

# ICR TREATMENT STUDY ANALYSIS

## Base Analysis and Data Review Comments

<b>Treatment Study ID</b>	1021
<b>Study Protocol</b>	Membrane Pilot-Scale treatment study
<b>Plant ICR Number</b>	430
<b>PWS Name</b>	Kansas City Missouri Water Services Dept.
<b>City, State, Zip</b>	Kansas City, MO 64116

### General Comments:

1. This pilot study was part of larger cooperative project that also involved Water District No. 1 of Johnson County. Johnson County conducted a single element study (study ID 1024), that served as a membrane screening study for the pilot study conducted by Kansas City.
2. During this pilot study, a single membrane type, the Hydranautics ESNA, was evaluated over a one year period.
3. During the first three quarters of this study, lime softening served as pretreatment to nanofiltration. Note that the chloramine feed was not used in Train #2 (as shown in Figure 1 of the Summary Report) during the pilot study with lime softening. During the last quarter, a Zenon microfiltration system was used to pretreat the raw water prior to nanofiltration.
4. Appendix D of the Summary Report contains a summary of operational events over the course of the pilot study.
5. A cost analysis is included in the Results and Discussion section of the Summary Report. The addition of a 216 MGD nanofiltration system was estimated to increase the cost of water from \$1.58 to \$2.81 per 1000 gallons. The cost of a new dual membrane MF/NF system was estimated at \$2.25 per 1000 gallons.

### Water Quality Comments:

1. Forty seven water quality outliers were identified and removed prior to base analysis.
2. During SDS testing, a target free residual of 1.0 mg/L was used during all quarters. The target incubation time and pH were also constant at 48 hours and 8.0, respectively. The target SDS incubation temperature ranged from 13 to 20°C.

3. In Table 1a of the Summary Report, units of ug/L are incorrectly listed for bromide. Concentrations are actually reported in mg/L.

### **Productivity Comments:**

1. Nine productivity outliers were identified and removed prior to base analysis.
2. During the first quarter of testing, sodium hexameta-phosphate (SHMP) was used as a scale inhibitor; however, exposure of SHMP to the atmosphere resulted in hydrolysis of SHMP to ortho-phosphate, which resulted in fouling and subsequent cleanings on days 20 and 27. To correct this problem, an alternative scale inhibitor, Hypersperse SI 300 was used from day 38 through the end of the study.
3. Membrane cleanings were performed with either an acid or an alkaline cleaning solution. Additional information about membrane cleaning procedure is given in the Materials and Methods section of the Summary Report.
4. Difficulty in maintaining the pH of the feed water was encountered during the first 30 days of the second quarter. The Summary Report indicates that fouling events on days 10 and 15 were due to pH control failure and elevated source water alkalinity.
5. On day 35 of the second quarter, operation of the pilot system was modified to recycle a portion of the stage 2 concentrate to the head of stage 1.
6. During the third quarter, sodium bisulfite was added to the pilot feed water once a day for 30 minutes at a concentration of 500 mg/L. This was a preventative measure for bio-fouling control.
7. On day 12 of the fourth quarter, the membrane surface area in the nanofiltration pilot was decreased due to flow limitations from the microfiltration system.
8. Microfiltration pretreatment during the fourth quarter did not show a substantial reduction in the rate of membrane fouling relative to lime softening pretreatment.
9. During EPA data analysis the productivity determinations were split into two sections, based on the pretreatment used: lime softening or microfiltration. The sustained system flux and specific flux during stable performance with the lime softening pretreatment were  $13.78 \pm 1.30$  gfd and  $0.128 \pm 0.007$  gfd/psi, respectively. The corresponding projected cleaning interval was  $55 \pm 23$  days. The sustained system flux and specific flux with the microfiltration pretreatment were  $10.63 \pm 0.60$  gfd and  $0.169 \pm 0.021$  gfd/psi, respectively. The corresponding projected cleaning interval was 30 days.

## ICR Information

ID / ICR#: MO1010415 / 430  
 ICR Contact: Connie Hull  
 Phone No.: 816 454-7600  
 Period: 4/14/98 - 7/8/98 (85 days)

## Membrane Information

Manufacturer: Hydranautics  
 Trade Name: ESNA  
 Membrane Model: ESNA-4040  
 MWCO: 200-300 Daltons  
 Element Size: 3.94" x 40"  
 Element Area: 85.0 ft<sup>2</sup>  
 Design Flux: 12.0 gfd  
 Mfr. NDP: 75.0 psi  
 Mfr. MTC<sub>w</sub>: 0.140 (gfd/psi)  
 Mfr. Temp: 25.0 °C  
 Maximum Flow: 16.0 gpm  
 Minimum Flow: 4.0 gpm  
 Total Width : 14.0 ft  
 Feed Spacer Thickness: 0.0010 ft  
 840 Element Area 400.0 ft<sup>2</sup>  
 840 Purchase Price: \$950

