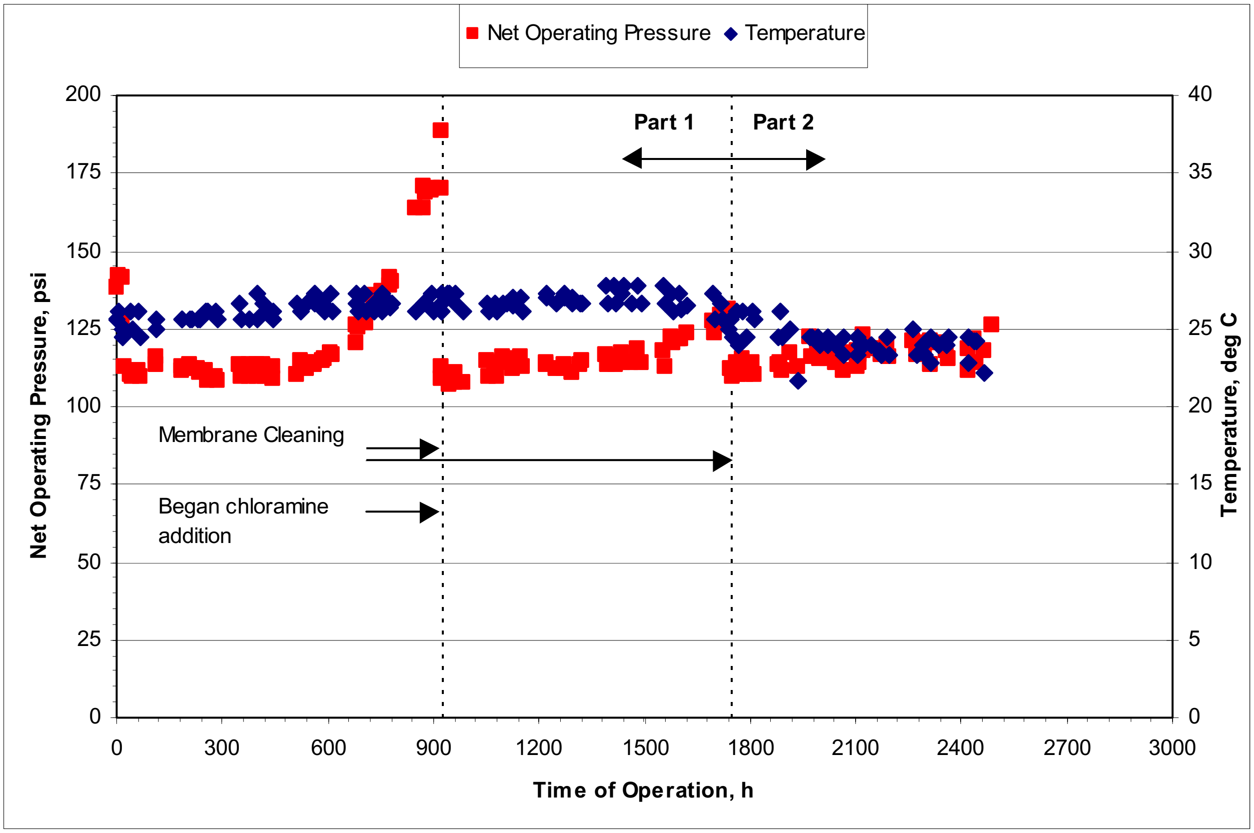


Figure 5-9: Saehan 4040 BL RO Membrane Performance



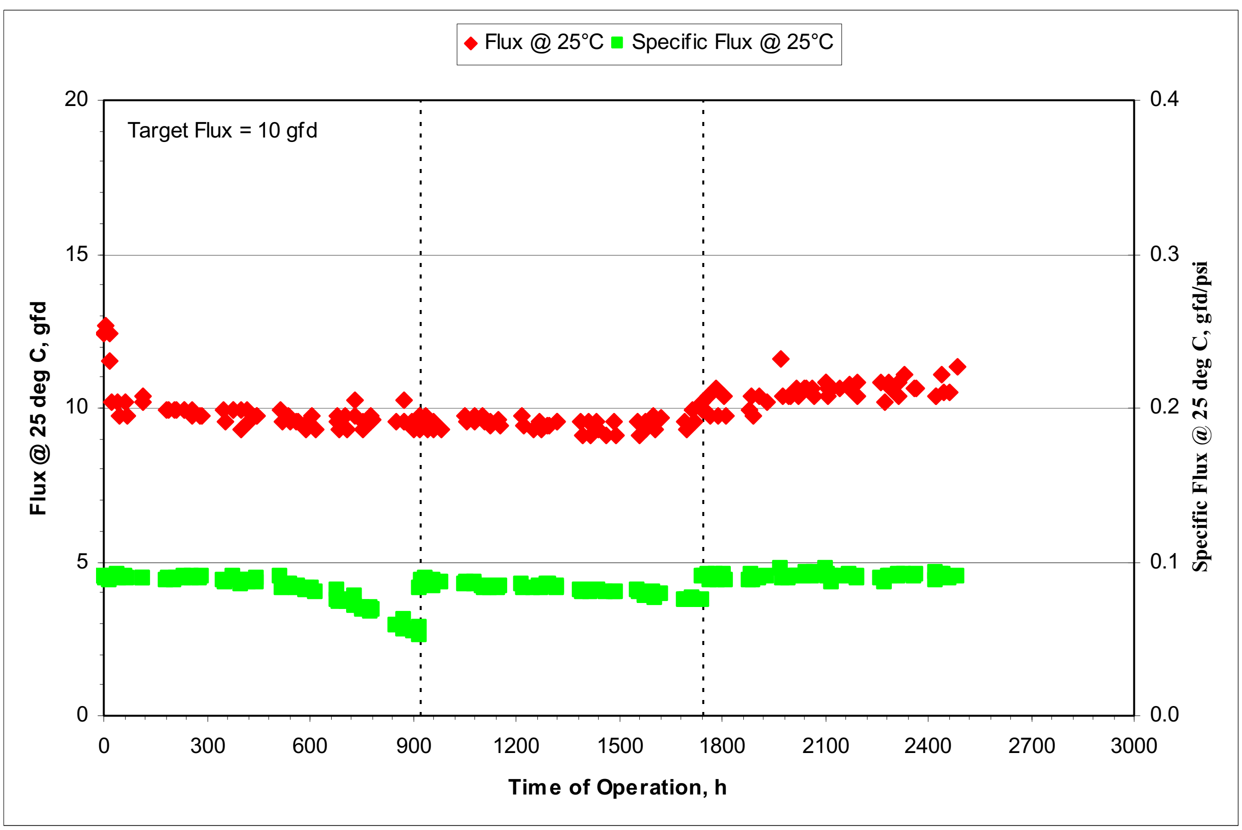


Figure 5-10: Hydranautics LFC3 RO Membrane Performance

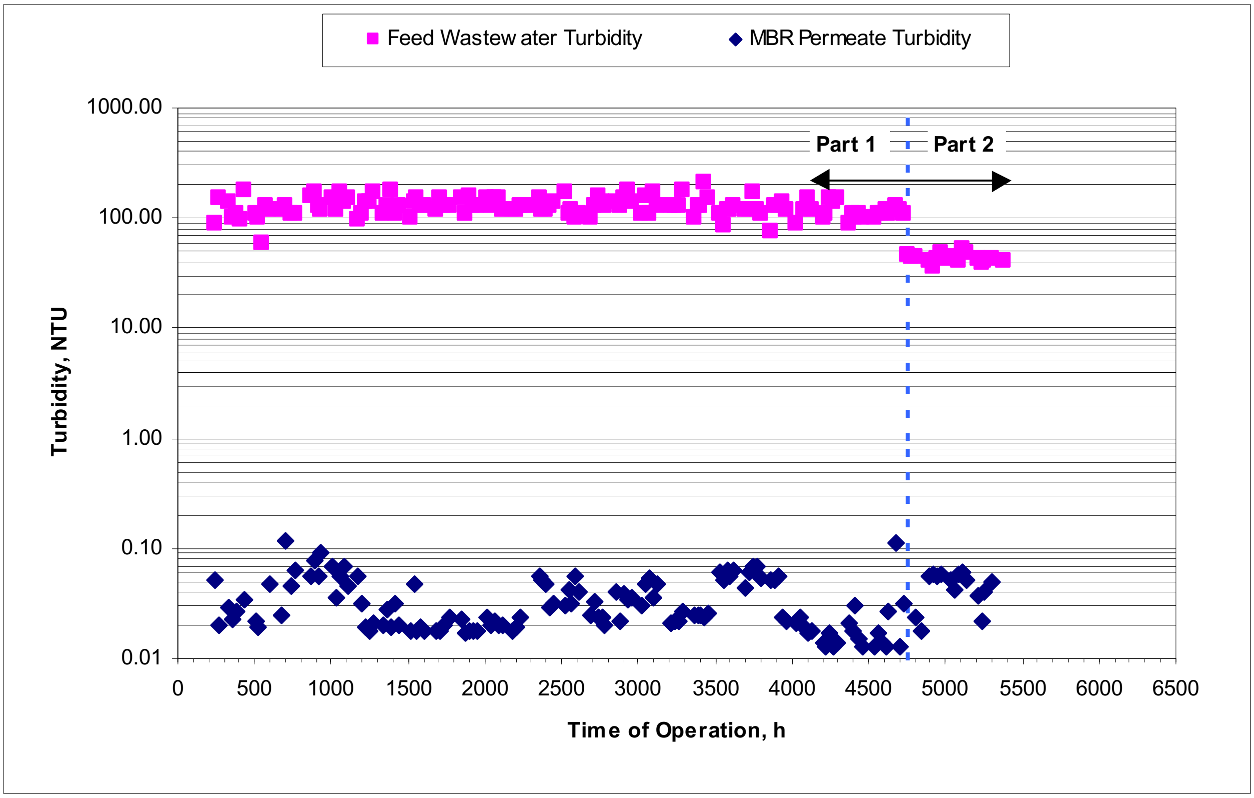


Figure 5-11: Turbidity Removal by the US Filter MBR

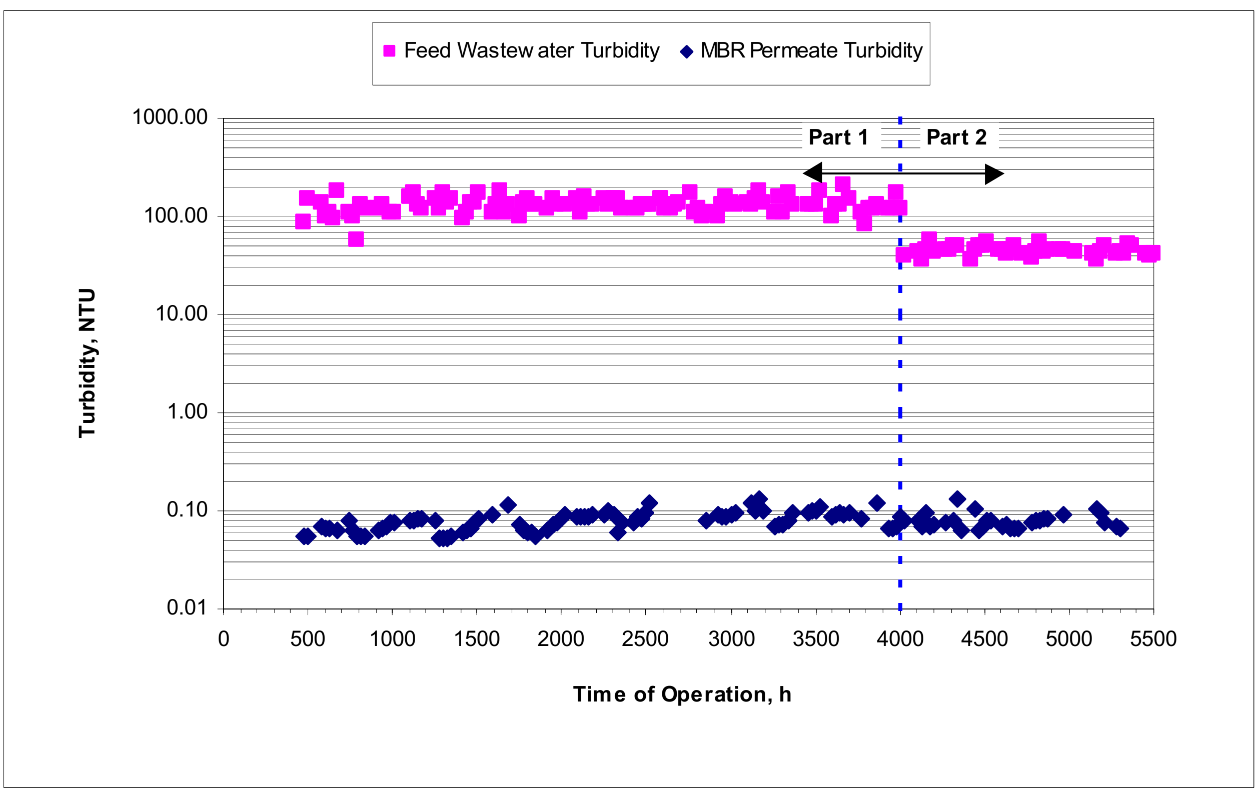


Figure 5-12: Turbidity Removal by the Kubota MBR

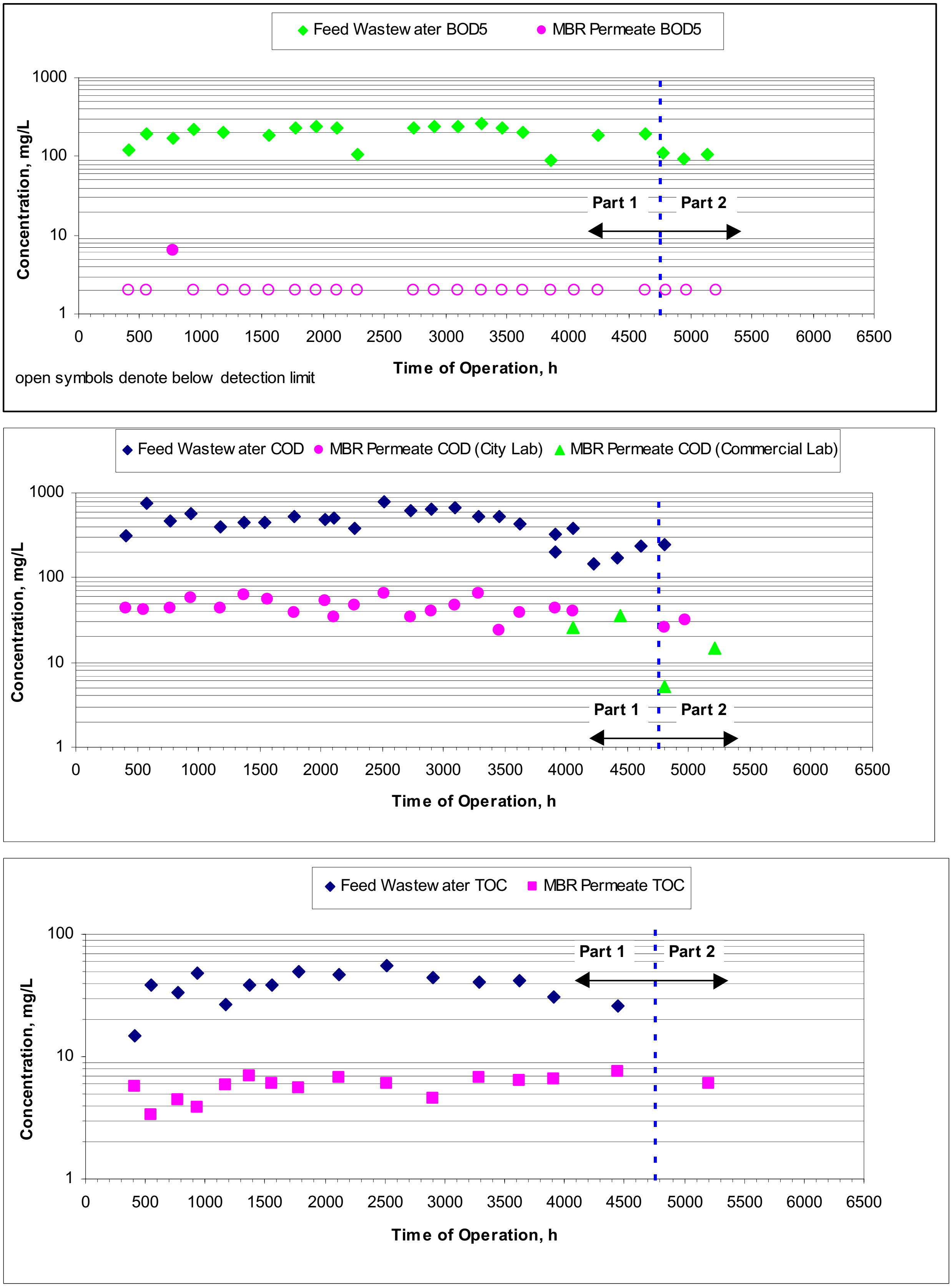


Figure 5-13: Organic Removal by the US Filter MBR

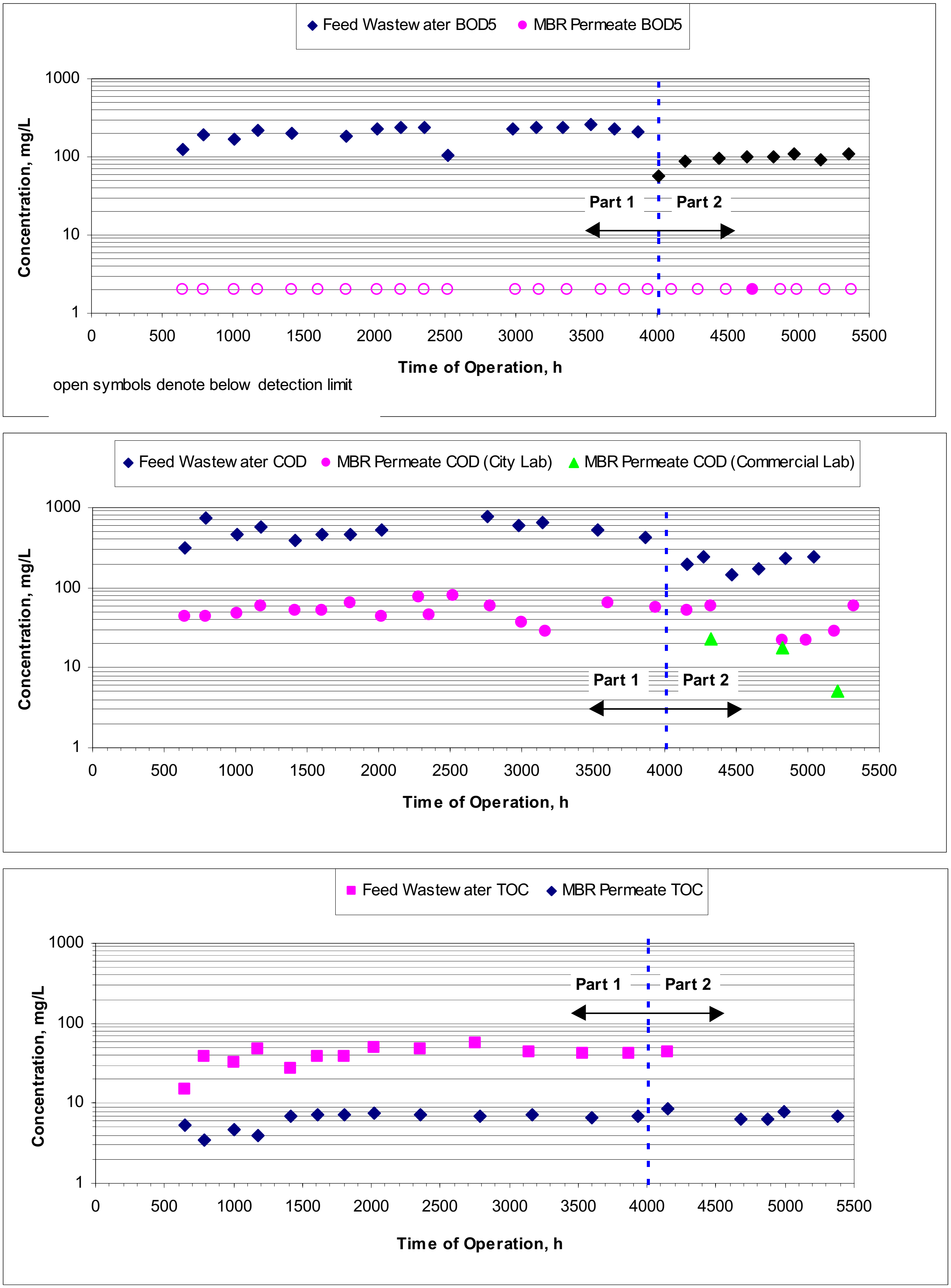


Figure 5-14: Organic Removal by the Kubota MBR

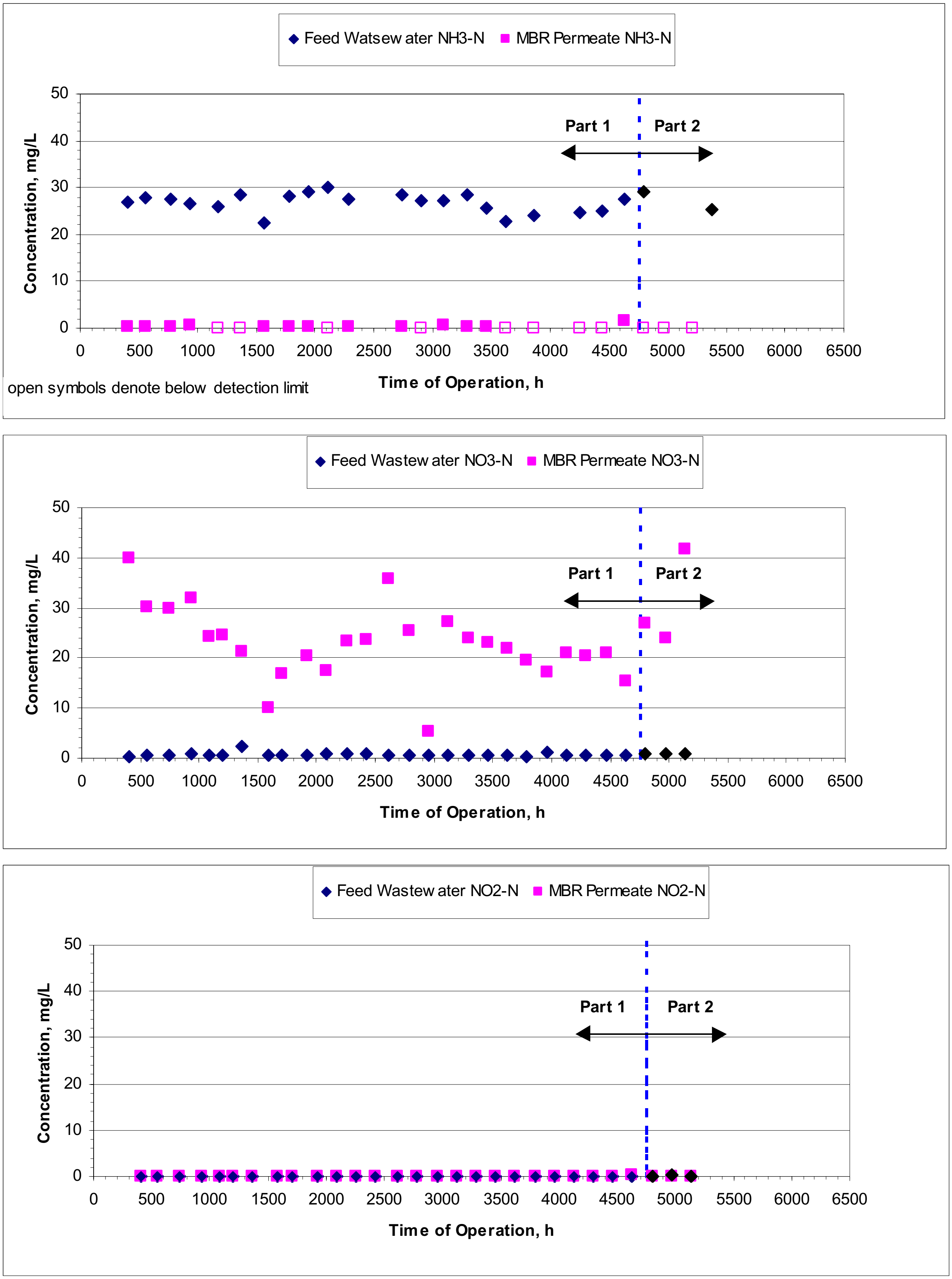


Figure 5-15: Inorganic Nitrogen Removal by the US Filter MBR

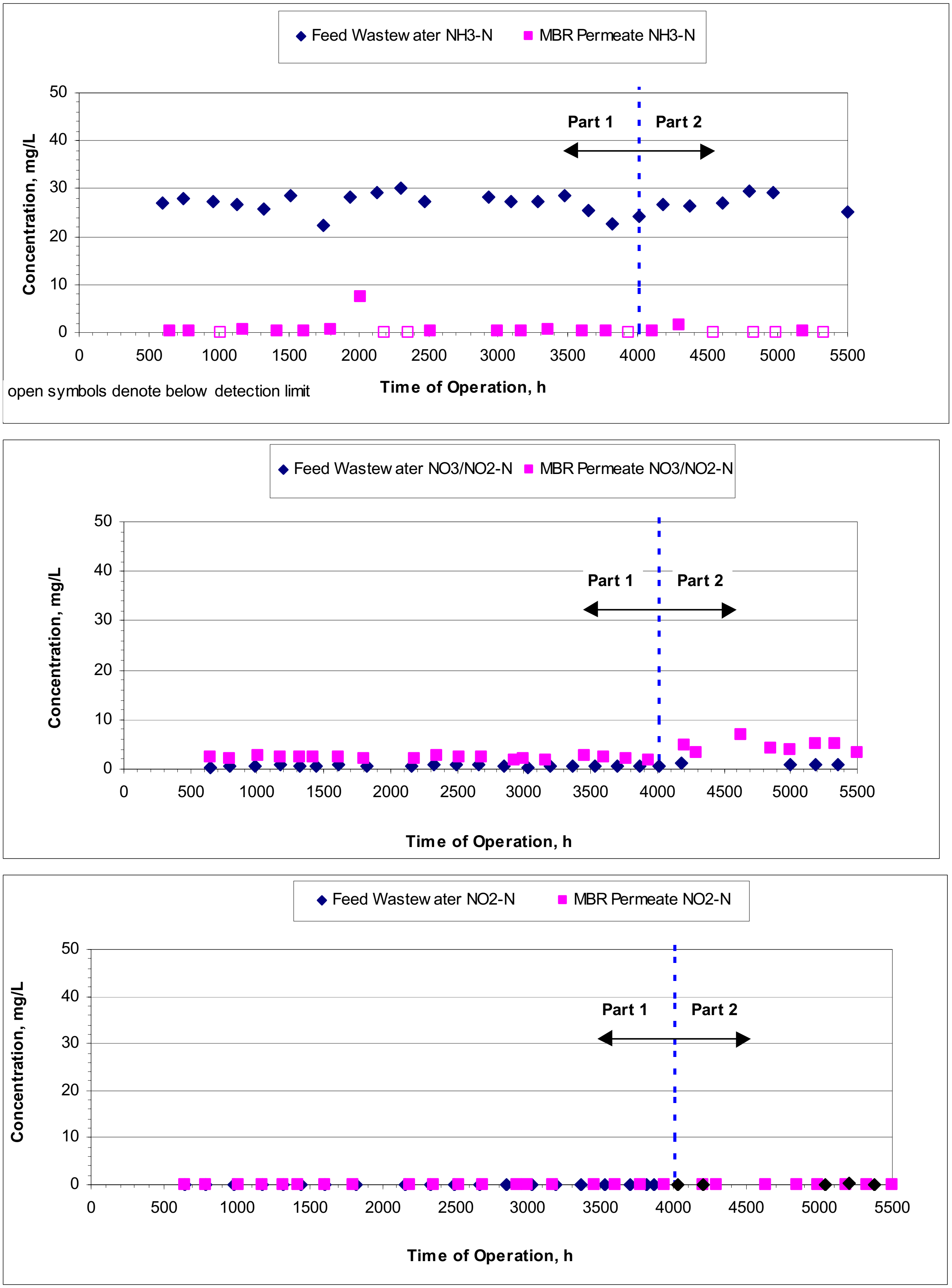


Figure 5-16: Inorganic Nitrogen Removal by the Kubota MBR

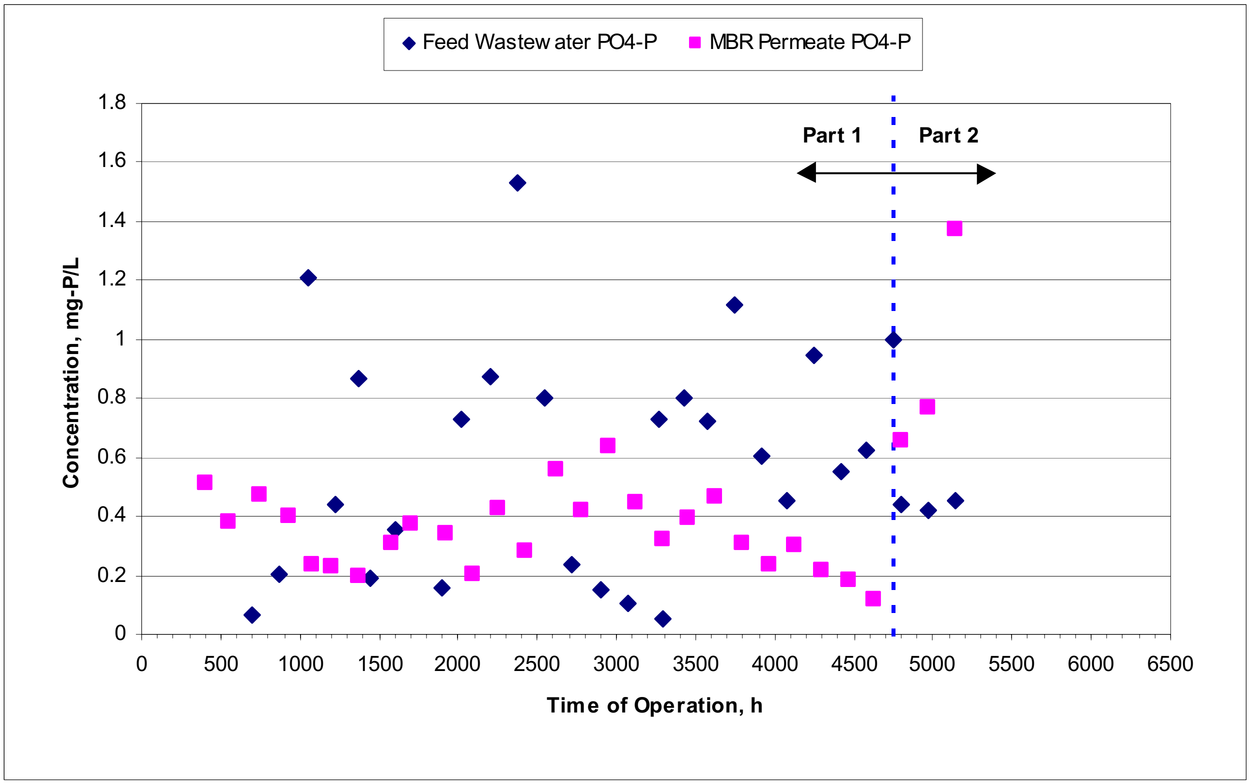


Figure 5-17: Ortho-Phosphate Removal by the US Filter MBR

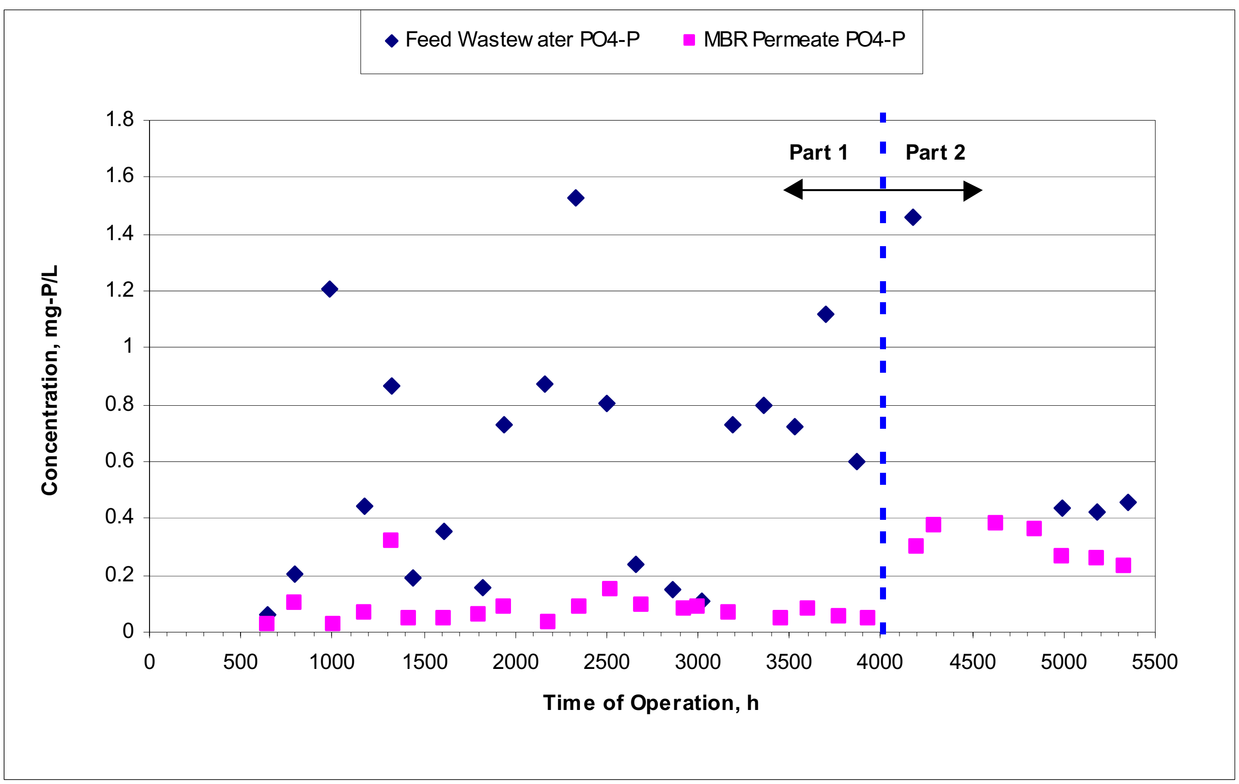


Figure 5-18: Ortho-Phosphate Removal by the Kubota MBR

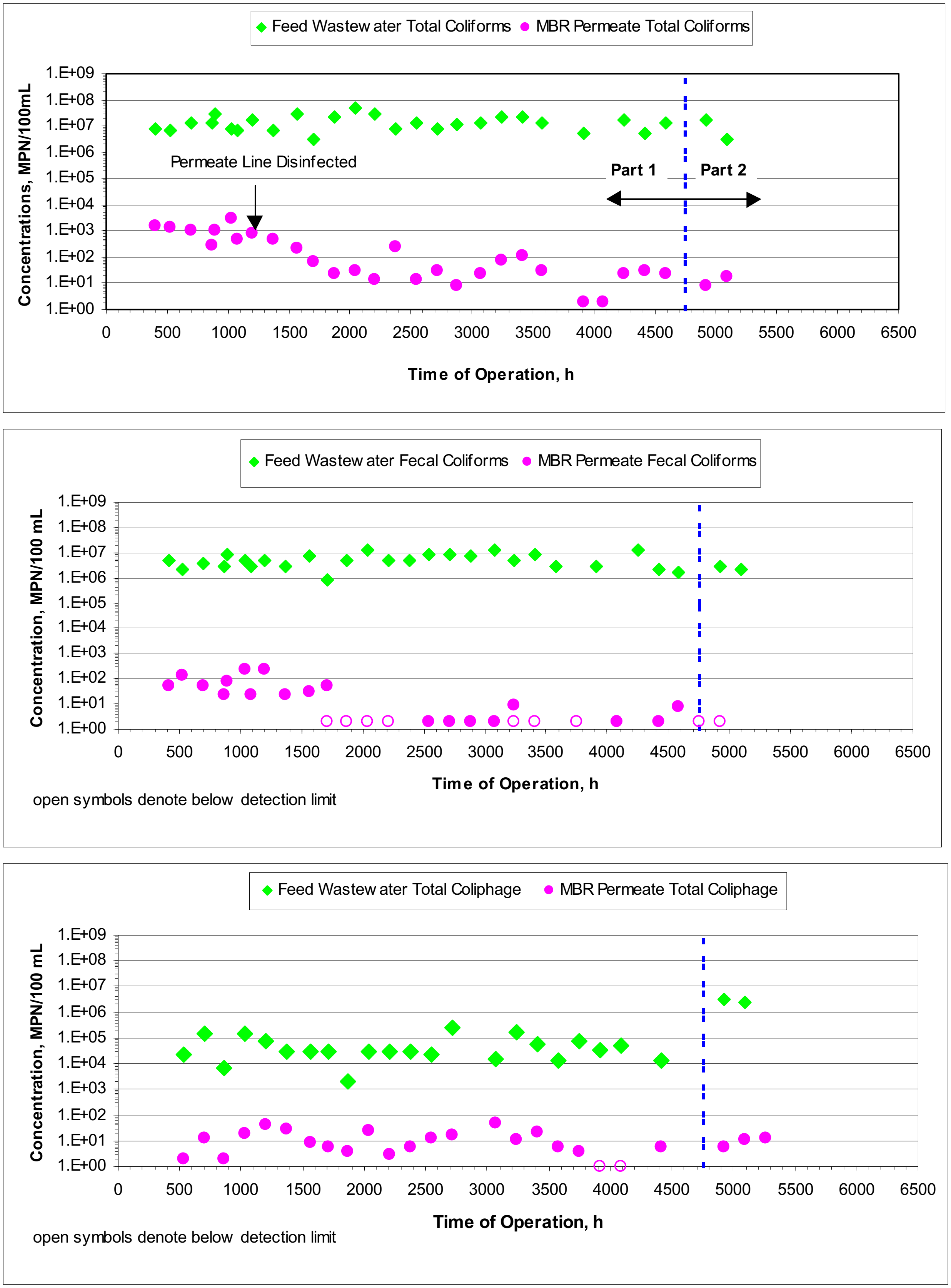


Figure 5-19: Coliform and Coliphage Removal by the US Filter MBR

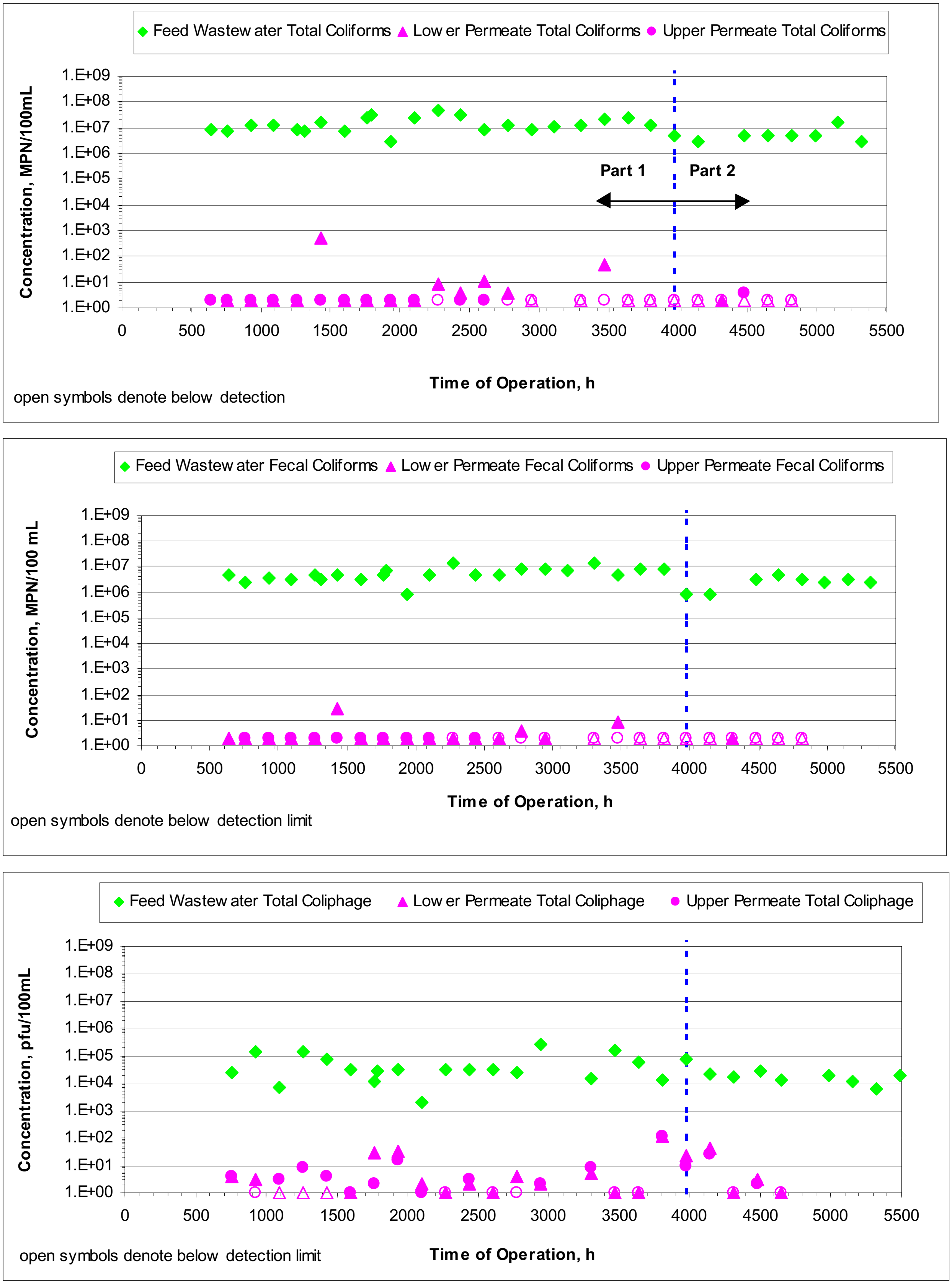
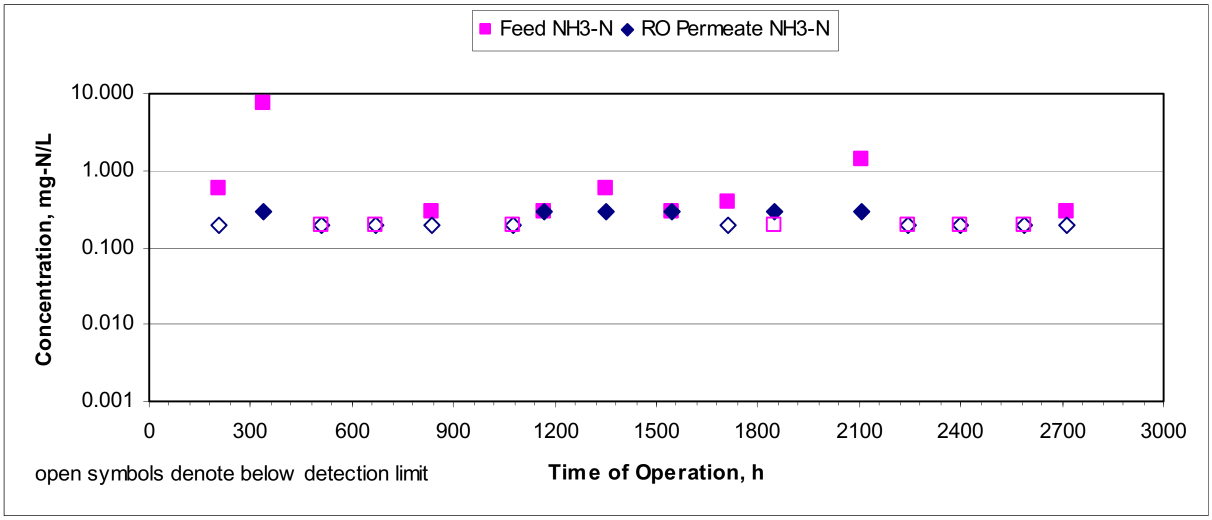
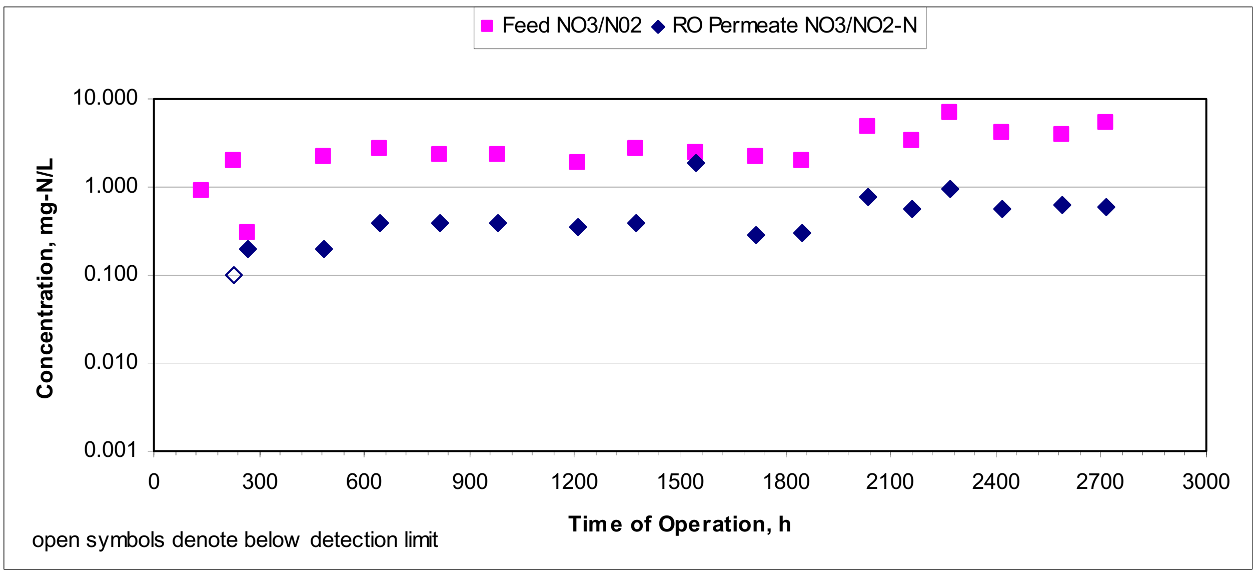


Figure 5-20: Coliform and Coliphage Removal by the Kubota MBR





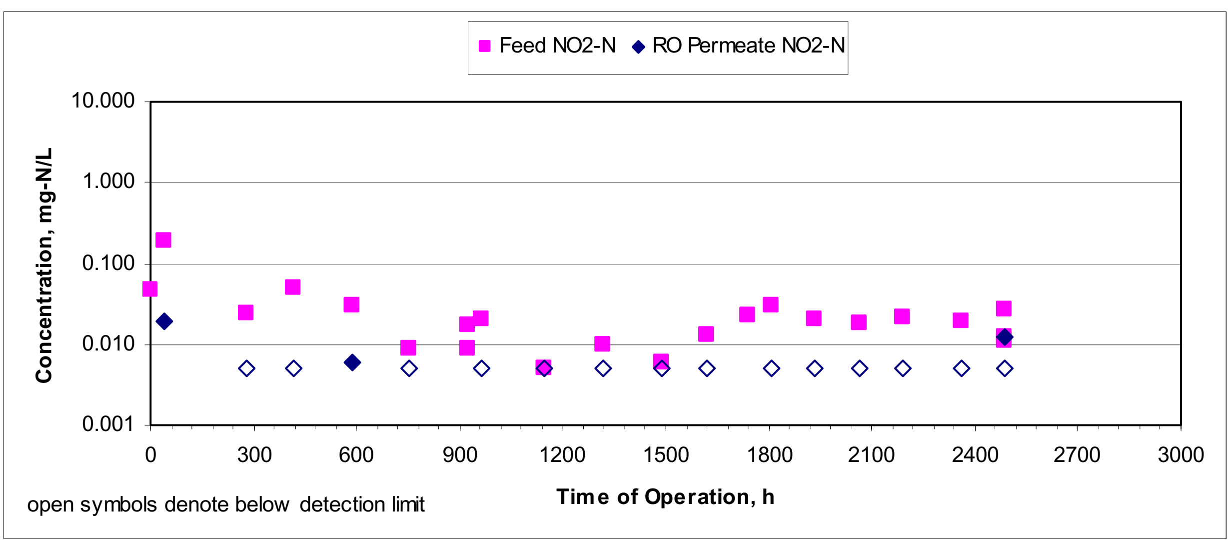


Figure 5-21: Inorganic Nitrogen Removal by the Saehan 4040 BL RO Membrane

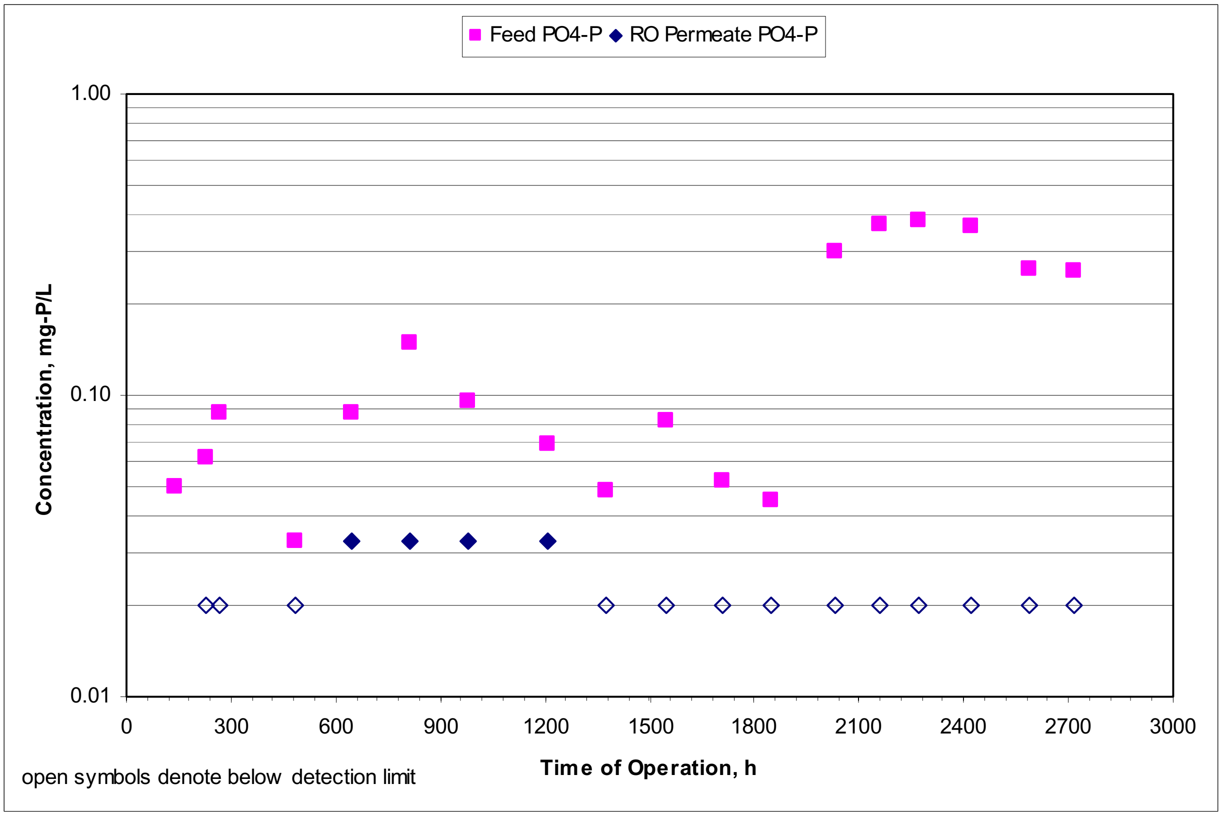


Figure 5-22: Ortho-Phosphate Removal by the Saehan 4040 BL RO Membrane

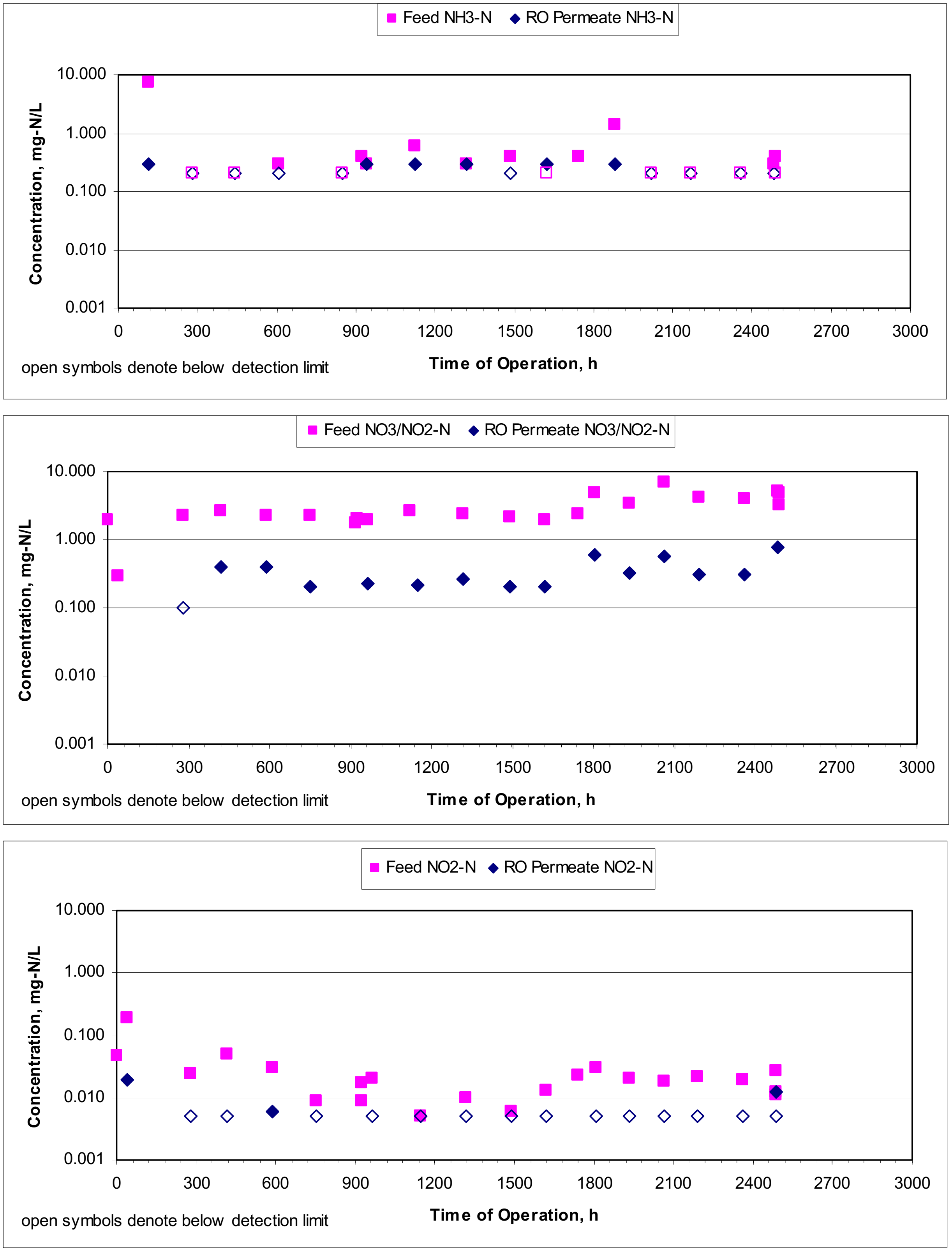


Figure 5-23: Inorganic Nitrogen Removal by the Hydranautics LFC3 RO Membrane

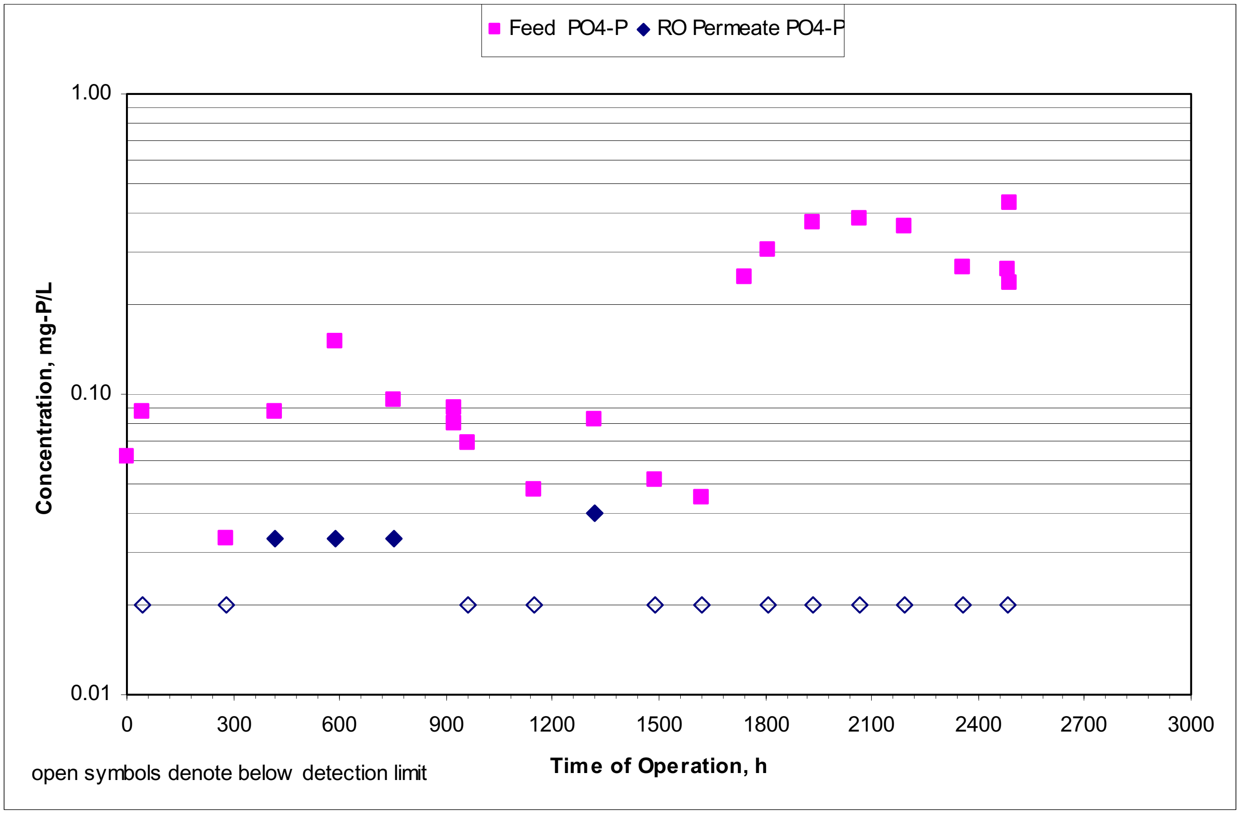


Figure 5-24: Ortho-Phosphate Removal by the Hydranautics LFC3 RO Membrane

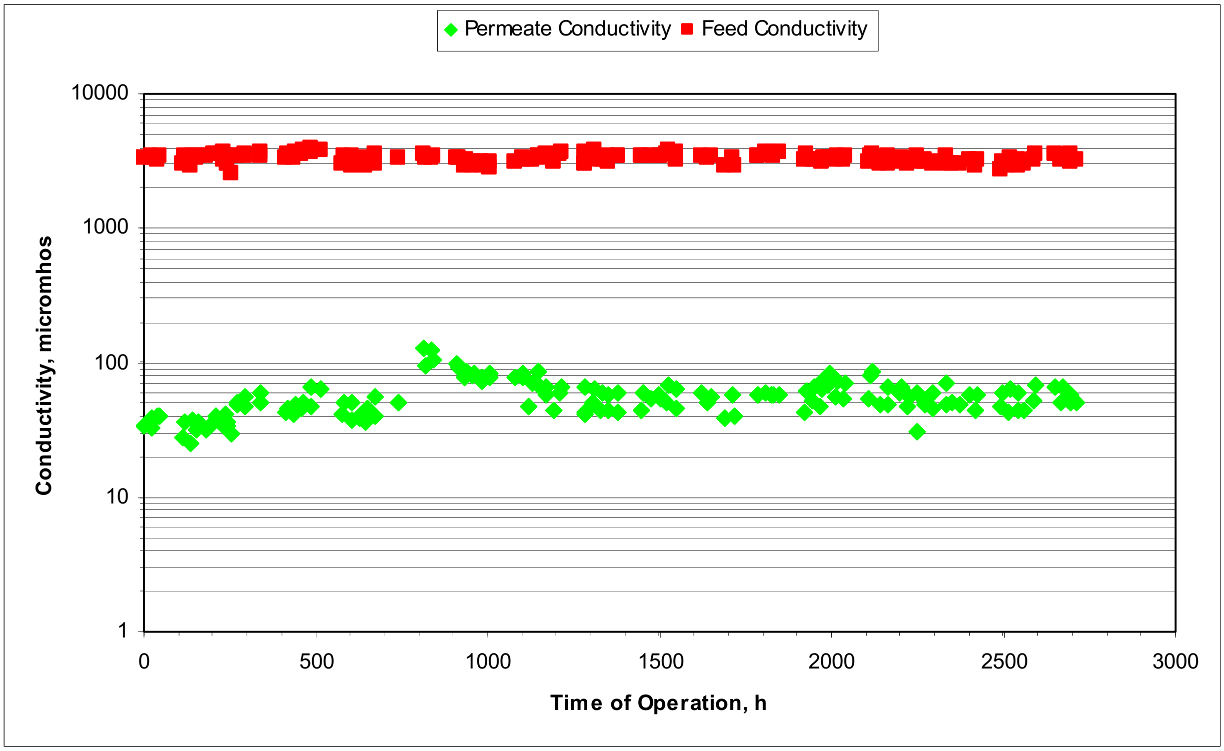


Figure 5-25: Conductivity Profile across the Saehan 4040 BL RO Membrane

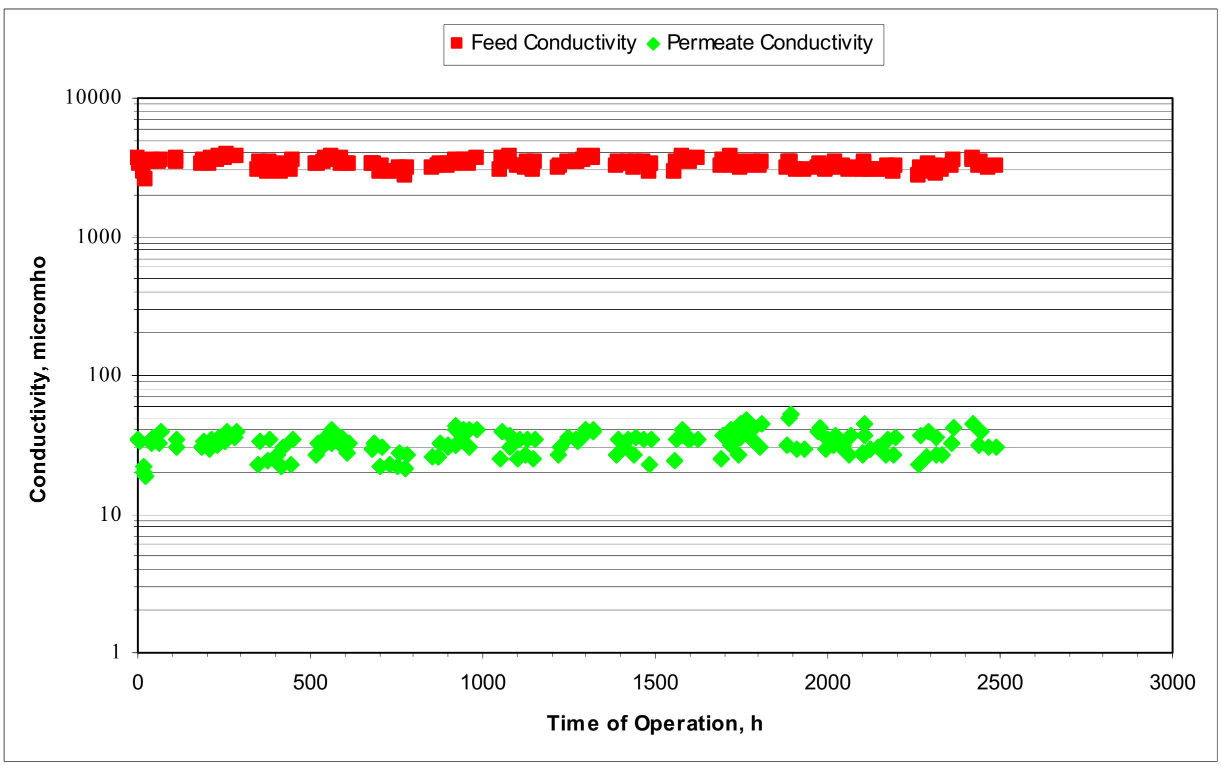
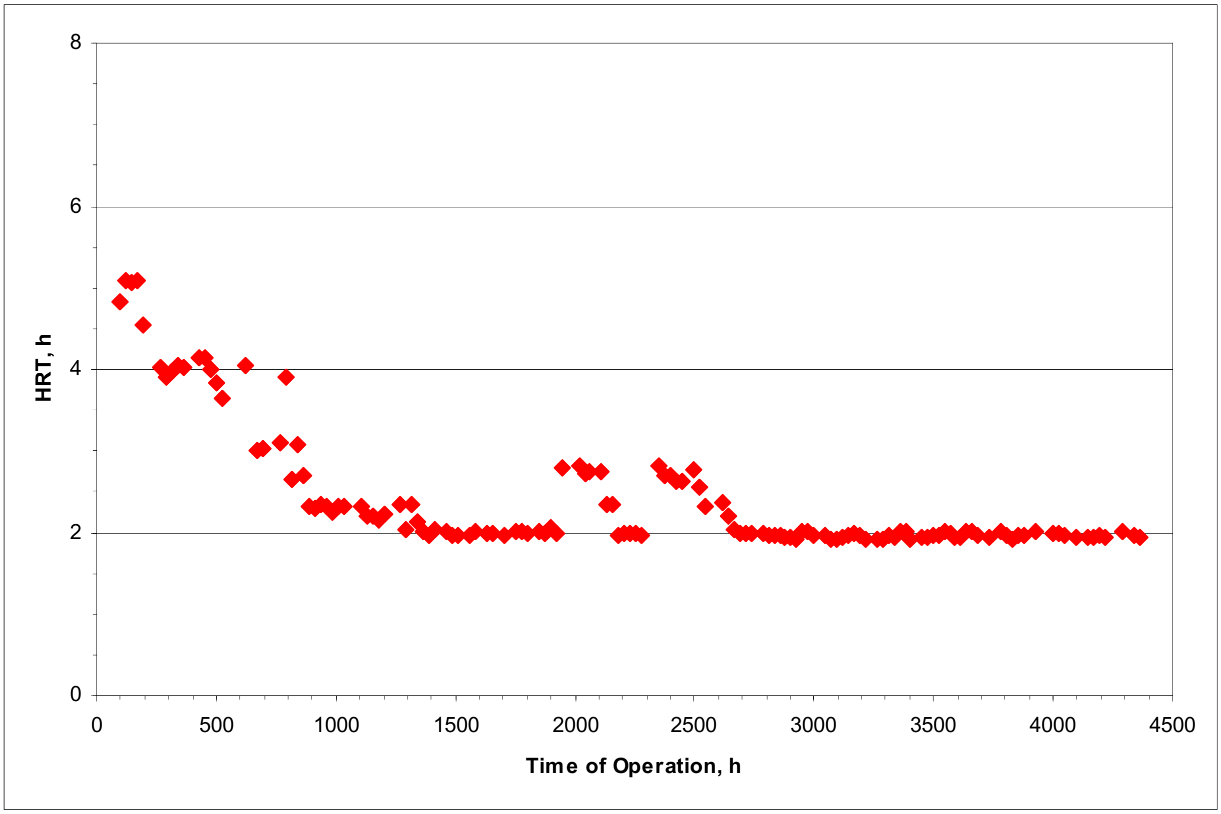


Figure 5-26: Conductivity Profile Across the Hydranautics LFC3 RO Membrane



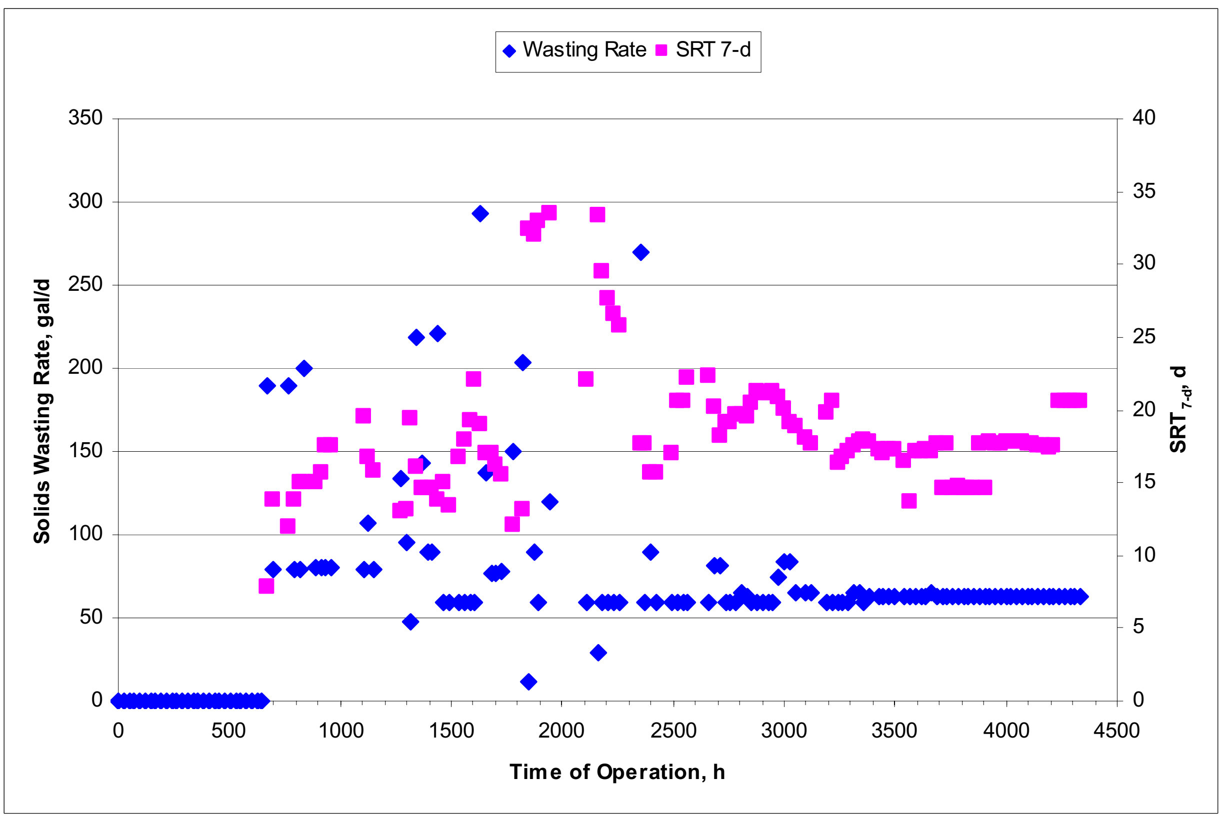


Figure 6-1: HRT and SRT7-d for the Zenon MBR

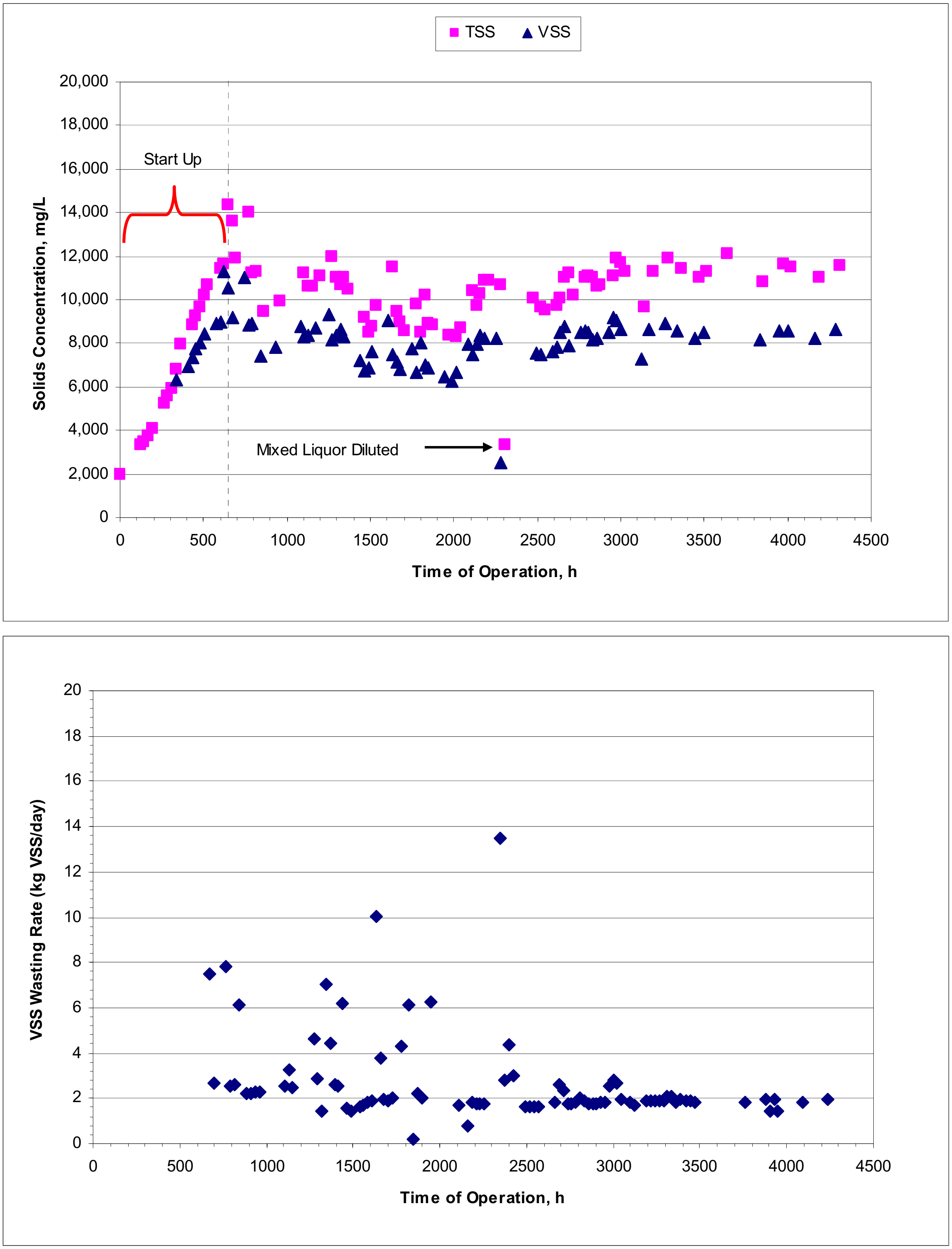


Figure 6-2: Mixed Liquor Solids Concentration for the Zenon MBR

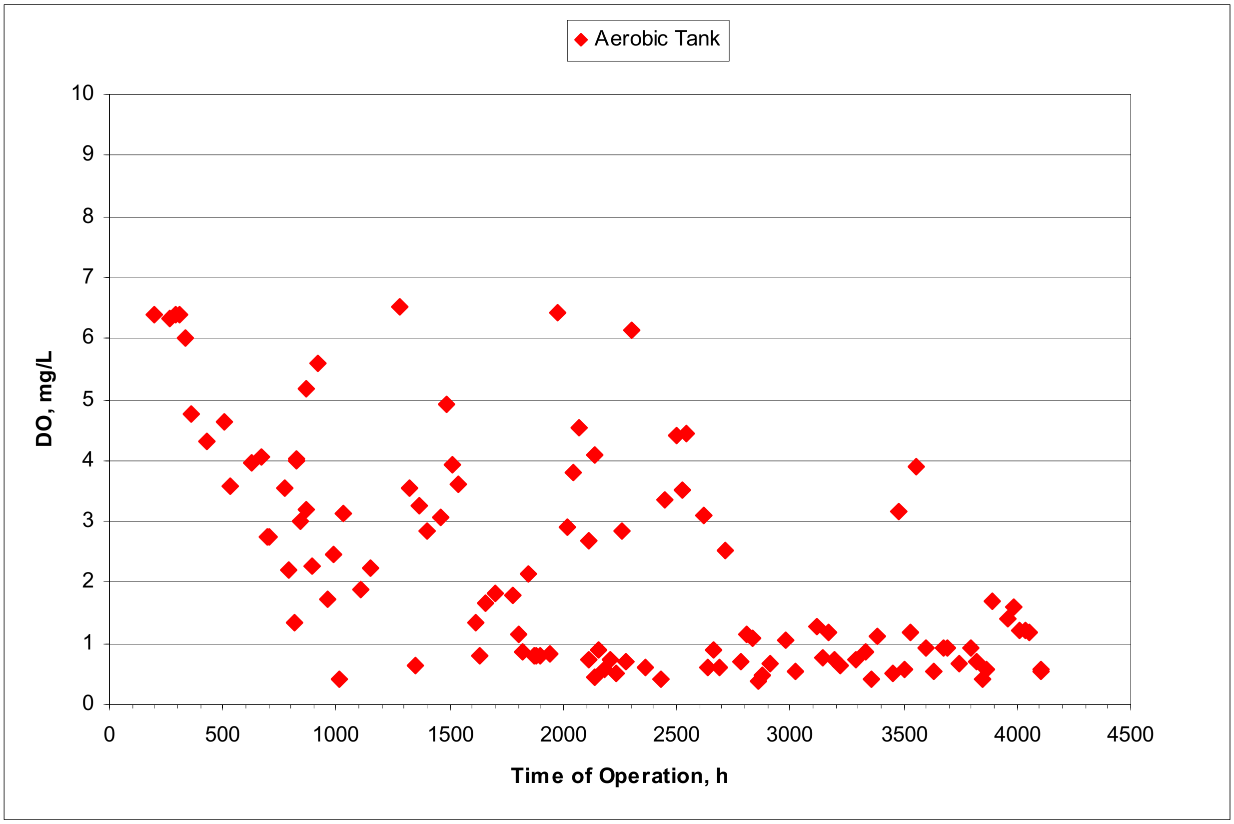


Figure 6-3: DO Concentrations in the Zenon MBR

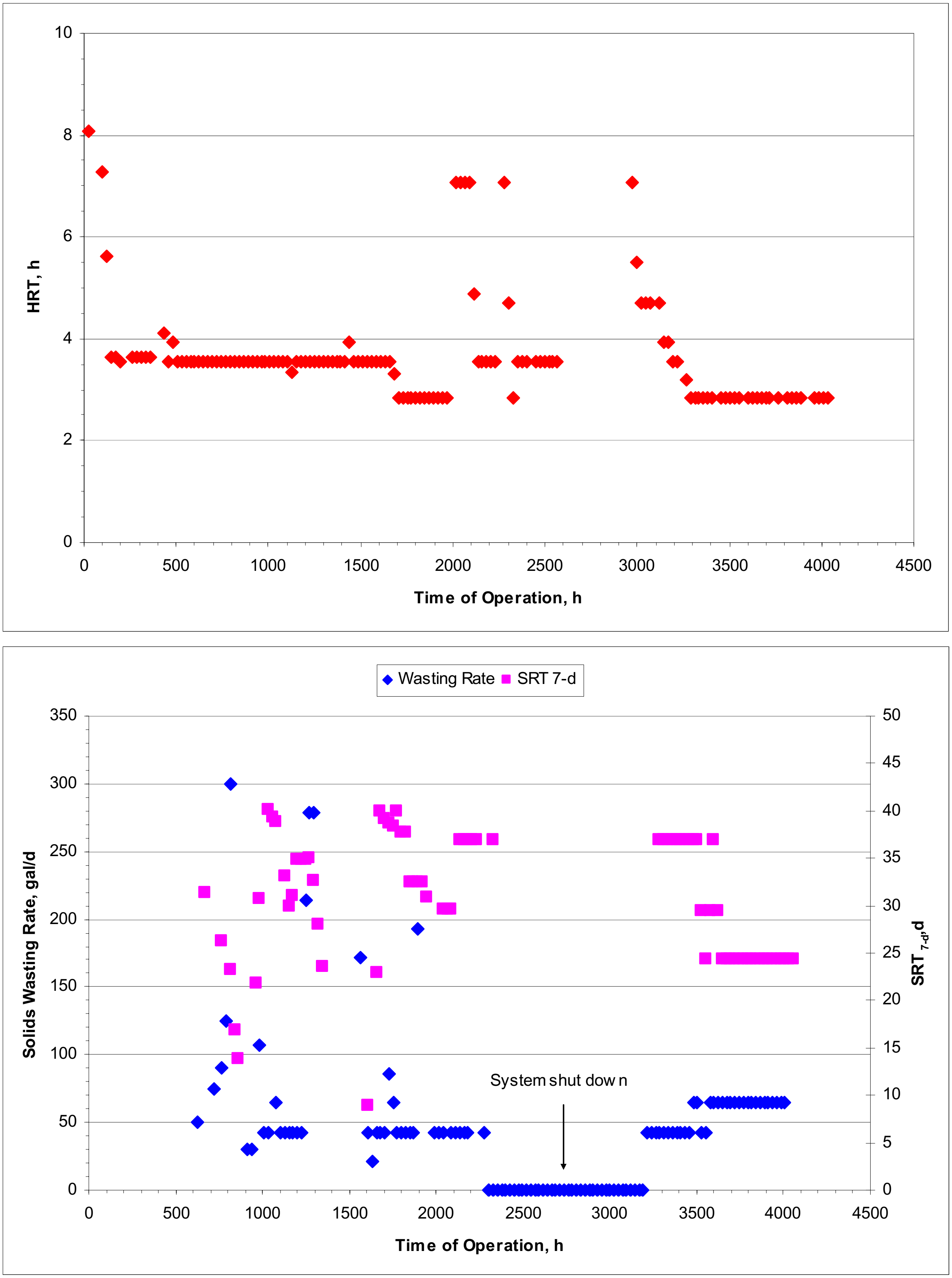


Figure 6-4: HRT and SRT7-d for the Mitsubishi MBR

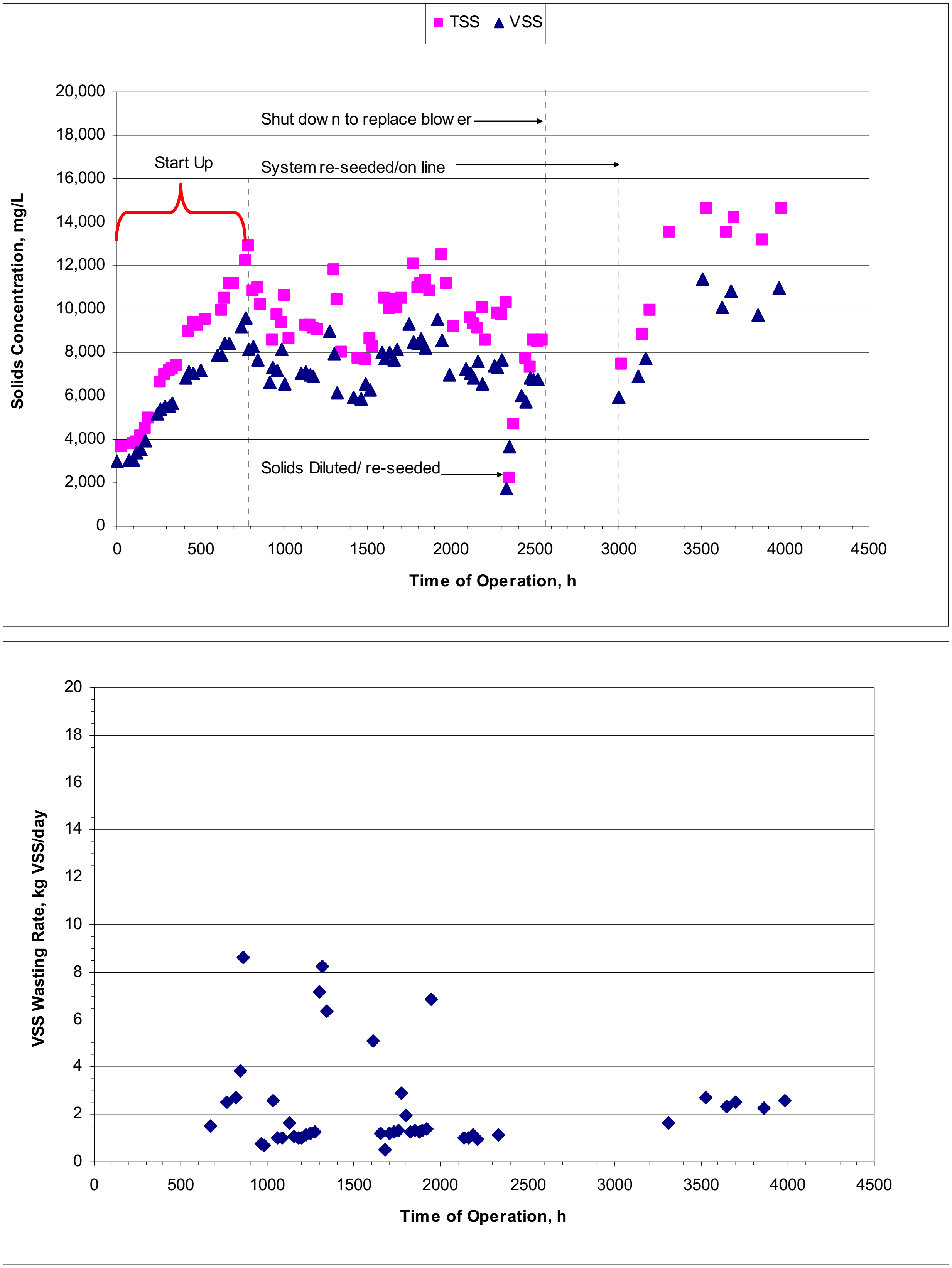


Figure 6-5: Mixed Liquor Solids Concentration for the Mitsubishi MBR

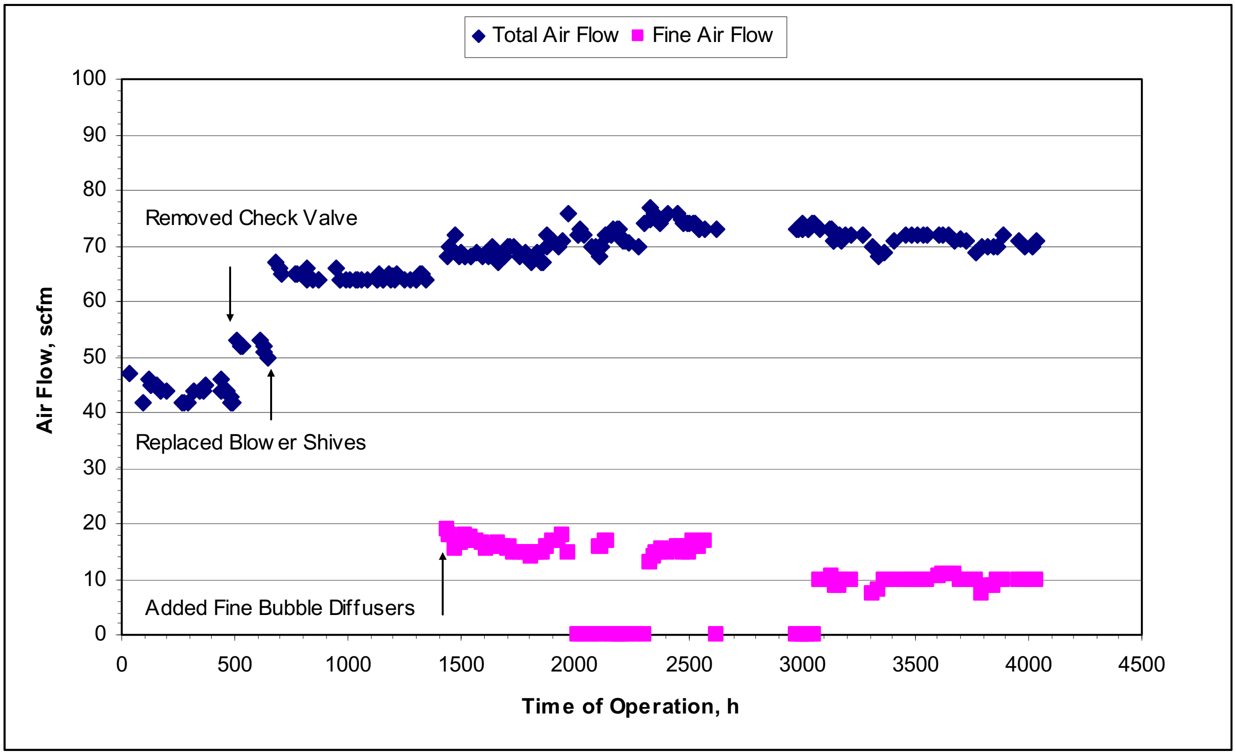


Figure 6-6: Air Flow to the Mitsubishi MBR

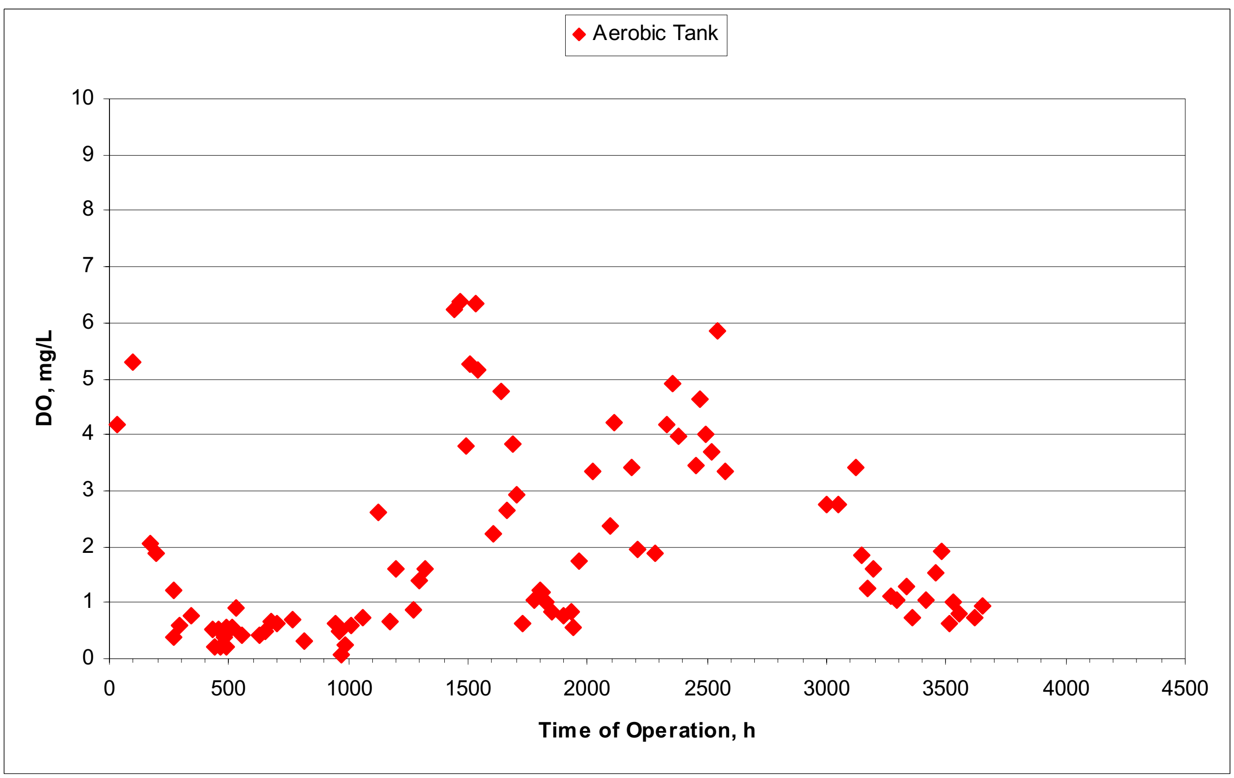


Figure 6-7: DO Concentrations in the Mitsubishi MBR

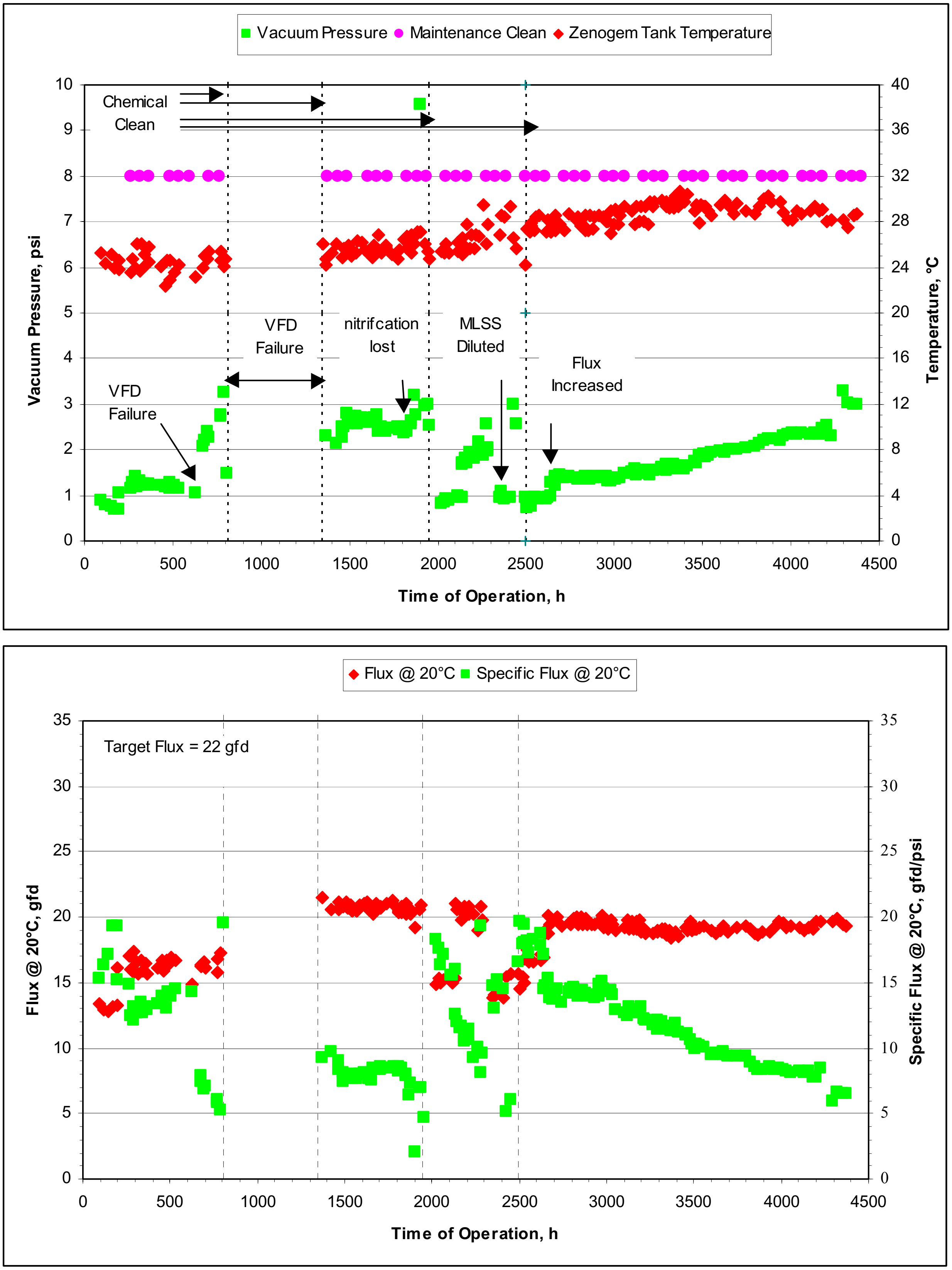
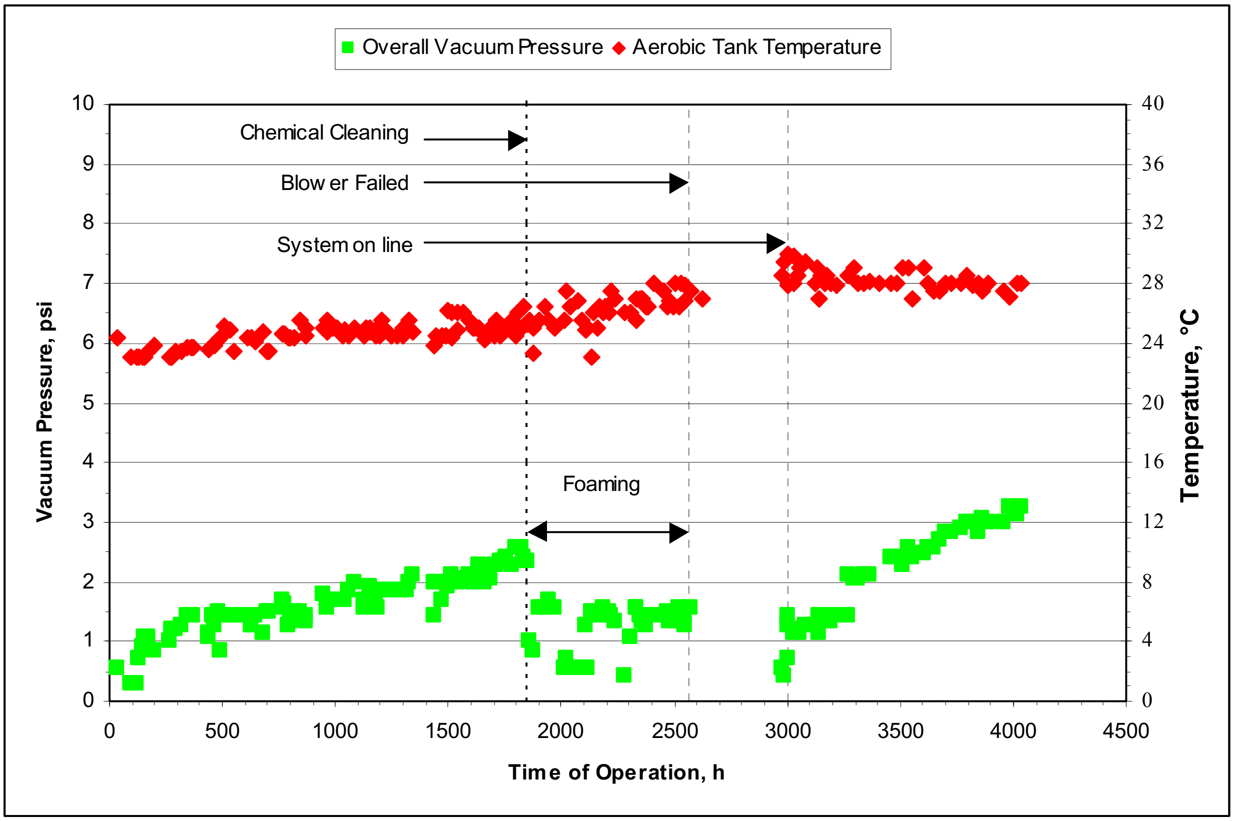


Figure 6-8: Membrane Performance of the Zenon MBR



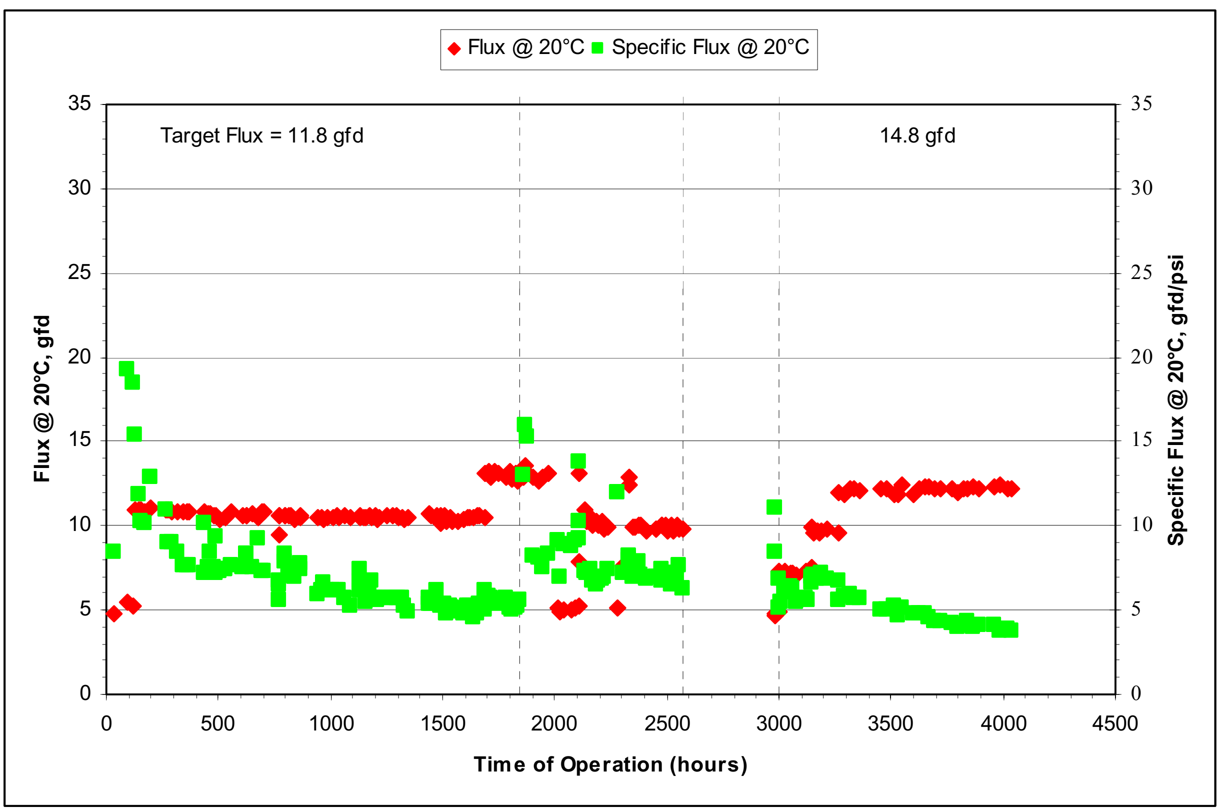


Figure 6-9: Membrane Performance of the Mitsubishi MBR

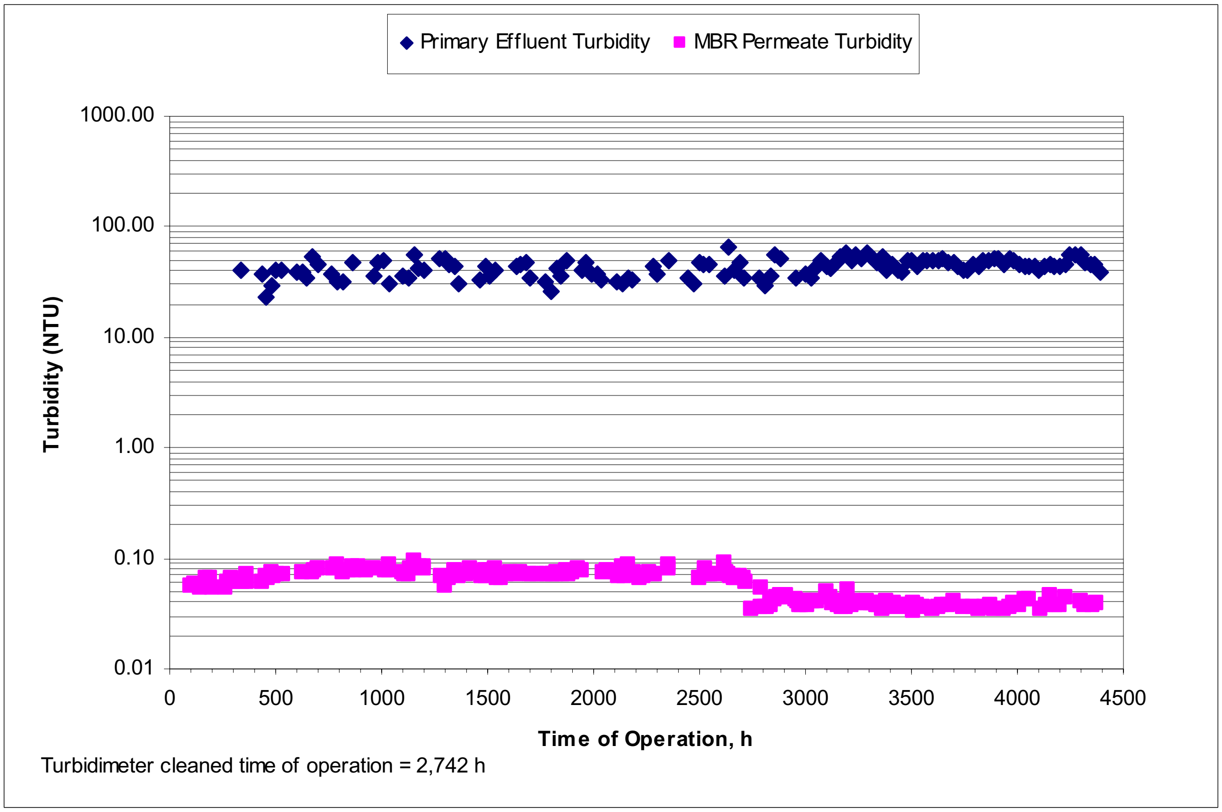


Figure 6-10: Turbidity Removal by the Zenon MBR

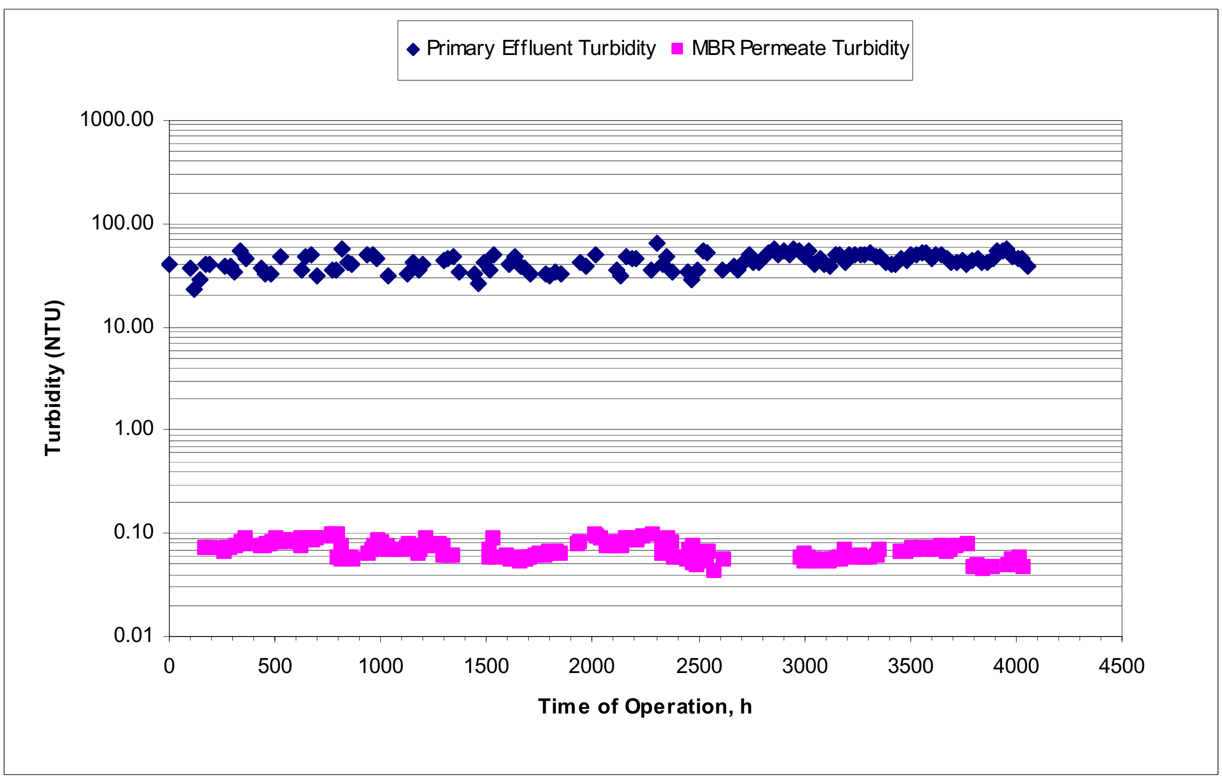
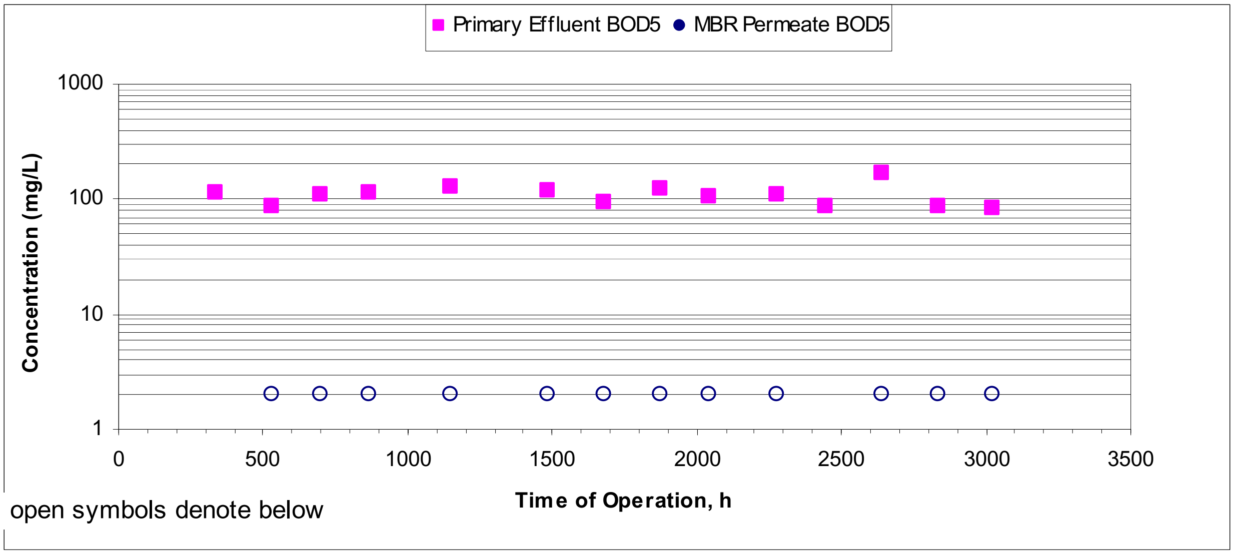
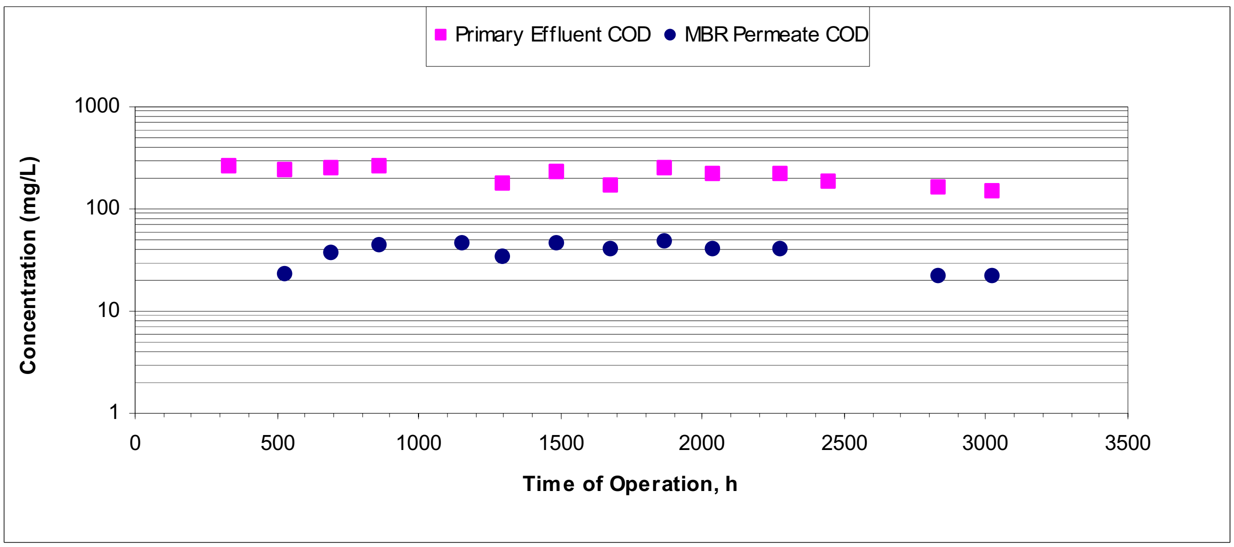


Figure 6-11: Turbidity Removal by the Mitsubishi MBR





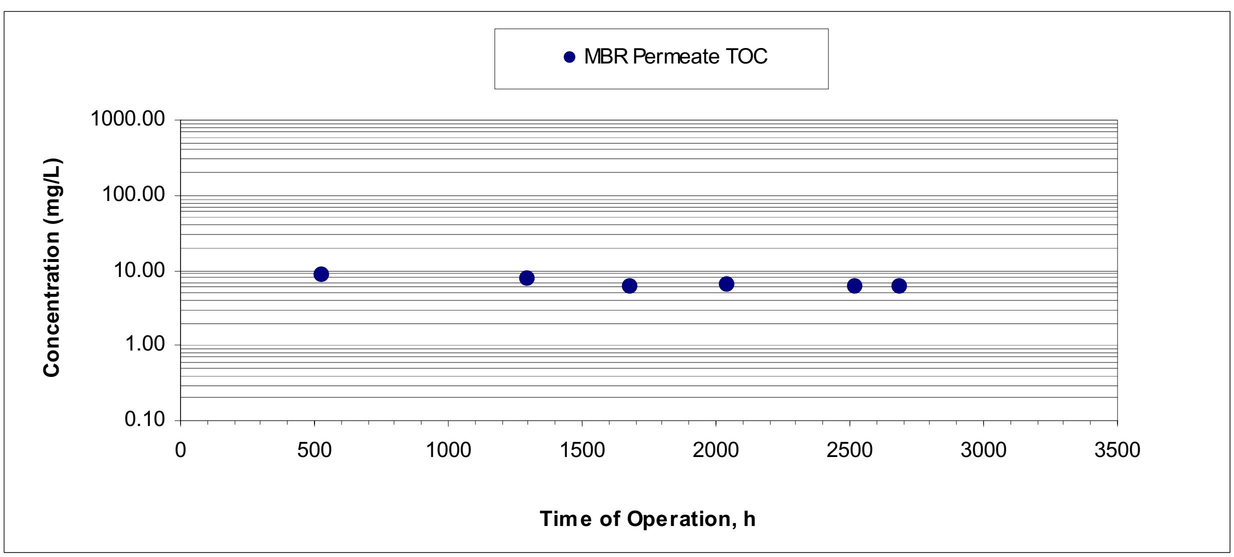


Figure 6-12: Organics Removal by the Zenon MBR

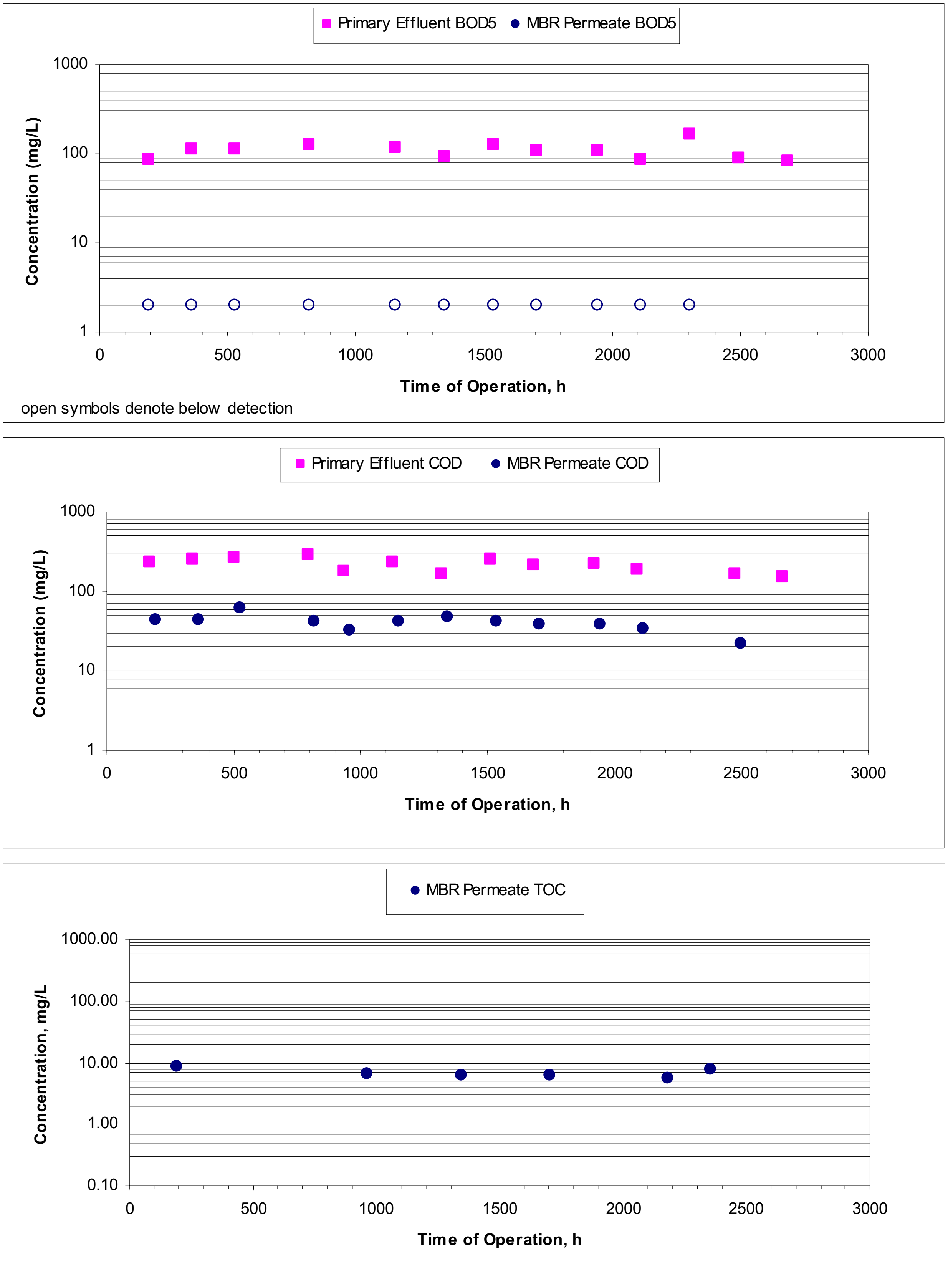


Figure 6-13: Organics Removal by the Mitsubishi MBR

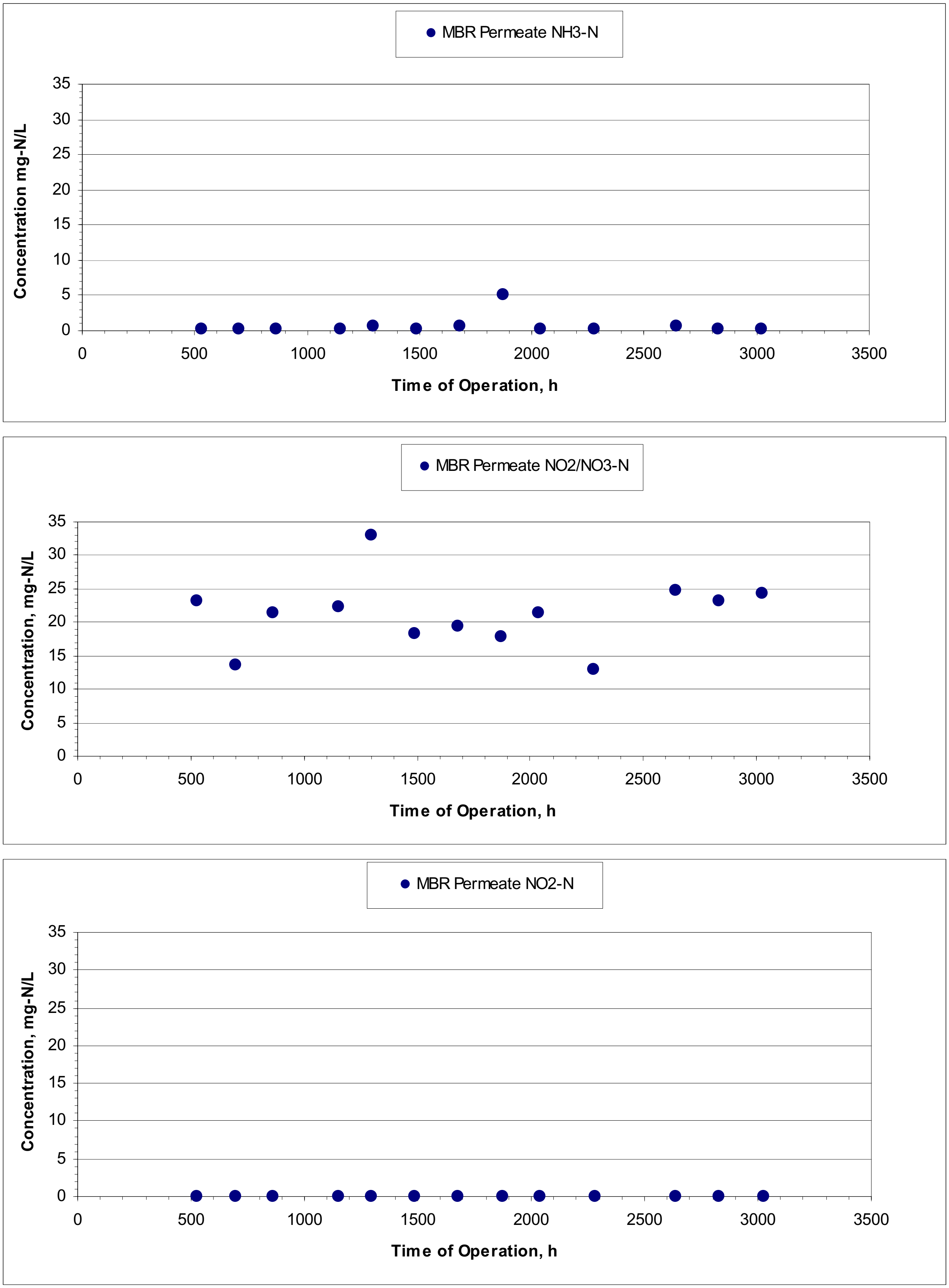


Figure 6-14: Inorganic Nitrogen Species in the Zenon MBR

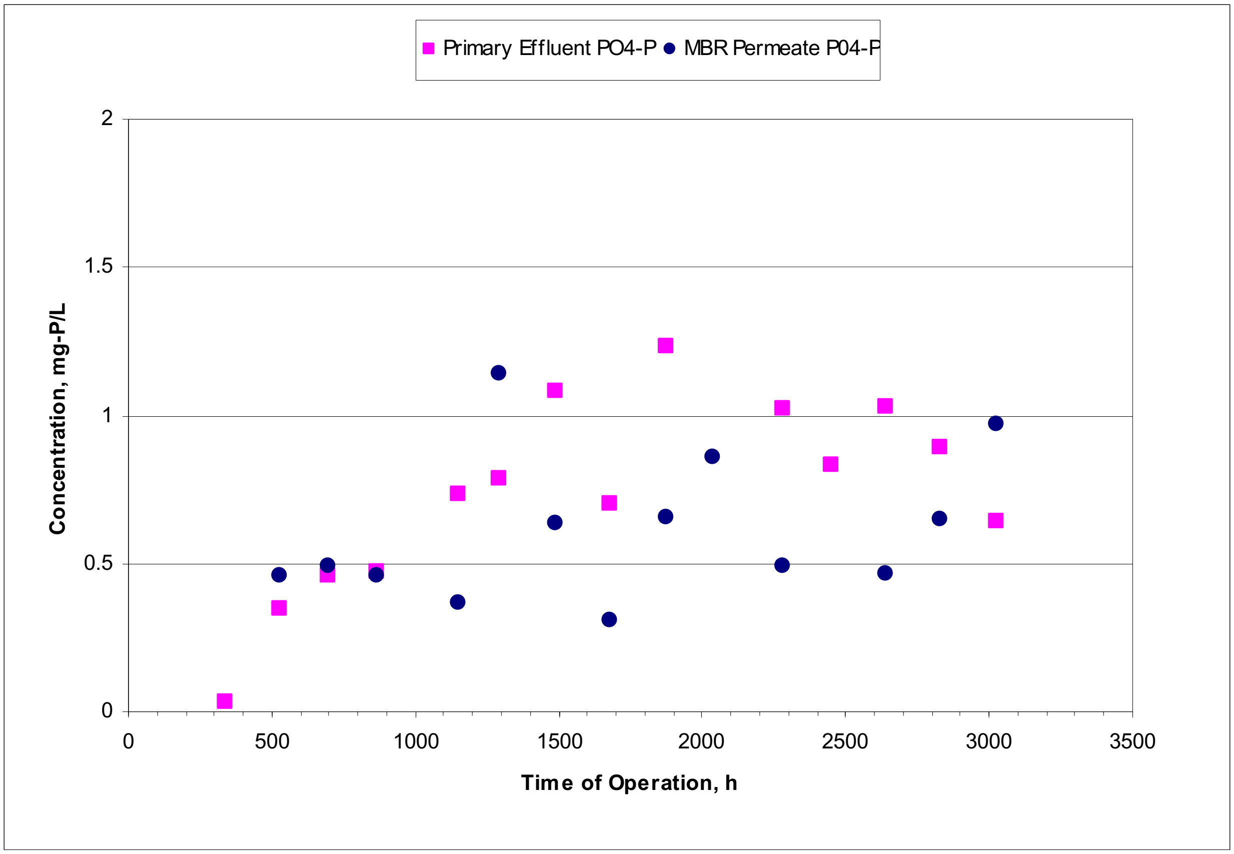


Figure 6-15: Ortho-Phosphate Removal by the Zenon MBR

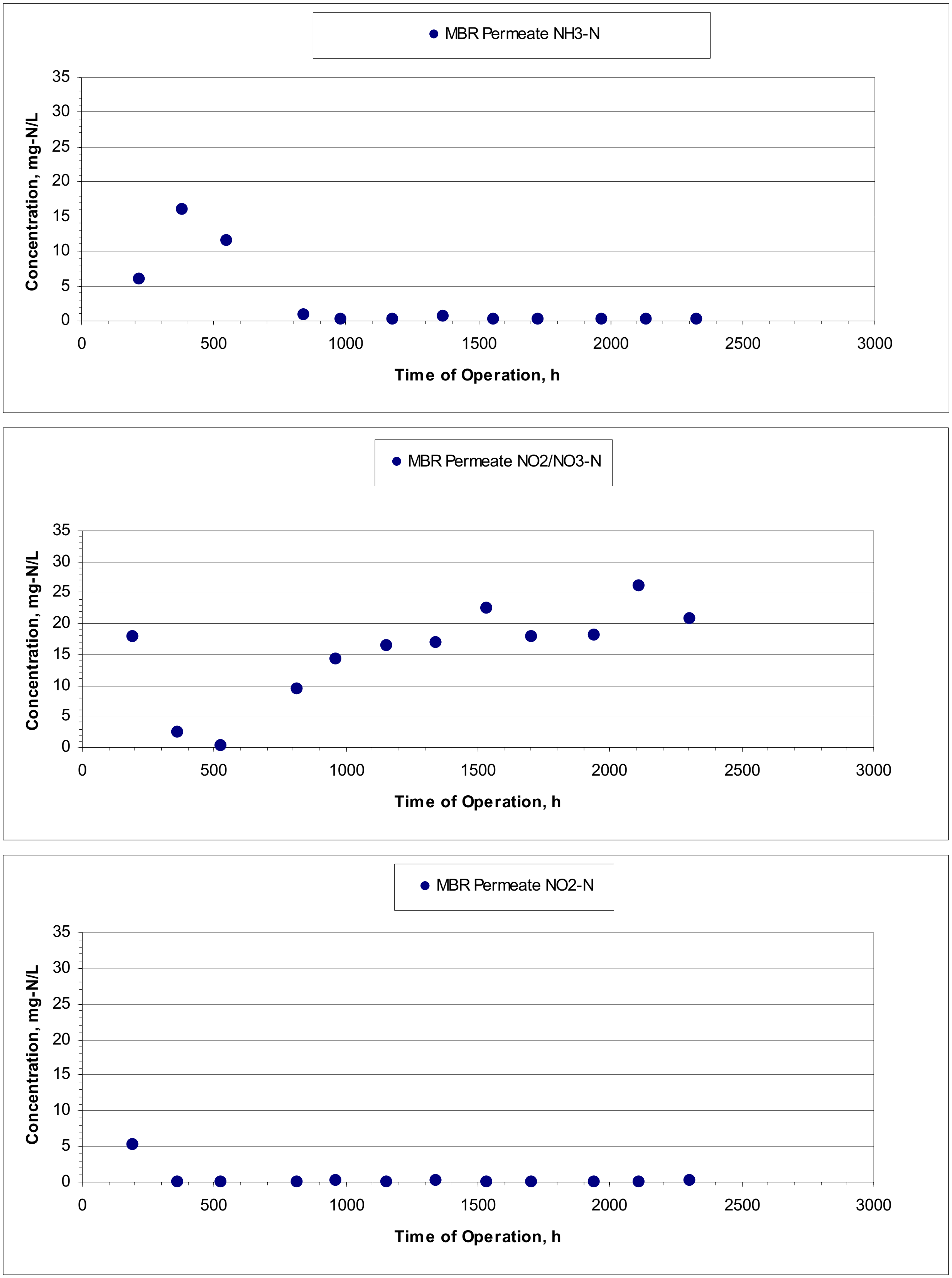


Figure 6-16: Inorganic Nitrogen Species in Mitsubishi MBR

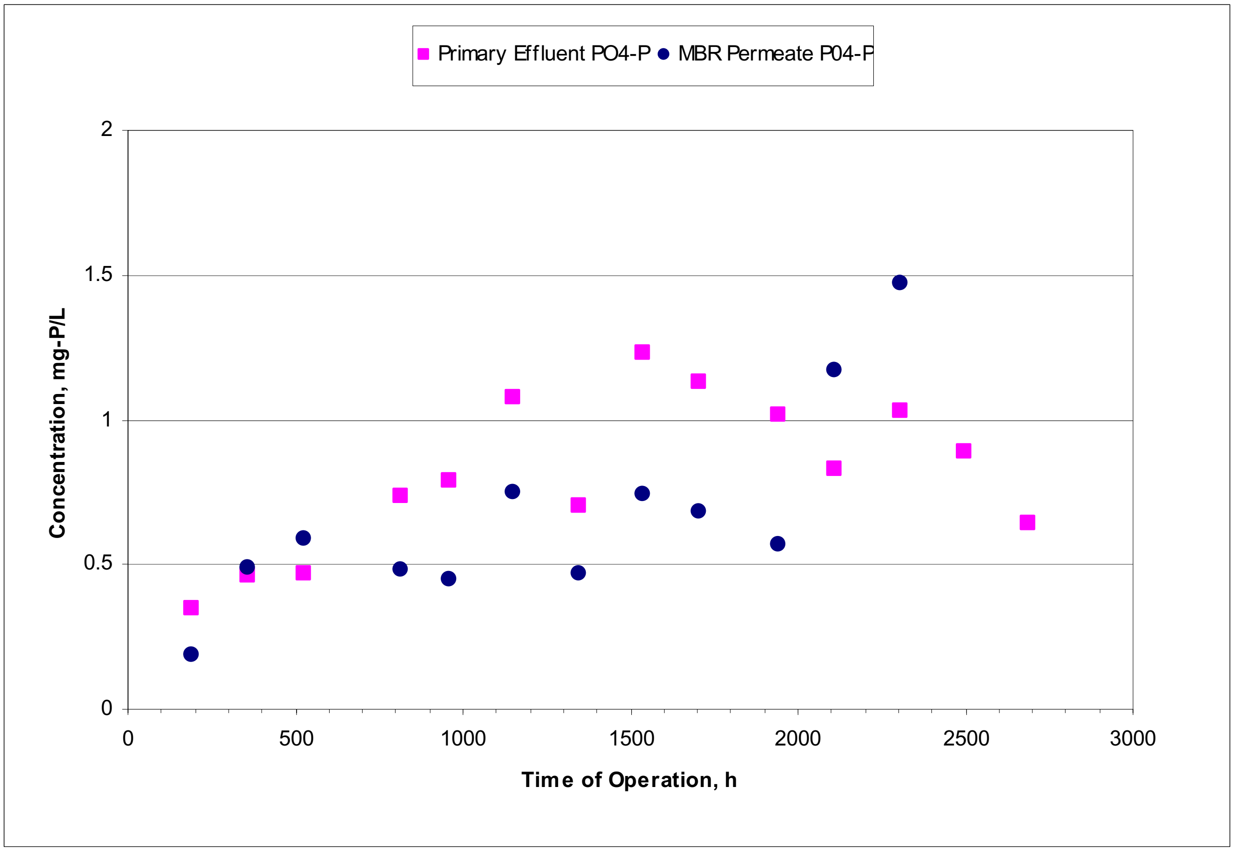


Figure 6-17: Ortho-Phosphate Removal by the Mitsubishi MBR

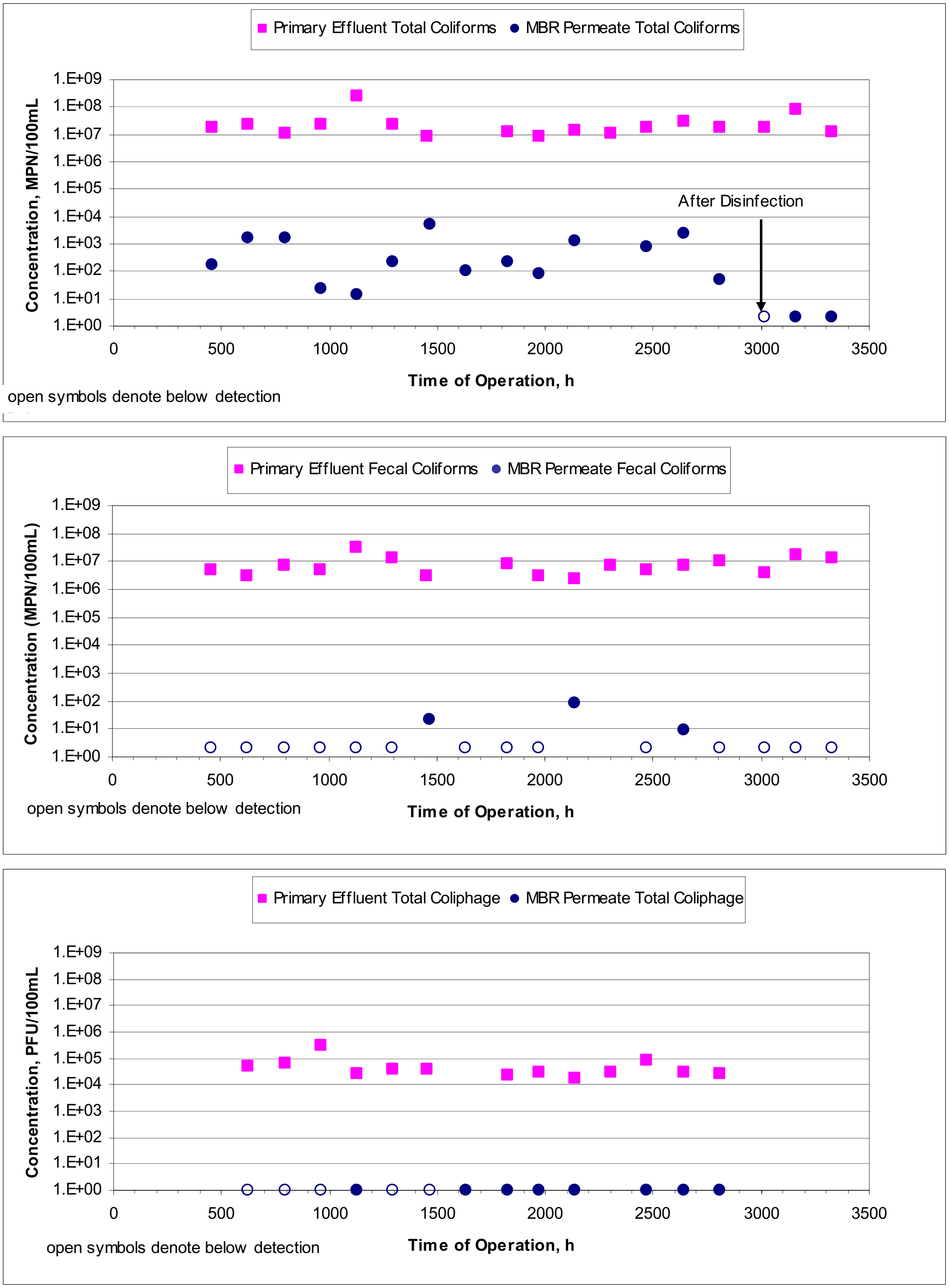
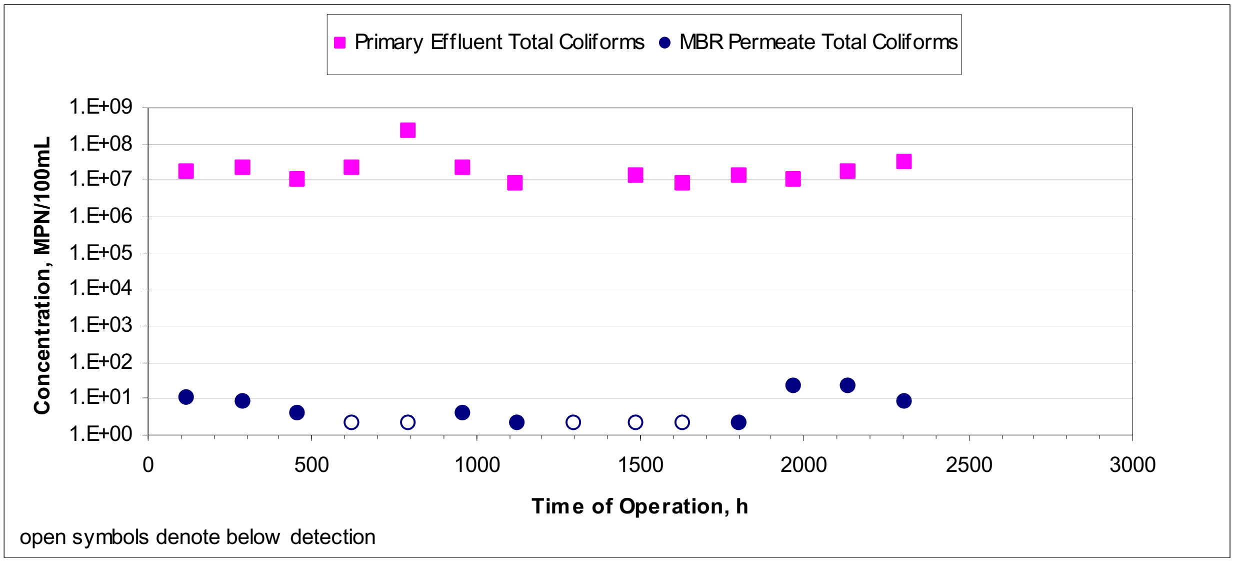
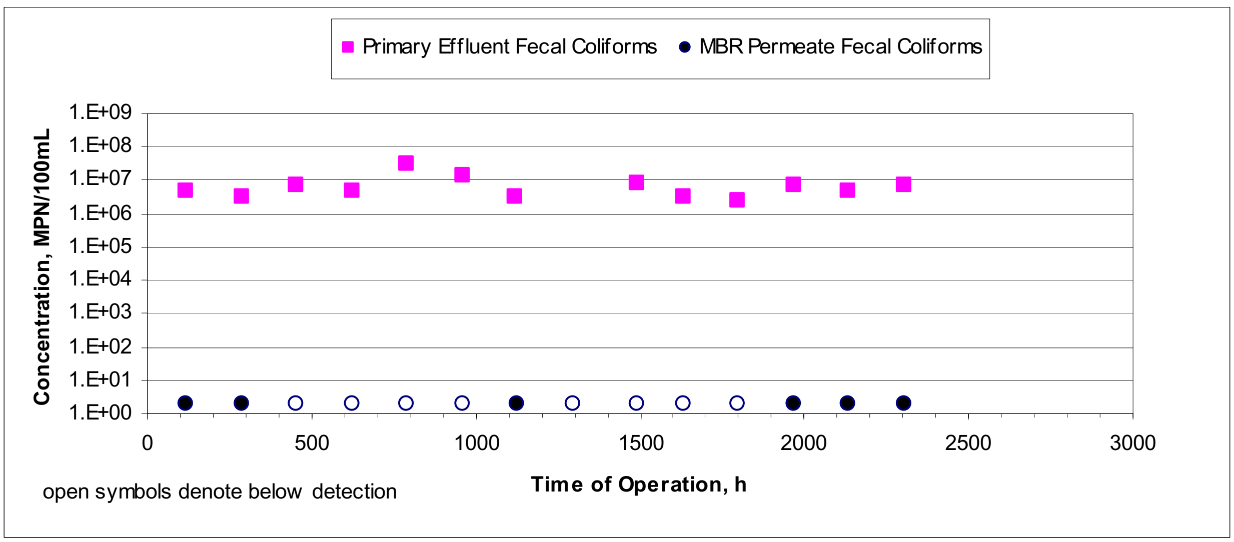


Figure 6-18: Coliform and Coliphage Removal by the Zenon MBR





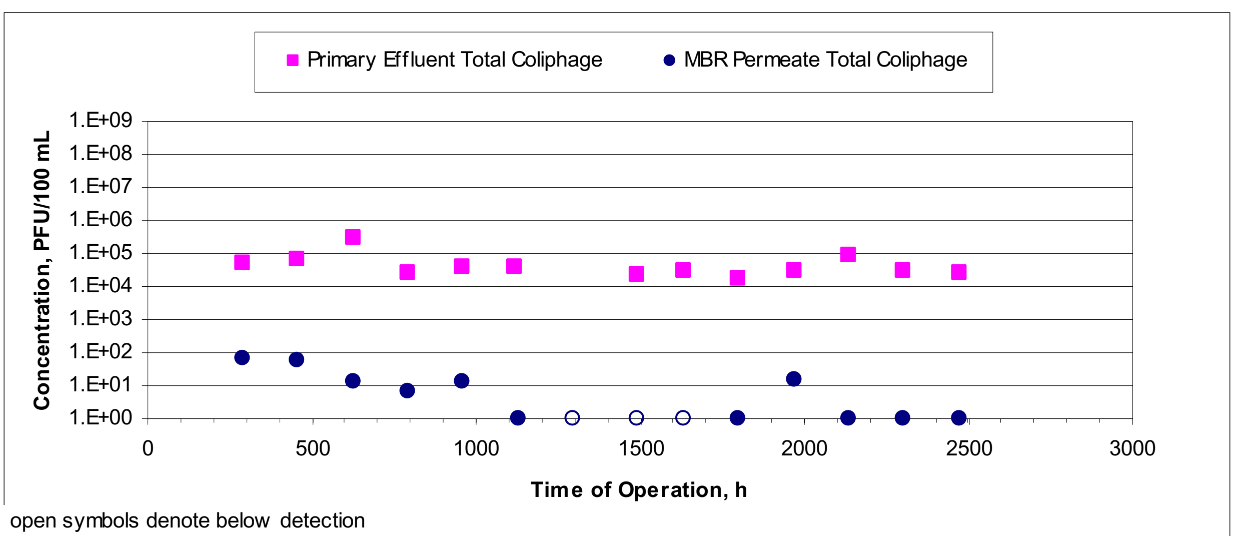


Figure 6-19: Coliform and Coliphage Removal by the Mitsubishi MBR

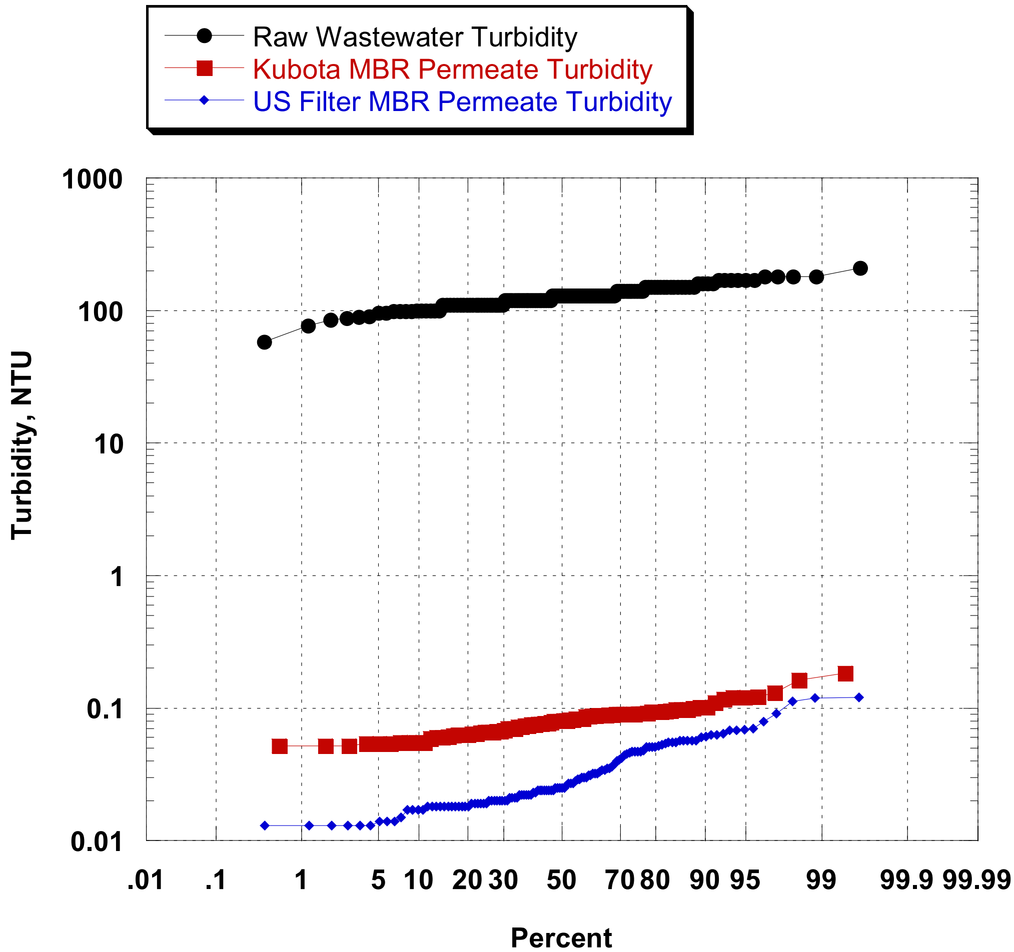


Figure 8-1: Probability Plot of Turbidity Removal by MBR Systems during Phase I (Part 1)

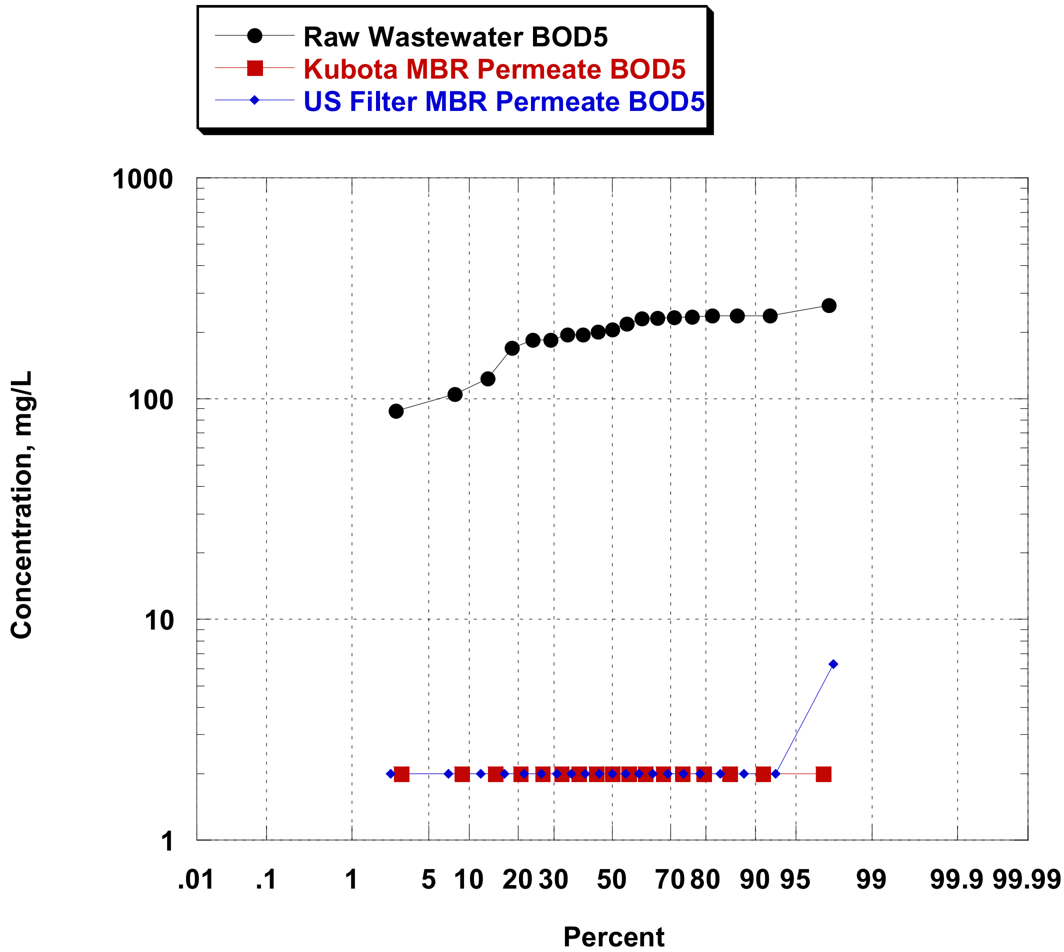


Figure 8-2 Probability Plot of BOD_5 Removal by MBR Systems during Phase I (Part 1)

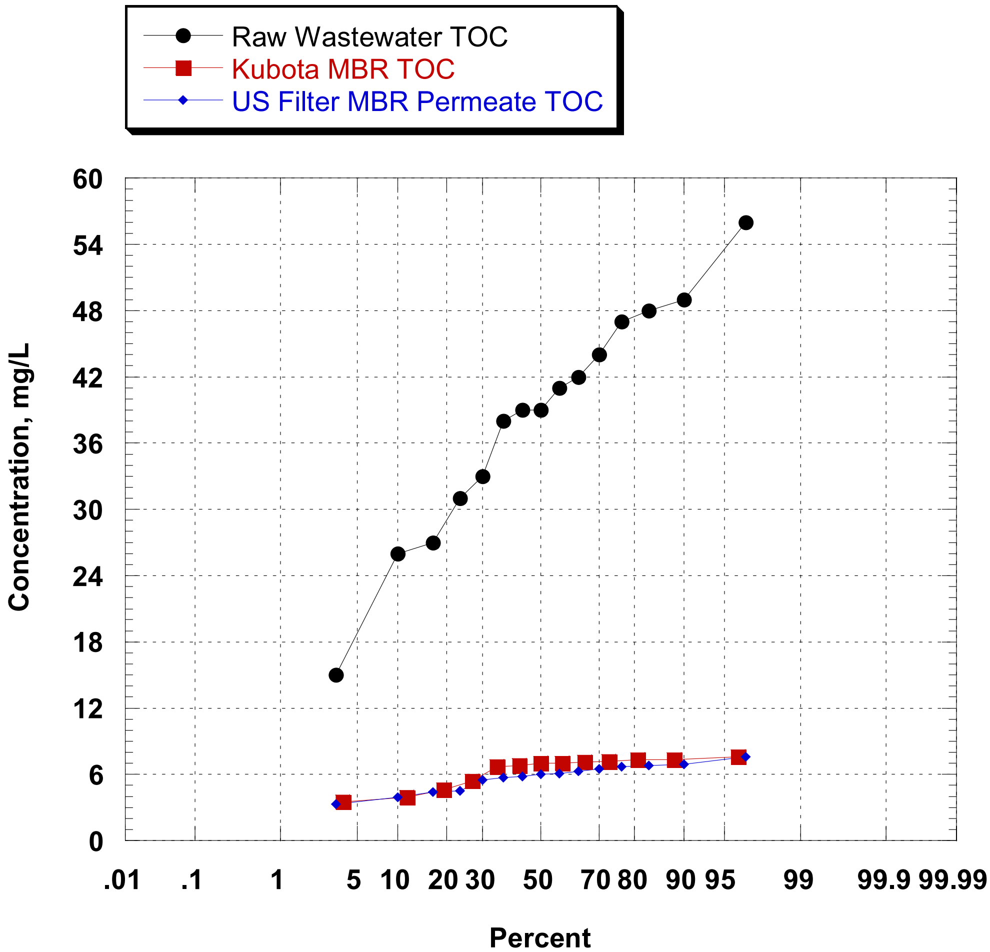


Figure 8-3 Probability Plot of TOC Removal by MBR Systems during Phase I (Part 1)

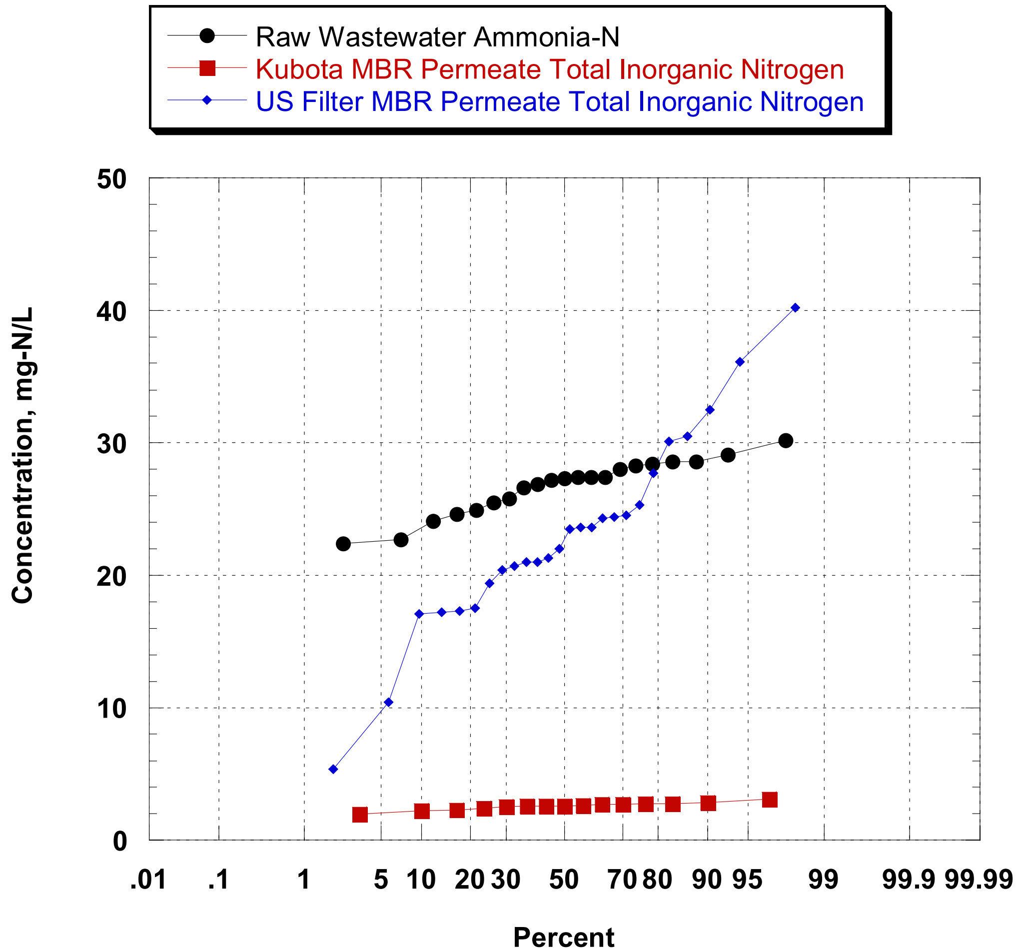


Figure 8-4 Probability Plot of Ammonia Removal by MBR Systems during Phase I (Part 1)

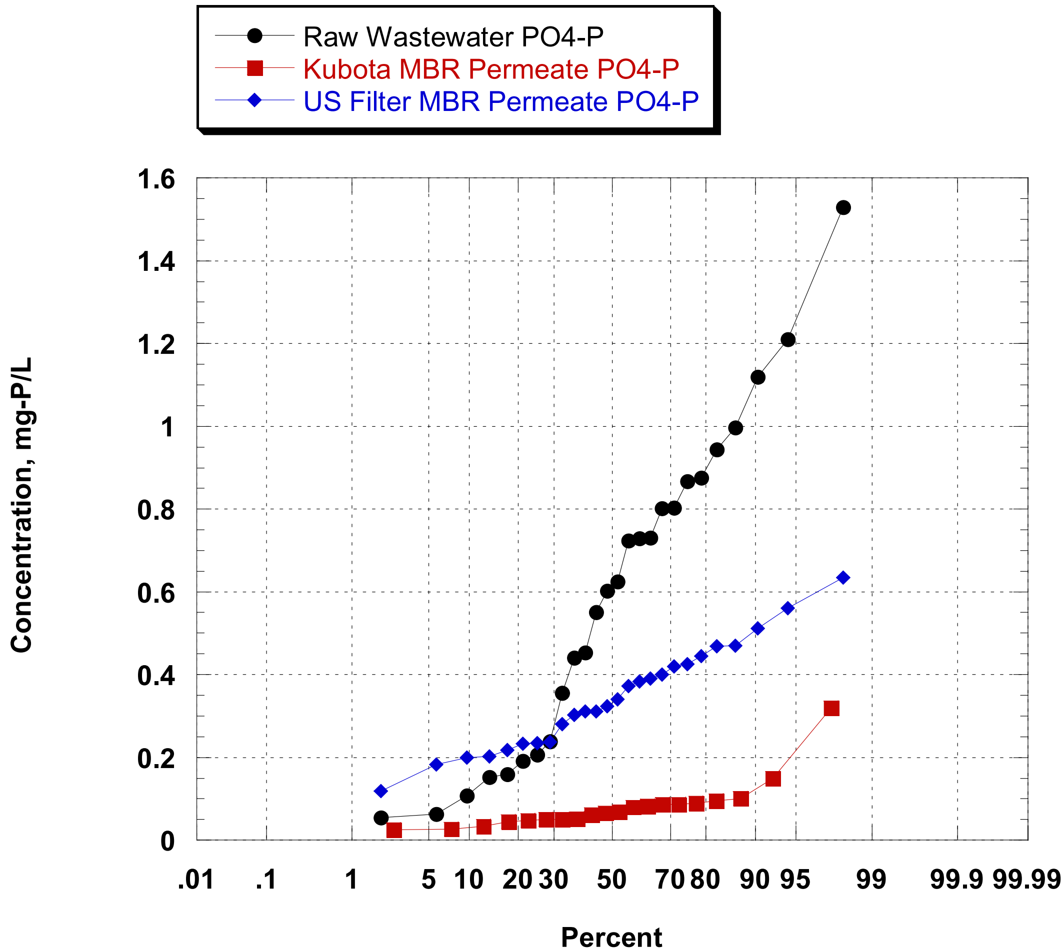


Figure 8-5 Probability Plot of Phosphate Removal by MBR Systems during Phase I (Part 1)

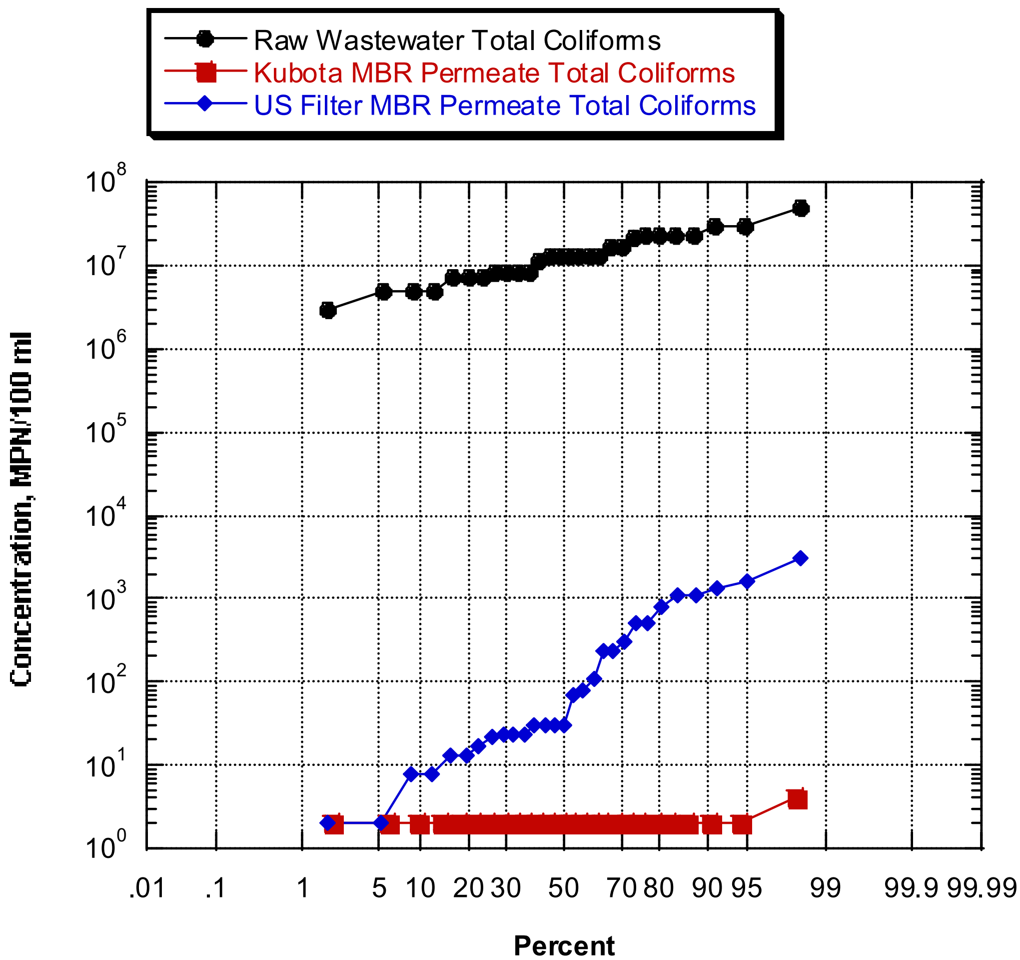


Figure 8-6 Probability Plot of Total Coliform Removal by MBRs during Phase I (Part 1)

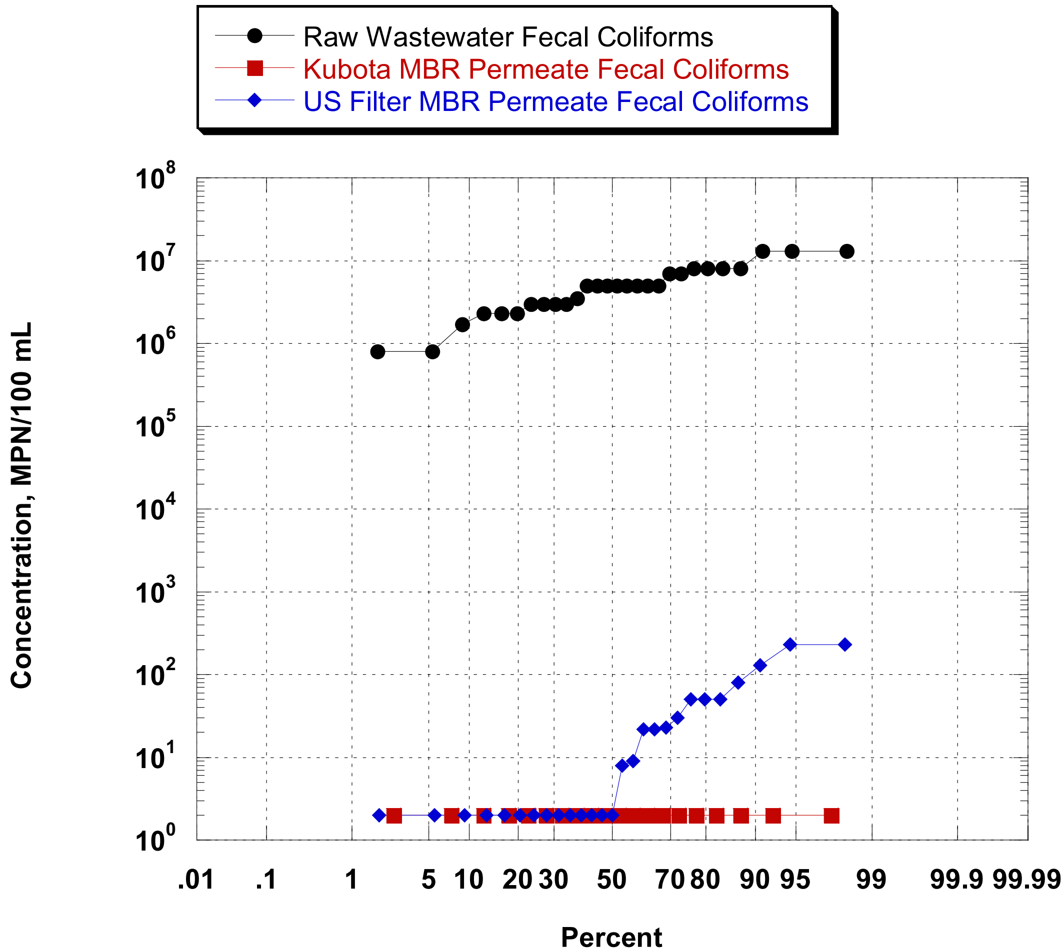


Figure 8-7 Probability Plot of Fecal Coliform Removal by MBRs during Phase I (Part 1)

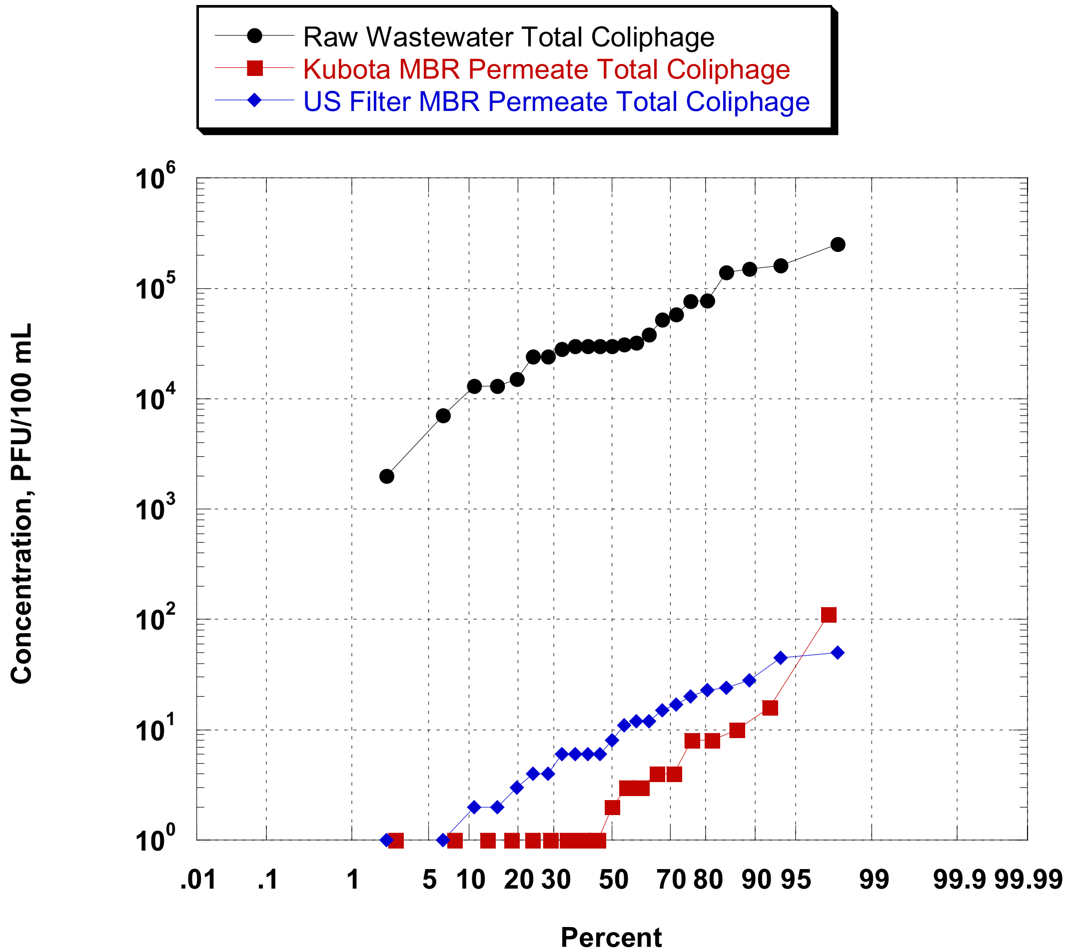


Figure 8-8 Probability Plot of the Total Coliphage Removal by MBRs during Phase I (Part 1)

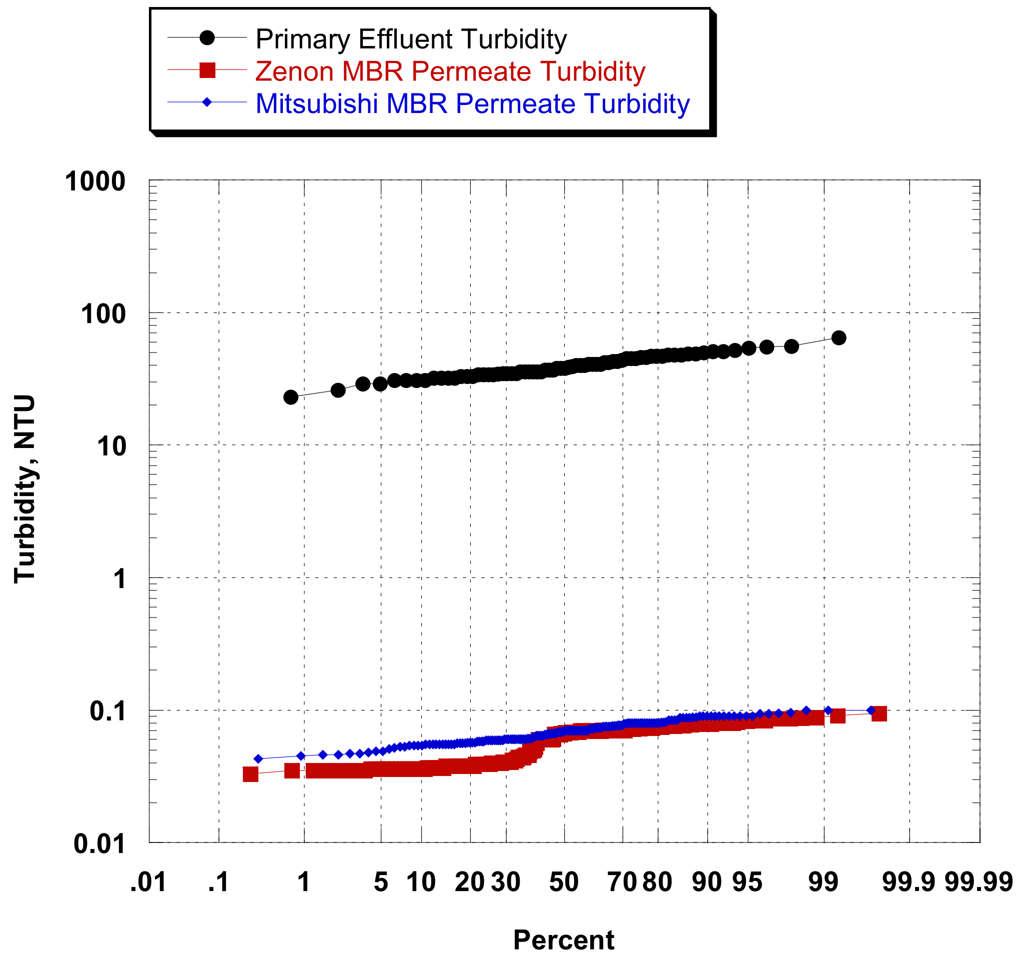


Figure 8-9 Probability Plot of the Turbidity Removal by MBRs during Phase II

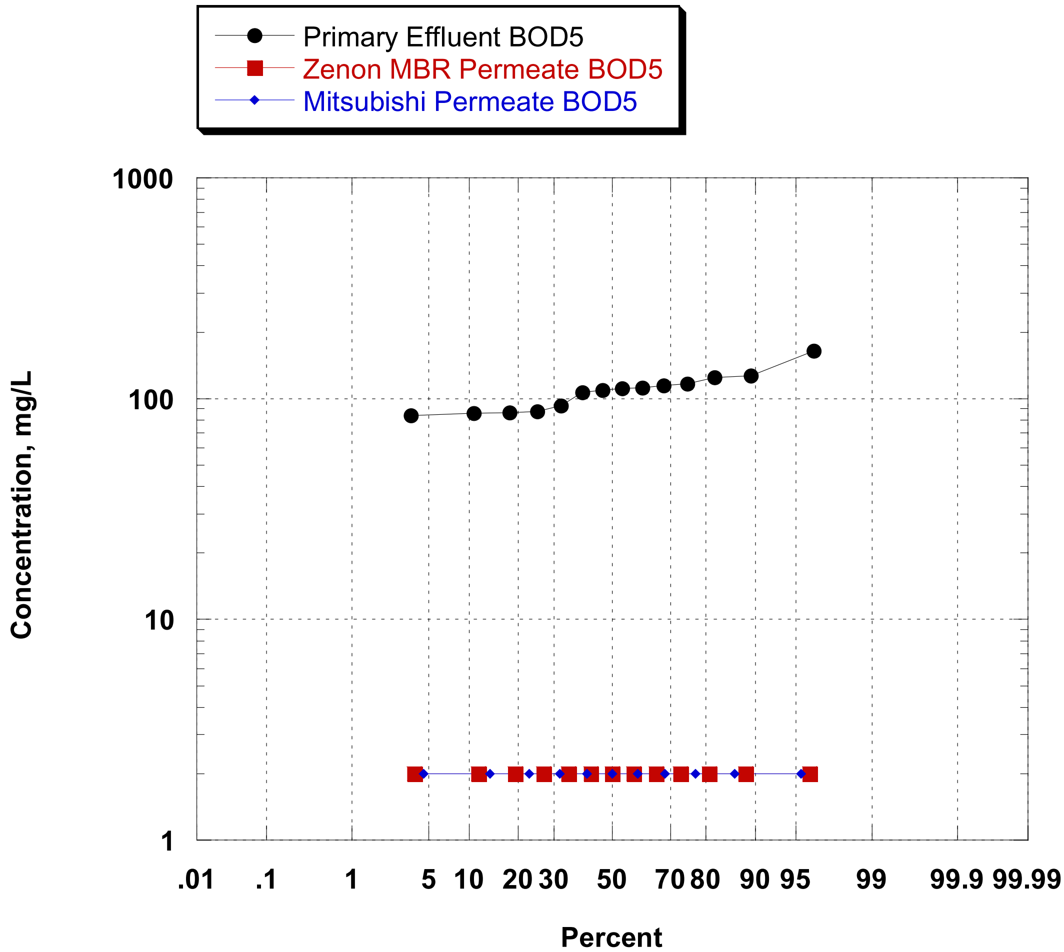


Figure 8-10 Probability Plot of BOD_5 Removal by MBR Systems during Phase II

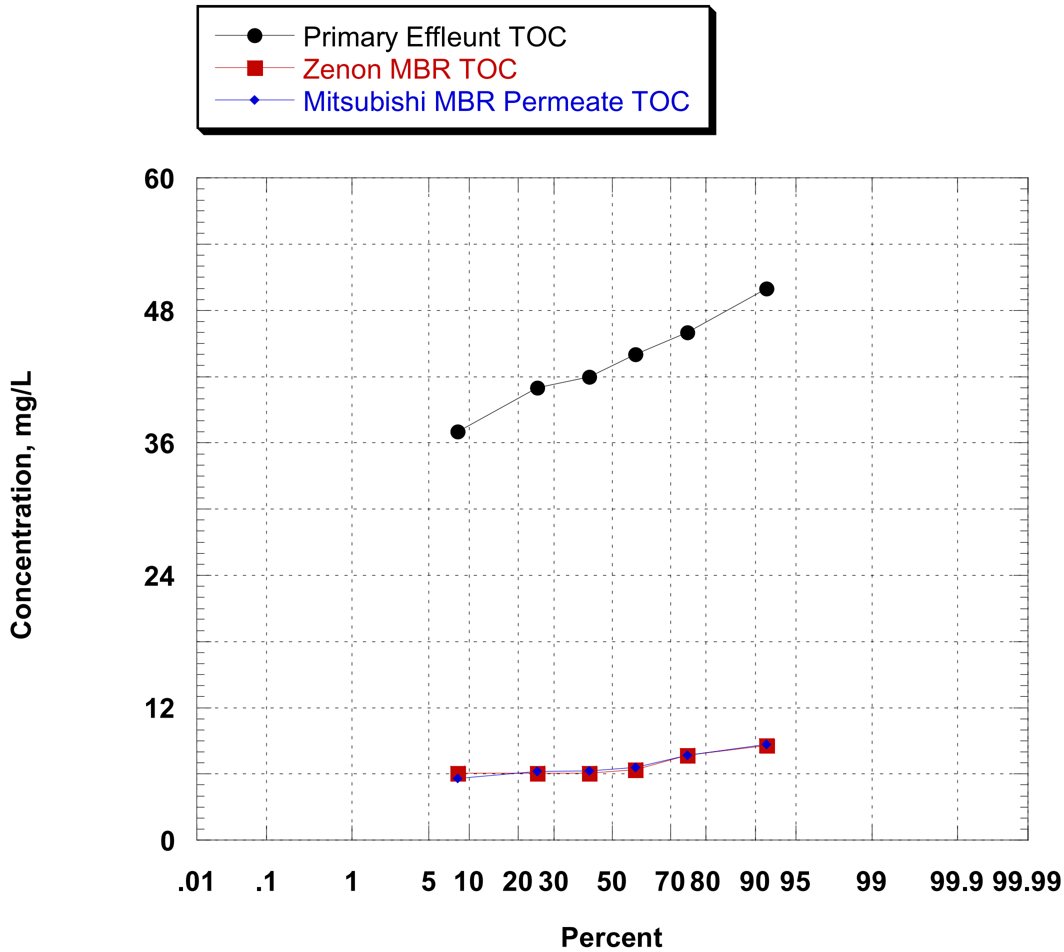


Figure 8-11 Probability Plot of TOC Removal by MBR Pilot Systems during Phase II

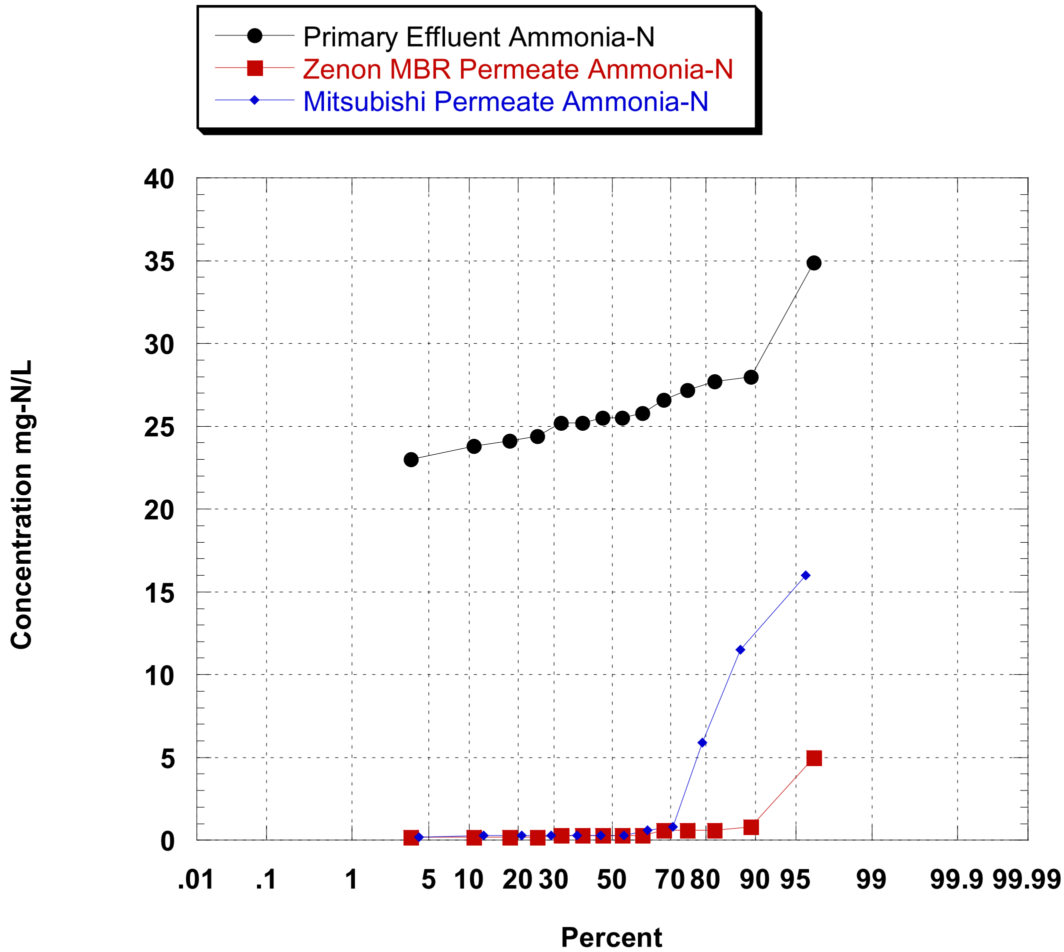


Figure 8-12 Probability Plot of Ammonia Removal by MBR Systems during Phase II

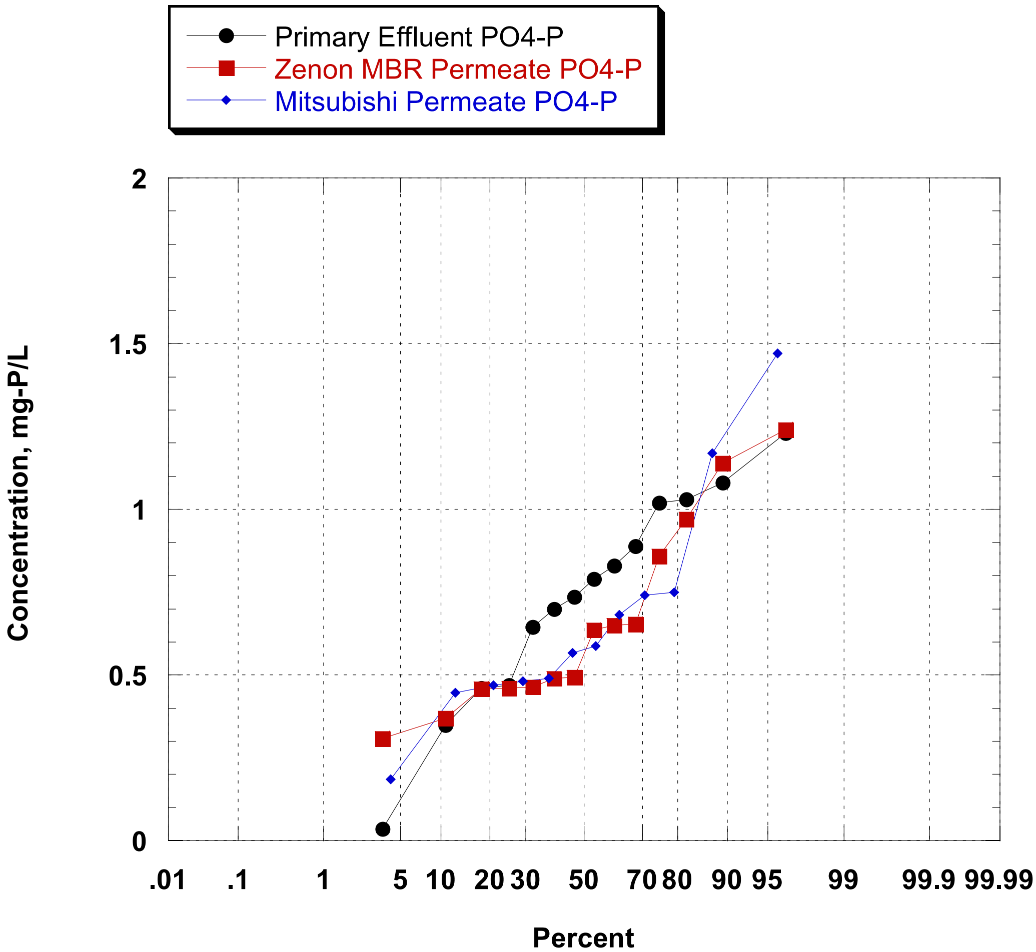


Figure 8-13 Probability Plot of Ortho-Phosphate Removal by MBR Systems during Phase II

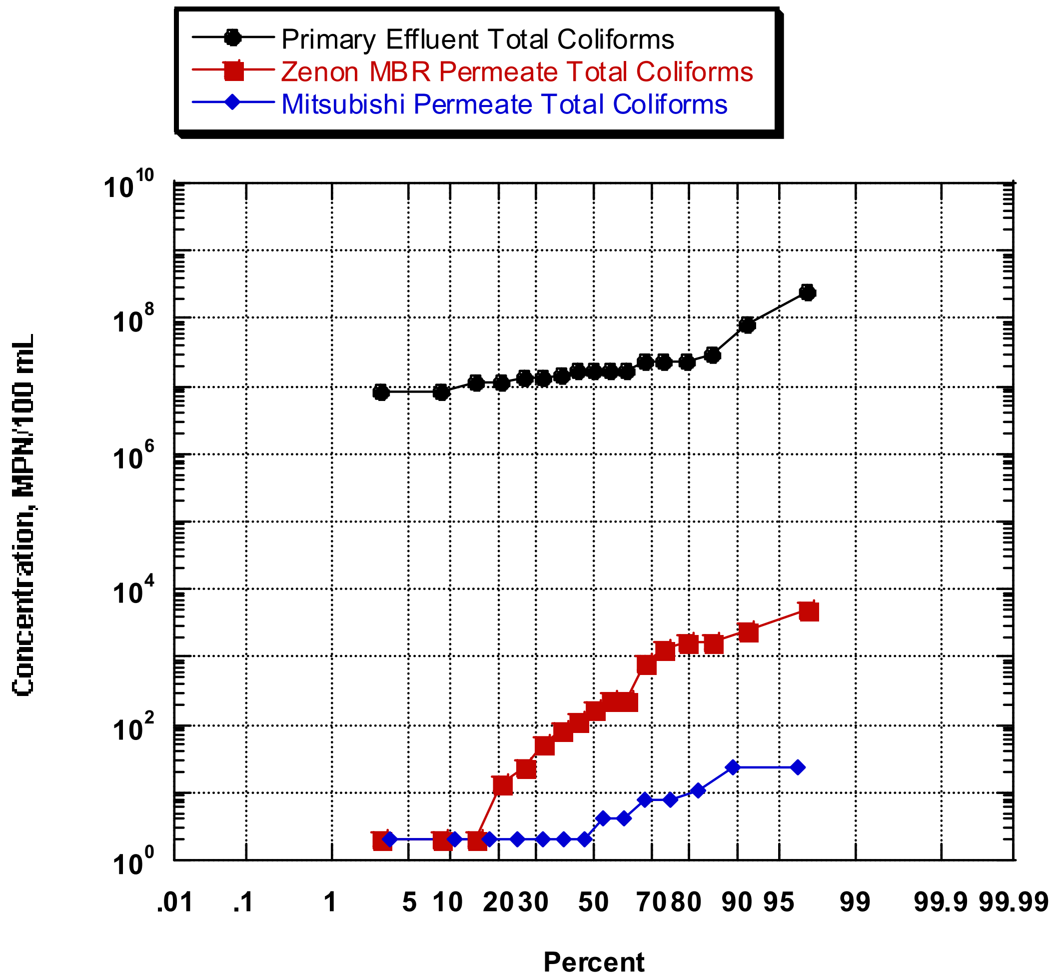


Figure 8-14 Probability Plot of Total Coliform Removal by MBR Systems during Phase II

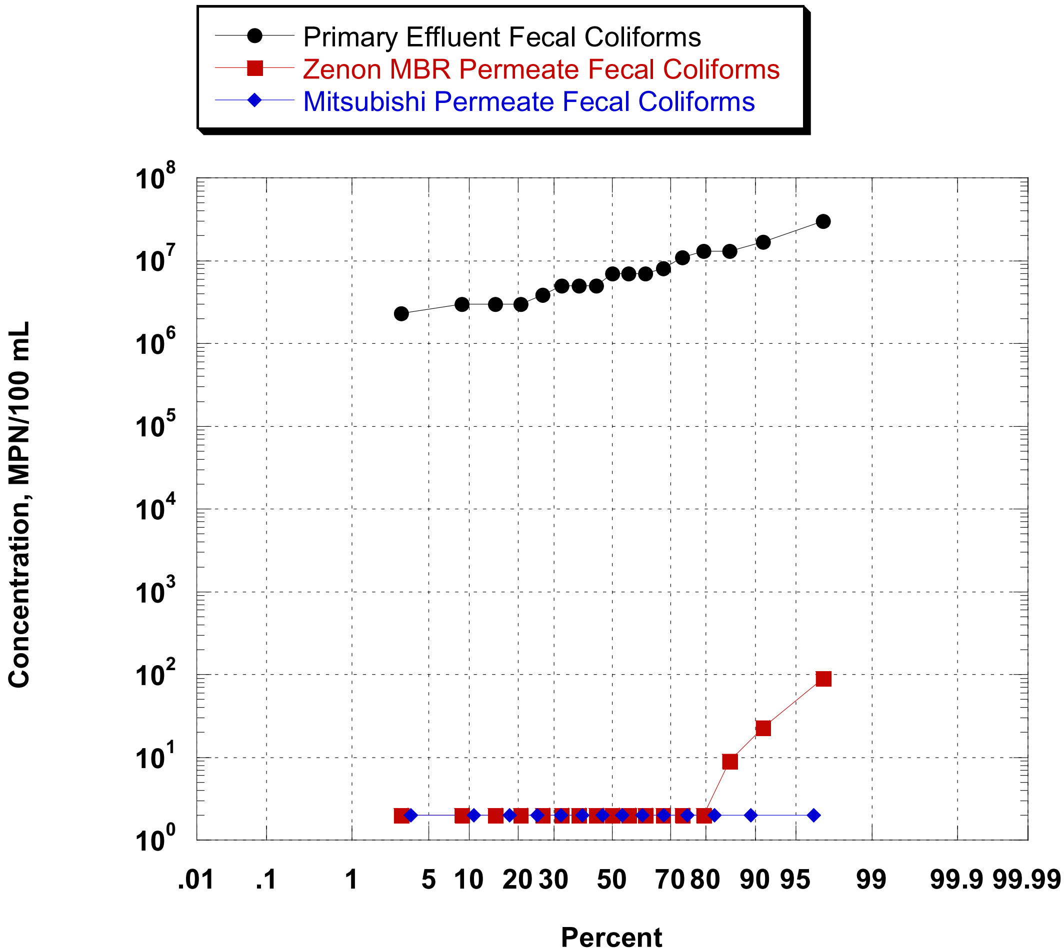


Figure 8-15 Probability Plot of Fecal Coliform Removal by MBR Systems during Phase II

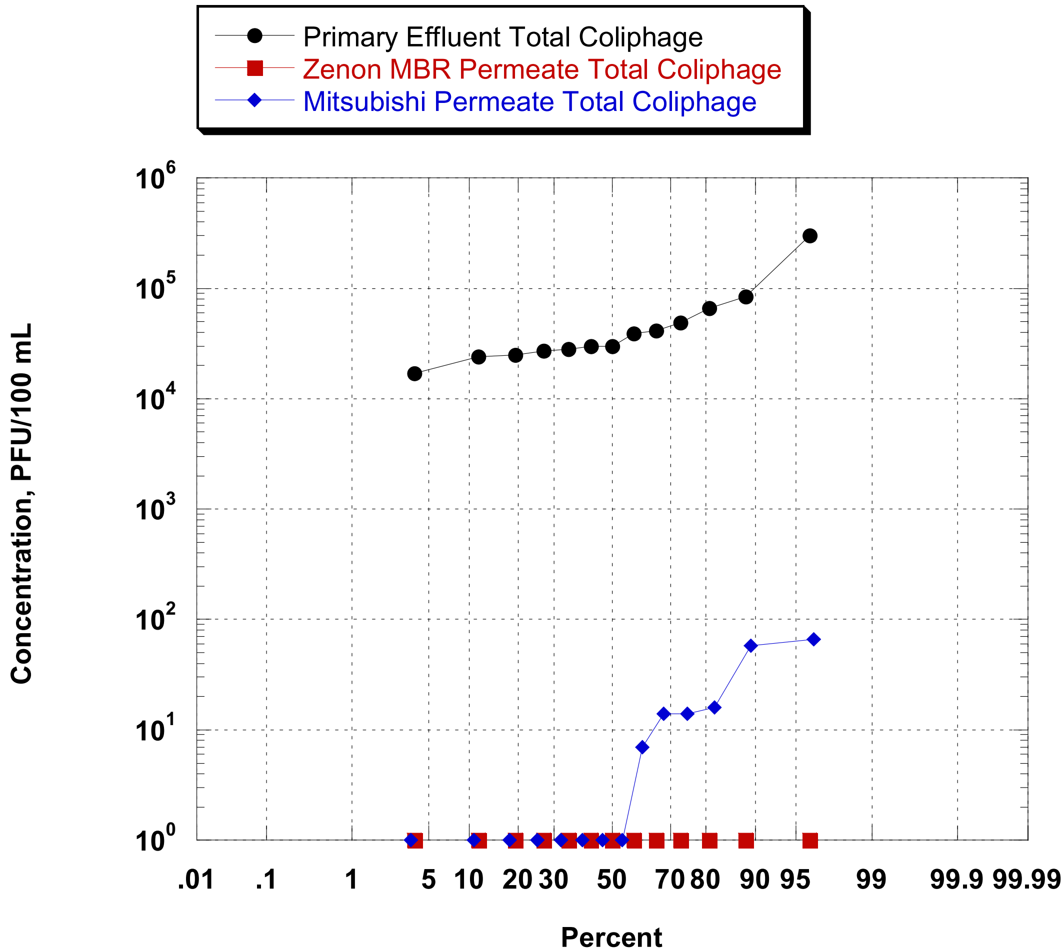


Figure 8-16 Probability Plot of Total Coliphage Removal by MBR Systems during Phase II

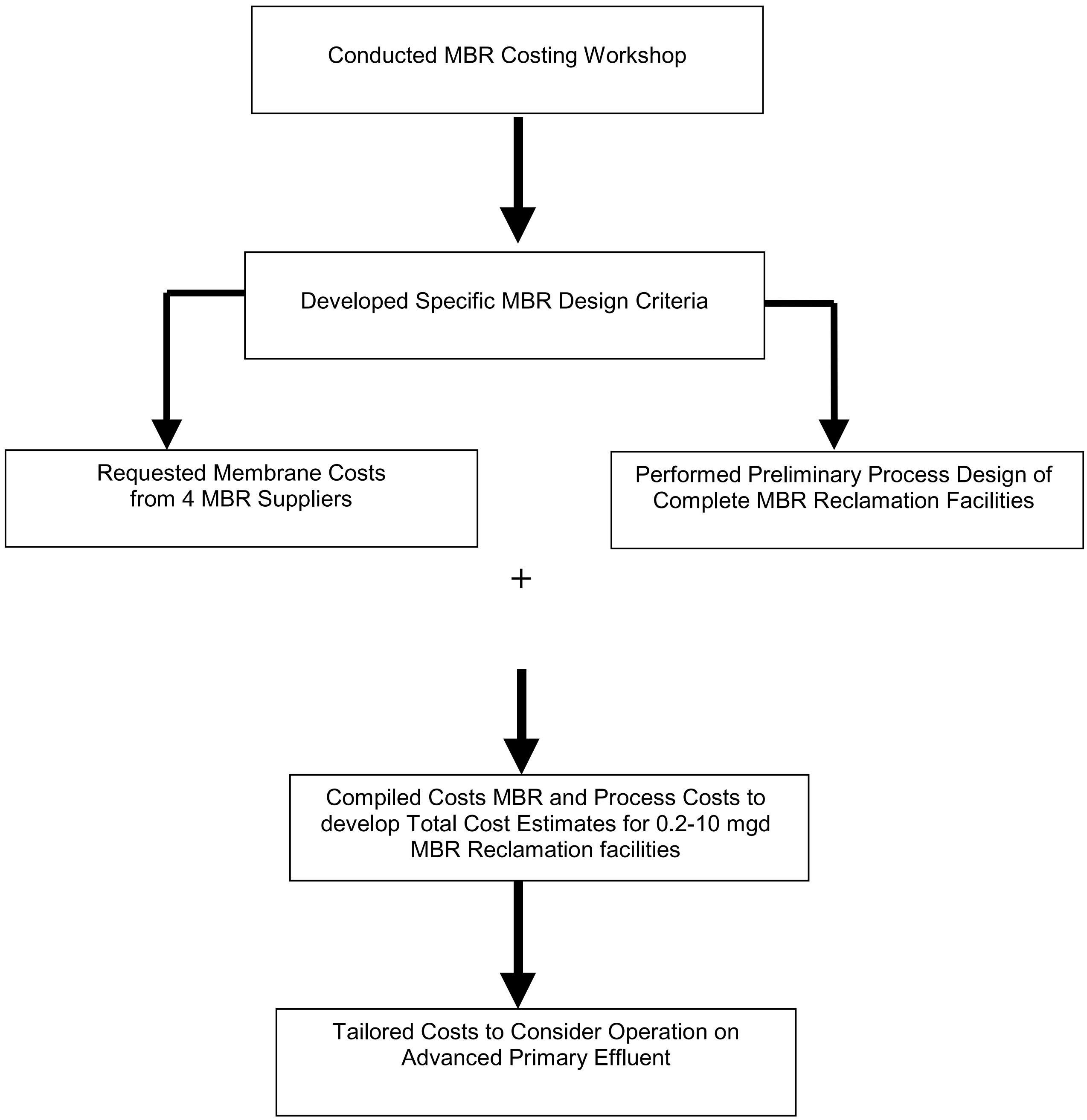


Figure 9-1 Outline of Costing Approach

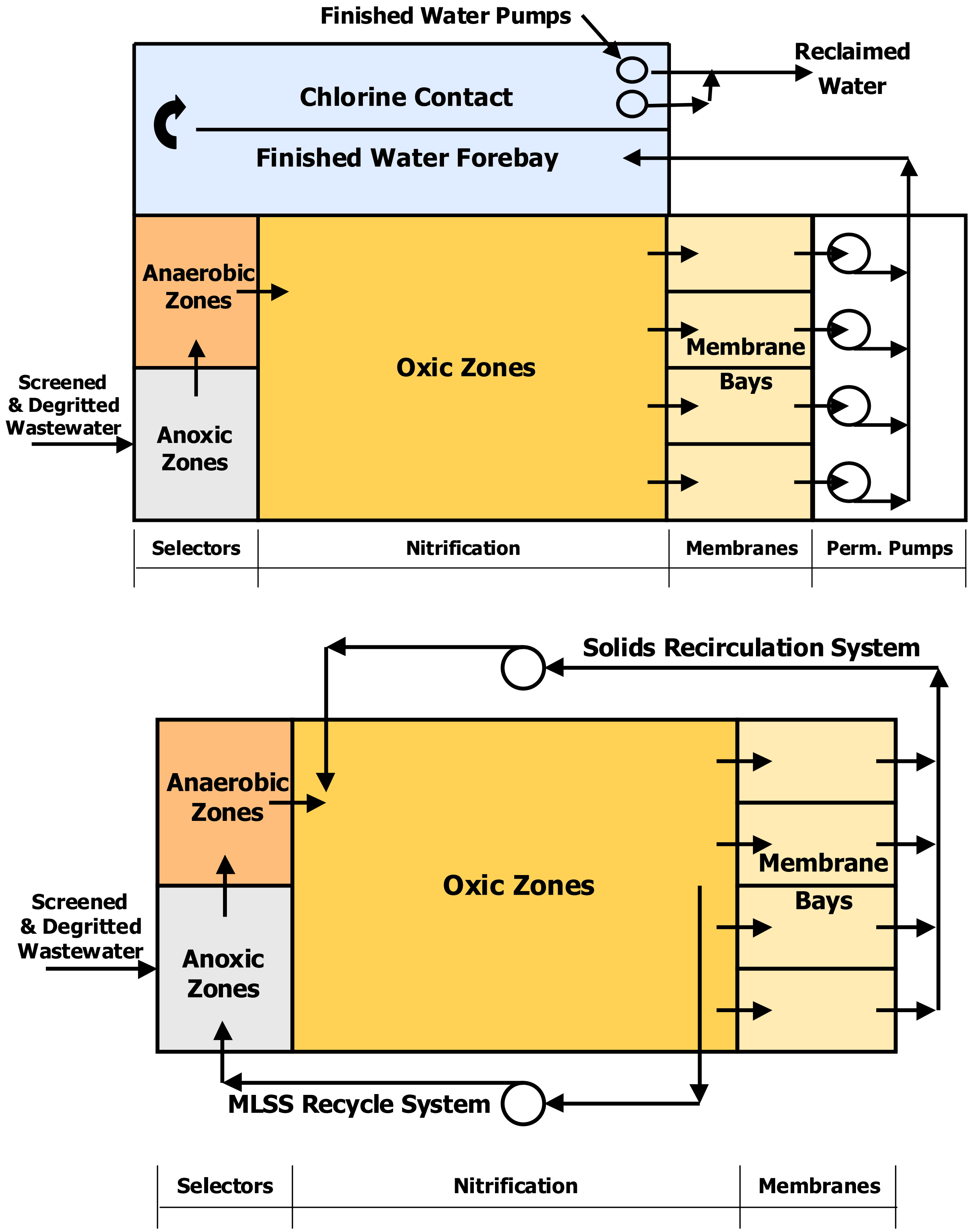


Figure 9-2 MBR Reclaimed Water Schematic: Forward Flow (Top); Recycled Flow (Bottom)

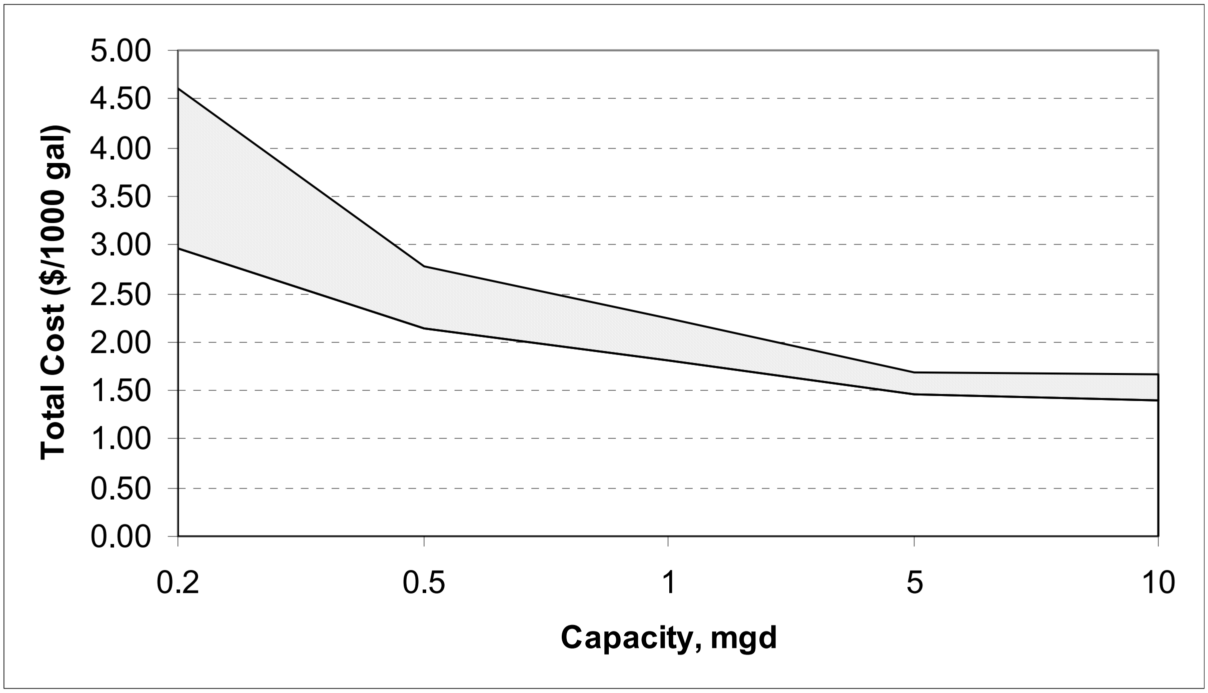


Figure 9-3: Total Costs of Various Capacity MBR Systems Operating on Raw wastewater

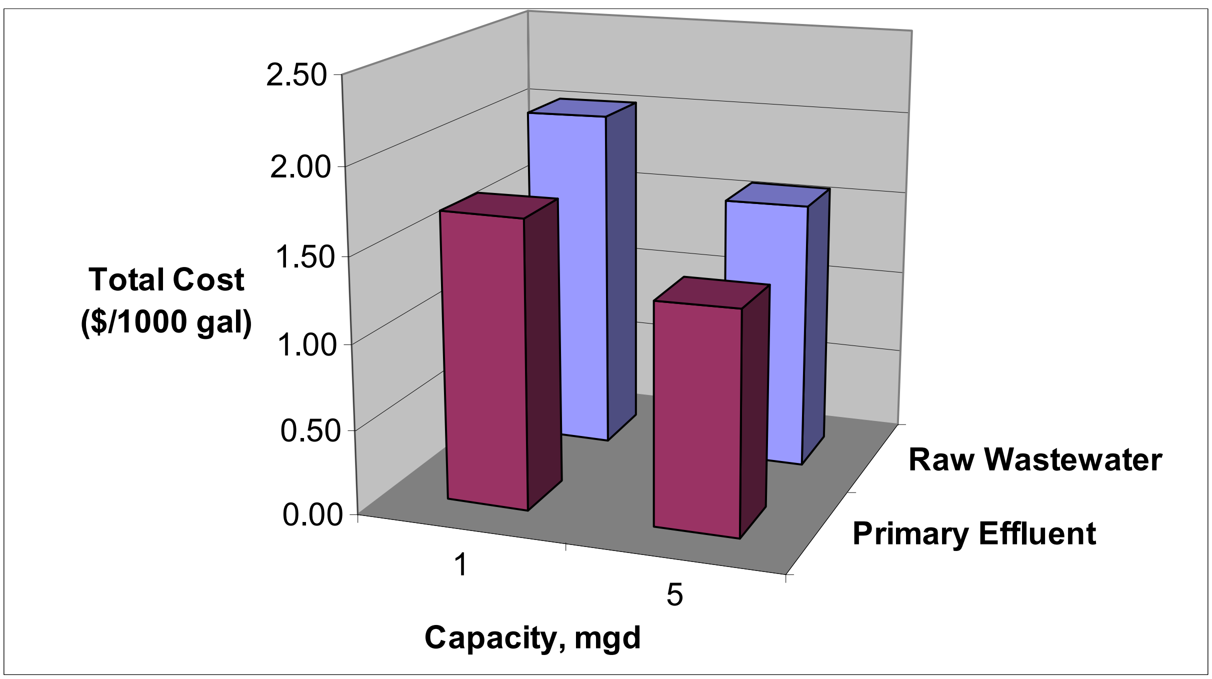


Figure 9-4: Total Costs of 1& 5 MGD MBR Systems (Raw Wastewater / Primary Effluent)

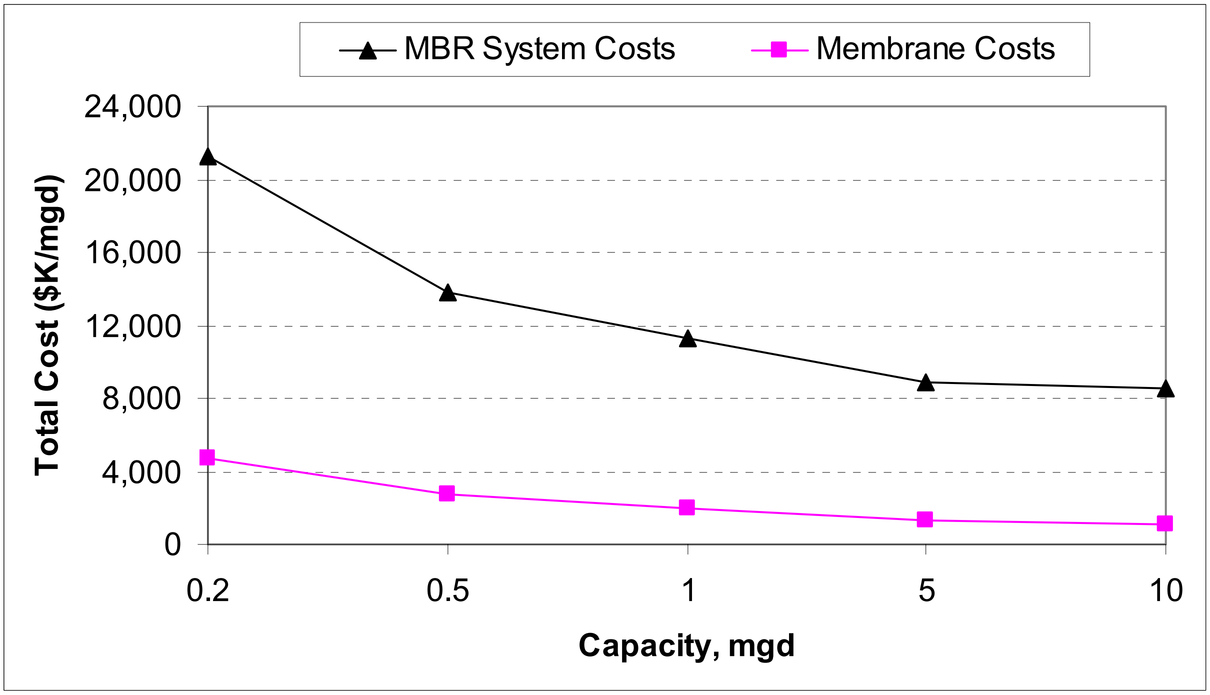


Figure 9-5: Economy of Scale Analysis for MBR Systems Operating on Raw Wastewater

APPENDIX B
Membrane Cleaning Protocols

MEMBRANE CHEMICAL CLEANING PROTOCOLS

Mitsubishi MBR In-Line Chemical Cleaning Protocol

In-Line Chlorine/Acid Cleaning

NaOCl: effective concentration of 3,000 mg/L (0.3%)
Citric Acid: effective concentration of 2,000 mg/L (0.2%)

1. Mix together water with cleaning compound to achieve desired solution in the chemical cleaning tank (40 gallons).
2. Close ball valve that is before the suction pump.
3. Open the two swagelok ball valves so the center chemical injection point is open to each side of the membrane fibers.
4. Connect the ball valve on the chemical tank to the union on the injection port.
5. Allow the chemical tank to rest on the edge of the MBR tank.
6. Open the ball valve on the chemical tank and allow the chemical solution to back flow through the membrane for 2 hours.
7. After 2 hours, close the valve on the chemical tank and allow the chemical solution to soak in the membrane fibers for an additional 2 hours.
8. Repeat for the other membrane side.
9. Once complete, close the swage valves and open the ball valve near the suction side of the pump.
10. Resume normal operation.

Zenon Clean-in-Place (CIP) Protocol

Chemical Reagent: Sodium Hypochlorite (effective chlorine concentration: 2,000 mg/L) or Citric Acid (effective pH = 2.0-3.0, approximately 2,000-3,000 mg/L)

1. Isolate the ZenoGem tank.
2. Drain the ZenoGem tank by pumping mixed liquor into the aeration basin.
3. Hose down ZenoGem until water appears clear.
4. Prepare chemical reagent in CIP tank.
5. Backpulse the cleaning solution through the membrane until tank is empty.
6. Recirculate the dilute solution through membranes; measure flux, then allow to soak.
7. Repeat Step 6 until flux is equal in two consecutive readings. Allow to soak overnight, if necessary.
8. Drain tank and hose down until there is no chlorine present.
9. Put back into service.

Zenon Maintenance Cleaning Protocol

Chemical Reagent: Sodium Hypochlorite (concentration = 250 mg/L in BW Tank) or Citric Acid (concentration = 2,000 mg/L in BW Tank)

1. Shut down pilot unit.
2. Let the system relax for 5 minutes.
3. Fill the CIP (clean in place) tank with the cleaning solution.
4. Put the system in Backpulse mode.
5. Backpulse the system for 15 seconds at a flow rate of 16.7 gpm.
6. Relax for 30 seconds.
7. Backpulse the system for 10 seconds.
8. Relax for 30 seconds.
9. Repeat steps 7 and 8, two times.
10. Put system back into service.

Kubota Chlorine Cleaning Protocol

1. Prepare 160 gallons of 0.5 % (w/w) of sodium hypochlorite.
2. Stop the feed to system.
3. Stop filtration.
4. Stop MBR blower.
5. Stop recycle pump
6. Open caps on the 2” permeate lines (upper and lower membrane banks) at the top of the nitrification tank.
7. Insert the chemical feed pump discharge into the upper permeate line.
8. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
9. Insert the chemical feed pump discharge into the lower permeate line.
10. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
11. Close caps on the permeate lines.
12. Soak membranes for 2 hours.
13. Turn all equipment back on and put the system in auto.

Kubota Oxalic Acid Cleaning Protocol

1. Prepare 160 gallons of 1% (w/w) Oxalic Acid.
2. Stop the feed to system.
3. Stop filtration.
4. Stop MBR blower.
5. Stop recycle pump
6. Open caps on the 2” permeate lines (upper and lower membrane banks) at the top of the nitrification tank.
7. Insert the chemical feed pump discharge into the upper permeate line.
8. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
9. Insert the chemical feed pump discharge into the lower permeate line.
10. Pump 80 gallons of the sodium hypochlorite solution prepared in Step 1.
11. Close caps on the permeate lines.
12. Soak membranes for 1 hour.
13. Turn all equipment back on and put the system in auto.

US Filter Chemical Cleaning Protocol

Chemical Reagent: Sodium Hypochlorite (chlorine concentration = 100 mg/L) or Citric Acid (acid concentration = 2,000 mg/L)

1. Isolate the aeration tank.
2. Pump the mixed liquor from the aeration tank.
3. Fill the aeration tank with rinse water (from the filtrate tank).
4. Aerate membranes and reticulate rinse water through mixed liquor manifold for 10 minutes.
5. Drain the rinse water.
6. Fill the aeration tank with chlorinated CIP water.
7. Recirculate chemical through lumens.
8. Recirculate chemical though mixed liquor manifolds.
9. Recirculate chemical through in-tank air manifold.
10. Soak for up to 4 minutes.
11. Drain tank and hose down until there is no chlorine present.
12. Return to normal operation.

Cleaning Protocol for Saehan RE4040 BL and Hydranautics LFC Reverse Osmosis Membranes

Chemical Reagent: 0.1 gallons for sodium hydroxide, 0.025 gallons of sodium lauryl dodecyl sulfate, pH 11 – 12, Temperature 30C, Volume of Chemical Reagent: 0.81 L/ft^2 of membrane area.

1. Flush pressure vessels at 5 gpm with RO permeate for several minutes.
2. Circulate the cleaning solution at 5 gpm for 30 minutes. If the cleaning solution colors becomes turbid, restart with freshly prepared cleaning solution.
3. Check pH of cleaning solution while in circulation. If pH increase by more than 0.5 pH units, add acid (HCL).
4. Turn recirculation pump off and allow the membranes to soak for 1 hour.
5. Circulate the cleaning solution again at 10 gpm for 30 - 60 minutes.
6. Drain and flush cleaning tank.
7. Rinse pressure vessels with RO permeate whose pH has been adjusted to 4.5 - 5.5 using hydrochloric acid (HCL) for several minutes. The minimum temperature of the rinse water should be 68 °F (20 °C). Have both permeate and concentrate valves open during flushing. Flushing should be once-through step.
8. Operate the system as normal.

APPENDIX C
QA/QC Memorandum

M E M O R A N D U M

MWH
MONTGOMERY WATSON HARZA

To:	**Samer Adham, Ph.D.**	**Date:**	10-09-03
From:	**James DeCarolis / Jude Grounds**	**Reference:**	
Subject:	**Optimization of Various MBR Systems for Water Reclamation: QA/QC Protocol**		

Pilot testing for the Bureau of Reclamation project entitled *Optimization of Various MBR Systems for Water Reclamation*, was begun in April of 2002 at the Point Loma Waste Water Treatment Plant (PLWWTP) in San Diego, California. To ensure the accuracy and integrity of the data collected, a number of quality assurance and quality control procedures were followed throughout the experiment. This Technical Memorandum (TM) summarizes these procedures for the on-site instrument verification and water quality analysis performed by the project team, including:

- On-line Turbidimeters
- On-line Conductivity Meter
- On-line Dissolved Oxygen (DO) Meters
- Membrane System Thermometers
- Membrane System Pressure Gauges
- Membrane System Rotameters
- Membrane System Level Sensors
- Membrane/UV System Run Hour Clock
- Chemical Feed Pumping Rate
- Portable DO/Temperature Meter
- Desktop pH Meter
- Desktop Turbidimeter
- Desktop Ultraviolet (UV) Spectrophotometer
- Desktop Silt Density Index (SDI) Analyzer

The sampling protocol for off-site water quality analysis is also described herein. All off-site water quality analysis were analyzed at one of the following locations: onsite, Point Loma laboratory (PL Lab) the City of San Diego Water Quality Laboratory @ Alvarado and Calscience Environmental Laboratories (CEL Lab). All labs have the State of California Department of Health Services (DHS) Environmental Laboratory Accredited Programs (ELAP), and follow the associated QA/QC requirements.

Lastly, this TM provides the QA/QC procedures followed to ensure accurate data management and data analyses of all water quality and operational data collected during this study.

ON-LINE TURBIDIMETERS

Two types of on line turbidimeters systems were used during testing to acquire MBR permeate turbidities. Permeate turbidities of the Kubota, Zenon and Mitsubishi MBR systems were measured using Hach 1720D turbidimeters while the US Filter permeate turbidity was measured using a GLI Accu4 turbidimeter system. The GLI system contained a Model T53 analyzer an 8320 sensor. Both the 1720 D and Accu4 systems are designed to accurately measure low range turbidity. Turbidity values were manually collected from each MBR on a daily basis. The following procedures were followed to ensure the integrity and accuracy of this data:

- A primary calibration of the on-line turbidimeters was performed at the beginning of the test period and as needed during testing.
- On-line turbidities were compared to desktop turbidities to verify accurate calibration.
- The manufacturer's specified acceptable discharge flow range for the Hach 1720 D is 250 to 750 mL/min and the GLI Accu4 is 190 to 1500 mL/min. On-line turbidimeter flows were verified daily with a graduated cylinder and stopwatch, and adjusted as necessary.
- The turbidmeters were periodically cleaned using a 50 ppm free chlorine solution to remove build of ferric hydroxide precipitate and/or algae.

ON-LINE CONDUCTIVITY METER

Three dedicated Fisher Scientific digital conductivity meters were used to check the conductivity of the RO feedwater (i.e. Kubota MBR permeate) and each of the RO permeates. These meters were calibrated at the beginning, and end of the test period using standard solutions; daily comparisons are performed between the on-line conductivity readings and on-site lab results. The first meter was used to measure the feed water to the RO system and was calibrated using a conductivity standard of 2764 µmhos @ 25 °C. The remaining conductivity meters were used for RO permeate and were calibrated using a 23 µmhos @ 25 °C standard.

ON-LINE DISSOLVED OXYGEN (DO) METER

DO meters equipped on the Kubota and US Filter MBR systems were calibrated using the manufacturers protocol at the beginning of the study. To ensure accuracy, values were compared throughout the study to those measured by the hand held DO meter.

MEMBRANE SYSTEM THERMOMETERS

At the beginning of the study, all thermometers that were verified at a normal operating temperature (25-30°C) using an NIST thermometer. Monthly verification of system thermometers was performed. The thermometers used to monitor the temperature of the MBRs were all within 5% error. The thermometers used to measure the RO influent water were also verified and within 5% error.

MEMBRANE SYSTEM PRESSURE GAUGES

Pressure and vacuum gauges supplied with the membrane systems tested were verified against recently purchased grade 3A certified pressure and vacuum gauges. The certified pressure and vacuum gauges were manufactured by Ashcroft and have an accuracy of 0.25% over their range (0-30 psi pressure, 0-30 in Hg vacuum). Where possible, system gauges were removed and tested over the expected range of operating pressures against the verification gauge, using a portable hand pump. The vacuum gauge for the Mitsubishi MBR is a pressure transmitter that has been factory calibrated to an accuracy of ±1%. The calibration report from the manufacturer is on file at the PLWTP pilot site. The vacuum gauge for the Zenon system had an average error less than 5 % over the range of normal operating pressures. The pressure gauges for the RO skids were also within 5% error.

MEMBRANE SYSTEM ROTAMETERS

Membrane system liquid flow rates were verified volumetrically by bucket tests using calibrated containers or graduated cylinders and a stopwatch. The measured flow rate was compared with flows indicated on the rotameters. Measured and indicated flow rates agreed to within 5% for both the Zenon MBR permeate and the Mitsubishi MBR permeate. The combined flow rates, concentrate and permeate, of the RO skid were checked volumetrically and were both within 5% error.

Membrane system air flow rotameters were factory calibrated prior to the study. [*Please note: there exists no practical method of volumetrically verifying the air flow rates during the pilot study*.]

MEMBRANE SYSTEM LEVEL SENSORS

Three Endress+Hauser level sensors were included as part of the Zenon MBR skid. All sensors were factory calibrated prior to installation; the accuracy of the sensors were verified over the range of values using a standard measuring tape.

MEMBRANE/UV SYSTEM RUN HOUR CLOCK

All system run hour clocks used during this study are periodically checked for accuracy using a stop watch.

CHEMICAL FEED PUMPING RATE

The LMI pumps used for chemical injection were continually checked for accuracy. Upon start-up, the pumps were checked on a daily basis; this frequency was decreased to once per week after pumping consistency was demonstrated. The accuracy is verified using a graduated cylinder and stopwatch.

PORTABLE DISSOLVED OXYGEN/TEMPERATURE METER

A hand-held YSI Model 55 dissolved oxygen meter was used to measure DO in the aerobic tank of the MBR systems. The DO meter was factory calibrated prior to the study, and was re-calibrated before every use according to manufacturer's directions. Periodic comparisons between the hand-held meter, and the PL Lab DO sensor were also performed to ensure continued accuracy. The meter membrane and electrolyte solution are replaced as needed.

DESKTOP pH METER

A Fisher Scientific Accumet Model AR 15 desktop pH meter1 was used throughout the study to determine pH of the raw wastewater, primary effluent, MBR Effluent and MLSS. The meter was calibrated daily using a 3 point calibration with buffers 4, 7, and 10. The calibration was confirmed daily using a Laboratory check standard.

DESKTOP TURBIDIMETER

A Hach 2100N desktop turbidimeter was used to perform onsite turbidity analyses of feed and permeate samples. Readings were recorded in non-ratio operating mode. The following quality assurance and quality control procedures were followed to ensure the integrity and accuracy of onsite laboratory turbidity data:

- Weekly primary calibration of turbidimeter according to manufacturer's specification.
- Daily secondary standard calibration verification. Two secondary standards (approx. 0.05 NTU, and 19.1 NTU) were recorded after primary calibration and on the remaining working days until the next primary calibration.

[1] Fisher Scientific International Inc. Accumet Research AR15, Hampton NH

DESKTOP UV SPECTROPHOTOMETER

Samples collected for TOC analysis were analyzed for UV-254 absorbency using a Hach DR/4000 UV spectrophoteter. This instrument was returned to the factory for calibration prior to the study; the instrument was "zeroed" prior to each measurement.

DESKTOP SDI ANALYZER

A Chemetek, model FPA-2000 was used to measure SDI values on Kubota and US filter permeate. This equipment was calibrated by the manufacturer prior to the pilot study. Electronic results from the SDI tests were periodically forwarded to the manufacturer to ensure continued accuracy.

The filters used for the SDI analysis were GelmanSciences 0.45 um, Sterile Acrodisc, HT Tuffryn membrane (low protein binding, non-pyrogenic, product number 4184). MWH has used these filters for SDI analysis in previous reclamation studies. Samples of these filters were also forwarded to Chemetek for independent analysis.

WATER QUALITY SAMPLING PROTOCOL

All sample lines are properly sterilized (for microbial samples) and flushed for a minimum of one minute prior to sampling. Sample containers are obtained from the labs performing the analyses and all preservation chemicals are added to the bottles by the lab prior to sampling, when required. Filtering or any other required preparatory steps are also be performed by the respective lab performing the analysis. A courier from the MWWD or CEL Labs transports all samples that will be analyzed off site. Standard shipping and packing procedures are followed, including isolating samples and storage of samples in a cooler packed with plastic bubble wrap to prevent breaking of glass sample bottles. Ice packs are added to the coolers containing samples requiring storage at 4 degrees C. The samples will be delivered and analyzed within the allotted holding time for each measured parameter.

A chain of custody is filled out on-site by the person performing the sampling and given to the courier when the samples are picked up for delivery. Upon receipt, a representative from the lab will sign the Chain of Custody and the samples will be released to their custody. A copy of the signed Chain of Custody will then be sent back to the sampler and will be kept on file at the pilot site.

DATA MANAGEMENT/ANALYSES

All water quality data collected on-site was merged with data obtained from offsite laboratories throughout the study. Operational data was recorded on raw data sheets and routinely inputted into a database. The water quality and operational databases were combined to create a comprehensive database which was used for data analysis, retrieval, reporting and graphics. All data inputted to the database was checked and verified by the onsite engineer. Lastly, data files were periodically sent to TAC members during the study for analysis.

APPENDIX D
Photographs of Pilot Equipment

Kubota MBR Pilot Unit

Kubota: Upper Membrane Cassette (top); Lower Membrane Cassette (bottom)

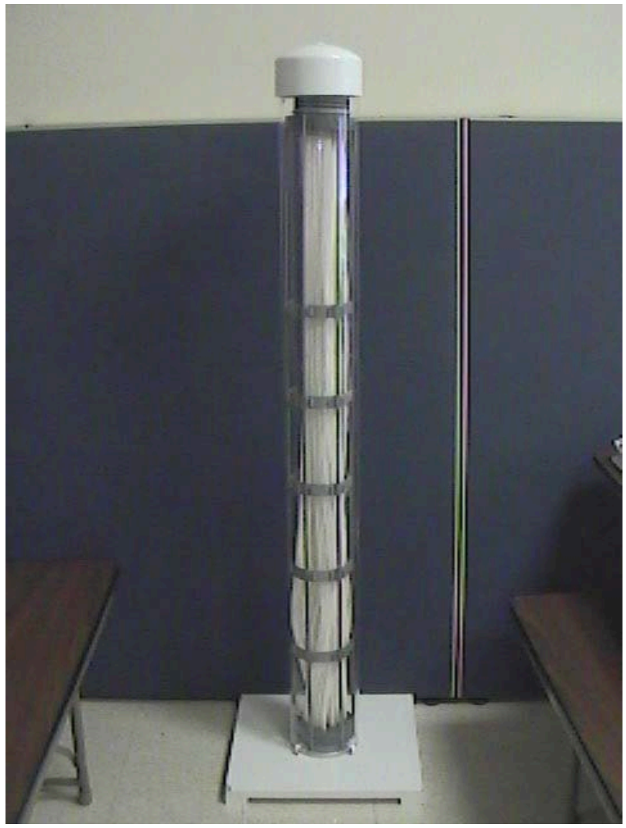
Kubota Type 510 Membrane (single sheet)

Kubota Type 510 Membrane (after 2 months operation)

US Filter MBR Pilot Unit

US Filter MBR Pilot Membrane Tank

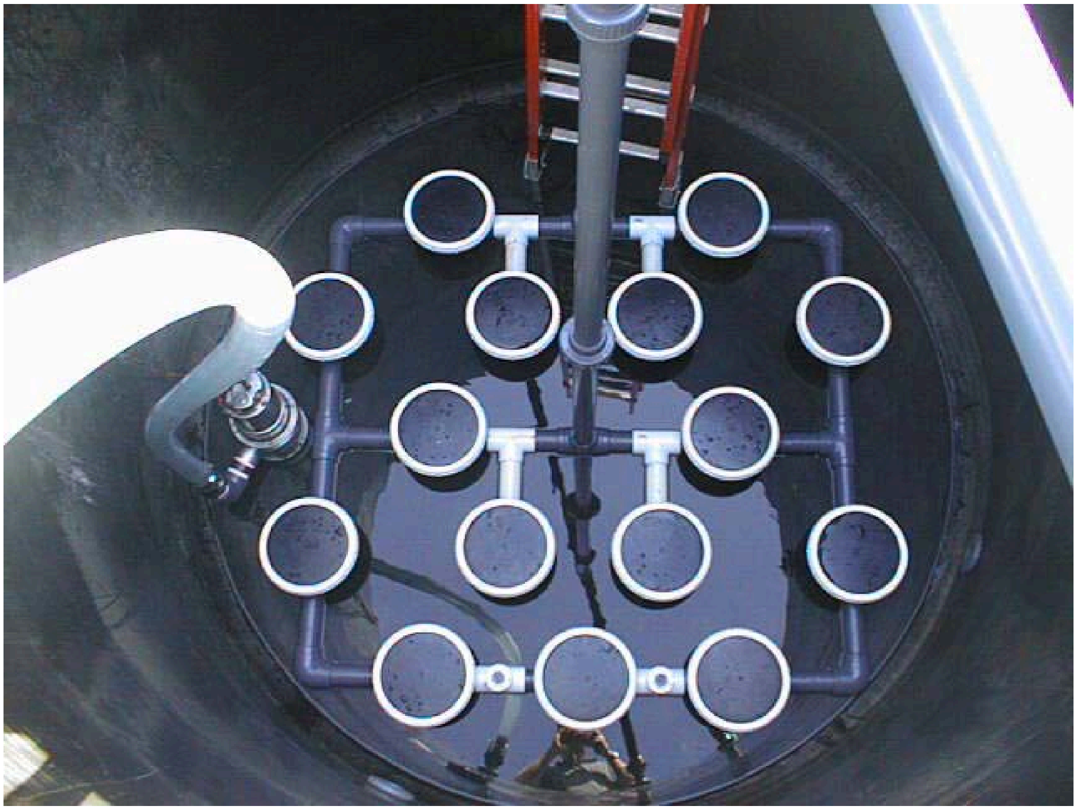
US Filter MemJet B10 R Membranes



US Filter MemJetB10 R Membranes

Zenon MBR Pilot Unit

Zenon 500d Membrane Cassette

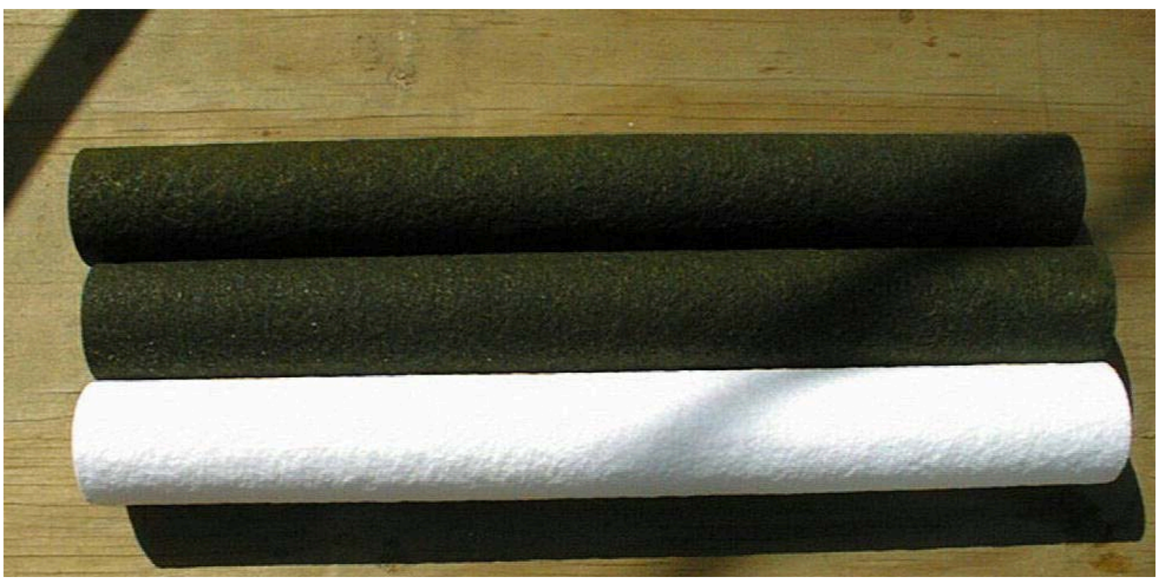

Zenon MBR Aeration Tank with Fine Bubble Diffusers (Plan View)

Mitsubishi MBR Pilot Unit (Plan view)

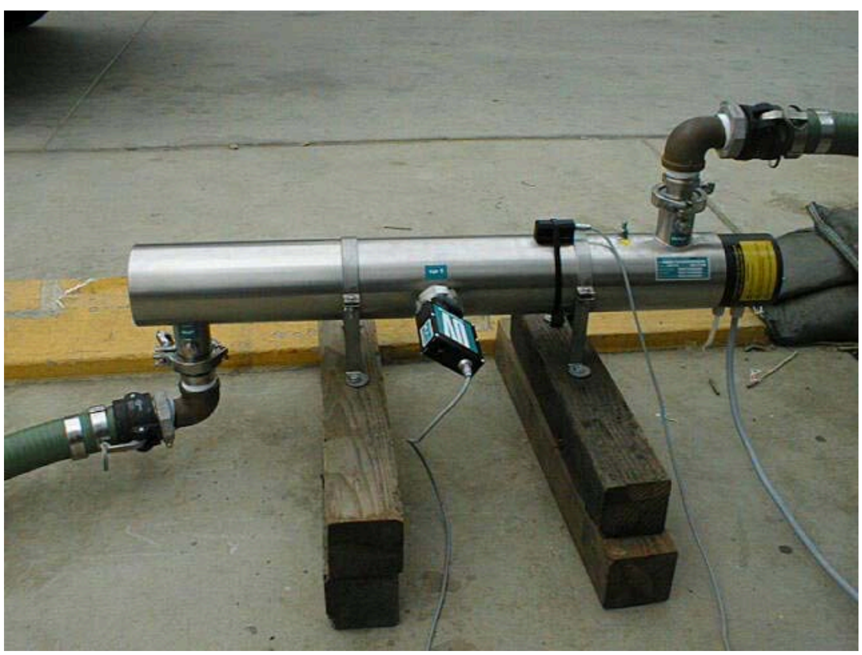
Mitsubishi MBR Pilot Unit (front view)

Mitsubishi Sterapore HF Microfiltration Membranes

RO Pilot Skid



RO Pre Filters: New (bottom); After 1 month Operation (top)



Aquionics UV Pilot System – Control Panel (Top); UV Reactor (Bottom)

Pre-Screen (Roto-Sieve Model 6013-11)

APPENDIX E
Kubota Title 22 Approval Letter

State of California—Health and Human Services Agency
Department of Health Services

California Department of Health Services
DIANA M. BONTÁ, R.N., Dr. P.H.
Director

GRAY DAVIS
Governor

March18, 2003

Mr. Hiroyuki Takatori
Kubota Corporation
Tokyo Head Office
1-3, Nihombashi-Muromachi 3-chome
Chuo-Ku, Tokyo 103-8310
Japan

Subject: Use of the Kubota Membrane Bioreactor (MBR) to comply with California Water Recycling Criteria

Dear Mr. Takatori:

By transmittal memo dated February 26, 2003, Montgomery Watson Harza, Consulting Engineers, requested Departmental approval of the Kubota 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 Harza entitled "Assessing the Ability of the Kubota Membrane Bioreactor to Meet Existing Water Reuse Criteria, dated February 2003. The report was prepared under a grant from the U.S. Bureau of Reclamation and outlines findings from a study conducted in the City of San Diego, California. The Department has reviewed this report and offers the following comments.

The Kubota MBR filtration system evaluated utilizes the Type 510 chlorinated polyethylene flat sheet membrane with a nominal pore

Division of Drinking Water and Environmental Management, Recycled Water Unit
1180 Eugenia Place, Suite 200, Carpinteria, California 93013
(805) 566-9767; (805) 745-8196 fax
Internet Address: www.dhs.ca.gov/ps/ddwem/

size of 0.4 micron. The membranes are submerged and operated under vacuum pressure with a maximum test flux of 20 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 Kubota 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 the Type 510 chlorinated polyethylene flat sheet membrane with a nominal pore size of 0.4 micron, 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 20 gfd and a maximum operating vacuum pressure of -3.0 psi.

The acceptance of your technology is specific to the Kubota Type 510 chlorinated polyethylene flat sheet membrane with a nominal pore size of 0.4 micron. 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: Enviroquip - Jim Porteous
Montgomery Watson - Samer Adham
City of San Diego - Steve Lagos
Recycled Water Committee

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APPENDIX F
Additional Costing Information

MEMORANDUM

MWH
MONTGOMERY WATSON HARZA

To: Membrane Manufacturer

From: Samer Adham, Ph.D./Steve Lacy, P.E.

Prepared by: James DeCarolis/Jude Grounds

Subject: MWH/MBR Vendor Workshop

MWH would like to thank you for your recent participation in the MBR Costing Workshop. The workshop generated a lot of discussion and information regarding full-scale design and costing issues related to the Bureau of Reclamation's (USBR) project entitled "Optimization of Various MBR Systems for Water Reclamation". To meet the costing requirements of the project, we would like to request additional capital and operation/maintenance information associated with the membrane and ancillary systems. The following memo outlines these additional requirements.

MWH will perform the biological portion of the design based on decisions made during the workshop. The following design criteria will be used for preliminary design and costing of the biological system:

1. **Feed Water** – Costs will be generated for operation on both raw wastewater and advanced primary effluent, assuming the following influent wastewater characteristics:.

Parameter	Raw Wastewater	Primary Effluent
BOD_5 (mg/L)	290	130
COD (mg/L)	700	280
TSS (mg/L)	320	65
VSS (mg/L)	260	50
NH_3-N (mg/L)	30	30
TKN (mg/L)	60	40
TDS (mg/L)	1,200	1,200
Alkalinity (mg/L)	245	230
Temperature (^oC)	20	20

2. **SRT –** The design SRT will between 10-15 days.
3. **MLSS –** MLSS will range from 8,000 – 10,000 mg/L.
4. **MBR Effluent –** The biological portion of the MBR system will be designed to meet the following effluent water conditions:

   - Complete nitrification (i.e. NH_4^+-N<1.0 mg/L),
   - Denitrification (i.e. NO_3-N<10 mg/L)
   - Biological Oxygen Demand (BOD) < 2.0 mg/L

Below are the key membrane system design criteria developed from discussions during the workshop. Please use these as guidelines when developing costs for the membrane system:

Capacity – Costs will be generated for 0.2, 0.5, 1.0, 5.0 and 10 MGD MBR systems. System will be for a sewer mining (scalping) plant. Residuals controlled through wasting to a downstream treatment facility.
Peaking – MBR systems will be designed with 1.0 Q.
Operating Flux – Membrane costs will be based on net operating flux of 15 gfd @ 15 deg C.
Operating TMP - Costs will be based on operating TMP of 2 psi, with a range of 1 – 4 psi.
Screening – Costs will include 0.8 mm perforated center feed rotary drum screens required for both feed water sources. Screen capacity will be based on peak flow; during periods of low flow, mixed liquor will be recycled/re-screened**.**
Cleaning Interval – A minimum of 2 CIPs will be required per year; the frequency of maintenance cleaning will be per the manufacturer's recommendation.
Redundancy – The MBR systems will be designed at average conditions to operate with one filter unit out of service (OOS) for a routine relaxing and an additional membrane filter unit OOS for chemical cleaning. System must be designed to accommodate increased flow to remaining filter units due to OOS unit.
Warranty – Costing will include a 5-year, non-prorated warranty. Warranty to cover manufacturing defects, normal wear and include the cost for providing replacement membranes to the plant site.

Please provide the following capital and operation/maintenance cost information as described below. For your convenience, we have attached a spreadsheet to be used for reporting cost estimates.

CAPITAL COSTS

Please provide the following capital costs for 0.2, 0.5, 1.0, 5.0 and 10 MGD capacities (for both feed waters, if different):

1. *Membrane Costs* - Please provide membrane costs for the capacities listed above. Include the membrane model number and values for total surface area and total

number of membrane filter units. The membrane cost shall be based on the following conditions:

- Net operating flux of 15 GFD @ 15°C
- Average operating TMP of 2.0 psi (This constitutes a average operating specific flux of 7.5 gfd/psi @ 15 °C)
- Net operating flux **does not** include loss of MBR permeate due to downtime and the use of MBR permeate for membrane cleaning (including relaxation or backwashing, CIPs and maintenance cleans, if applicable)
- Assume that 15% of the active membrane area will be lost over a 5 year period due to irreversible fouling
- The number of membrane units used for costing must meet the redundancy criteria listed above

2. *Chemical Cleaning Equipment* – Please provide itemized list of cost for any equipment necessary to perform CIPs and maintenance cleans including: pumps, tanks, valves and ancillary equipment/instrumentation.

3. *Membrane Chamber* – Please provide the sizing requirements for the membrane chamber(s) to accommodate the various MBR system capacities. Include in the costs for the membranes any internal components to the membrane chamber such as membrane support systems, internal beams and ancillary equipment. The membrane chamber must be sized with four feet of free-board for foam control.

4. *Valves, piping and system controls* – Please provide itemized list of costs for all valves piping and system controls necessary in the membrane chamber. Include any costs for standard PLC associated with the membrane tank.

5. *Membrane Aeration System* – Please provide the membrane aeration system design and costs for the various components of the membrane aeration system. The design should include items such as: air flow control valves, isolation valves, flow meters and rotameters. The design should be based on the necessary airflow requirement for membrane scouring. Please include membrane aeration system design and costs for 0.2, 0.5, 1.0, 5.0 and 10 MGD facilities. Equipment to provide air for the biological treatment will be provided by others.

6. *Permeate Collection System* - Please provide costs for pumps, flow control valves, and isolation valves related to the permeate collection system. In addition, please provide cost of turbidimeters, flow meters, and TMP measuring equipment and associated transmitters.

7. *Warranty*- Please provide a description and cost for a 5-year non-prorated warranty for the various plant capacities.

OPERATION AND MAINTENANCE COSTS (O&M)

Please provide the following O&M costs for 0.2, 0.5, 1.0, 5.0 and 10 MGD capacities (for both feed waters, if different):

1. *Personnel* – Please estimate the number of hours per day for operation and maintenance.

2. *Chemical Requirements* – Please provide the amount of chemical required (lbs/year) to perform CIPs and maintenance cleans. This quantity should be adequate to perform a minimum of 2 CIPs per year and the manufacturer's recommended number of maintenance cleans per year. It should be noted the system should be operated to meet the TMP requirement listed above.
3. *Membrane replacement* – Please provide estimated membrane replacement cost over a twenty year period. Assume membrane replacement every 8 years.
4. *Electrical* – Permeate and backwash pump and blower demands (kWh) based on a normal operating TMP of 2 psi. Additionally, electrical demands for all ancillary systems should also be included in the estimate.
5. *Spare parts* – Please identify and estimate the cost of spare parts typically incurred on yearly basis.

To meet the project schedules, we would appreciate if you could provide these costs no later than July 25th, 2003. If you would like to discuss any of the information requested above, please contact James DeCarolis (619 221-8325).

Unit Cost Assumptions used to estimate MBR O&M Costs

Annual Cost	Units	Unit Cost	Assumptions
Electrical power for process/miscellaneous	kwh	$0.08	Power usage = 100 kwh/day-mgd.
Equipment repairs/lubricants/replacement	ls/yr	2%	Percentage of Capital Equipment inc. Headworks, MBR system, Mechanical and Blower and pump building.
Crane	per rental	$1,000.00	Crane rental needed 2/yr for 0.2 mgd; 3/yr for 0.5 mgd. Crane to be purchased for 1, 5 and 10 mgd systems included in capital costs.
Chemical Cleaning (Membranes)			
Sodium Hypochlorite	gallons	$0.50	
Citric Acid	kg	$2.40	Total Costs based on 2 cleanings per year. Quantity of each chemical required derived from estimates provided by Zenon Environmental.
Sodium Hydroxide (neutralization)	kg	$0.31	
Sodium Bisulfite (neutralization)	kg	$0.77	
Chemical Cost for Disinfection			
Sodium Hypochlorite	gallons	$0.50	Annual cost based on 3 mg/L dose @12% sol.
Diffuser Replacement	per diffuser	$25	8-year replacement life; 9" fine bubble diffusers.
Membrane Replacement	ls/yr	NA	8-year replacement life;provided by mfgs.
Labor	per hour	$50	**(0.2 mgd)** = 1 hr/day, 5 days/week + 1 hr /day, 2 days /week (**0.5 mgd)** = 1.5 hr/day, 5 days/week + 1 hr /day, 2 days /week (**1 mgd)** = 2 hr/day, 5 days/week + 1 hr /day, 2 days /week **(5 mgd)** = 6 hr/day, 5 days/week + 2 hr /day, 2 days /week (**10 mgd)** = 16 hr/day, 5 days/week + 4 hr /day, 2 days /week.