## Design Parameters

Norm Temp: 14.4 °C  
 Temp Norm MTC-w: 0.102 TavGC  
 Design Recovery: 0.90  
 Avg Sys Flux F<sub>w</sub>: 15.0 gfd  
 # of Elem in P.V.: 4  
 # Pres Ves in Stg 1: 2  
 # Pres Ves in Stg 2: 1  
 Pres Ves in Stg 3: NA  
 Design Flux: 15.0 gfd  
 Recycle Ratio: #VALUE!  
 Osmotic P Stage 1: 3.0 psi  
 Osmotic P Stage 2: 22.0 psi  
 Osmotic P Stage 3: NA

## Water Quality Summary

Feed (System)					Permeate (System)				Concentrate (System)			
Summary	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max
pH	6.2	1.2	5	4.1 - 7.2	6.0	0.5	4	5.2 - 6.4	6.6	1.8	5	3.4 - 7.6
Temp	21.5	5.3	5	14.2 - 27.9	21.5	5.3	5	14.2 - 27.9	21.5	5.3	5	14.2 - 27.9
Alk	32	12	4	22 - 49	1	2	5	0 - 5	336	131	4	207 - 495
TDS	315	88	5	215 - 422	24	8	5	14 - 32	2680	753	5	1742 - 3494
TotHard	162	44	5	118 - 217	1	2	5	0 - 4	1944	532	5	1454 - 2736
CaHard	148	41	5	110 - 193	2	1	5	0 - 4	1766	539	5	1281 - 2622
Turb	0.38	0.1	5	0.20 - 0.55	0.06	0.0	5	0.05 - 0.09	0.38	0.1	5	0.30 - 0.53
Amm	0.05	0.01	5	0.03 - 0.06	0.03	0.02	5	0.00 - 0.05	0.46	0.19	5	0.2 - 0.6
TOC	2.2	0.3	5	1.7 - 2.5	0.3	0.0	5	0.3 - 0.3	23.7	3.7	5	18.8 - 28.3
UV254	0.052	0.0	5	0.047 - 0.059	0.019	0.0	5	0.017 - 0.023	0.469	0.1	5	0.398 - 0.574
SUVA	2.45	0.20	5	2.22 - 2.76	7.56	0.94	5	6.80 - 9.20	1.99	0.14	5	1.84 - 2.21
Bromide	65	27	5	40 - 110	16	13	5	10 - 40				
TOX	128	19	5	108 - 159	13	0	5	13 - 13				
CHCl3	28.9	7.7	5	23.0 - 42.4	1.8	0.8	5	1.0 - 2.9	Mass Balance Closure Errors (%)			
BDCM	14.1	2.4	5	12.2 - 18.2	0.5	0.7	5	0.0 - 1.5				
DBCM	4.6	0.9	5	3.3 - 5.5	0.0	0.0	5	0.0 - 0.0	WQP	Count	Avg	SD/RD
CHBr3	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	Alk	1	-5	n/a
THM4	47.7	10.3	5	41.6 - 65.8	2.3	1.4	5	1.0 - 4.4	TDS	5	-41	8
MCAA	0.0	0.0	4	0.0 - 0.0	0.0	0.0	4	0.0 - 0.0	TotHard	3	0	10
DCAA	11.6	2.8	4	9.0 - 15.2	1.9	0.7	4	1.3 - 3.0	CaHard	5	-8	14
TCAA	10.1	2.3	4	8.0 - 13.4	1.1	0.8	4	0.0 - 1.9	Turb	5	-1028	602
MBAA	0.7	1.4	4	0.0 - 2.9	0.0	0.0	4	0.0 - 0.0	Amm	4	68	30
DBAA	0.6	0.7	4	0.0 - 1.4	0.0	0.0	4	0.0 - 0.0	TOC	4	0	5
BCAA	5.3	0.7	4	4.6 - 6.1	0.3	0.5	4	0.0 - 1.1	UV254	5	5	9
TBAA	0.0	0.0	4	0.0 - 0.0	0.0	0.0	4	0.0 - 0.0				
CDBAA	0.0	0.0	4	0.0 - 0.0	0.0	0.0	4	0.0 - 0.0	TDS	70	-35	15
DCBAA	7.5	0.8	4	6.3 - 8.2	0.0	0.0	4	0.0 - 0.0	Comments:			
HAA5	23.1	6.0	4	18.1 - 31.4	2.9	1.4	4	1.6 - 4.8				
HAA6	28.4	6.4	4	22.7 - 37.0	3.2	1.9	4	1.6 - 5.9				
HAA9	35.9	6.9	4	29.0 - 44.8	3.2	1.9	4	1.6 - 5.9				
SDS Conditions					Pretreatment Information							
WQP	Avg	SD	Count	Min - Max	Process	Description						Scale
Res (0)	0.66	0.12	10	0.50 - 0.80	Lime Softening, Ca(OH)2	1802 pounds per M.G. net filtered as Ca(OH) Full						
Temp (°C)	15.0	0.0	10	15.0 - 15.0	Ferric Sulfate, Fe2(SO4)3	107.8 pounds per M.G. net filtered as Fe Full						
pH (unit)	7.5	0.2	10	7.2 - 7.9	Potassium Perm., KMnO4	1.9 pounds per M.G. net filtered as KMnO4 Full						
Time (hr)	48.0	0.0	10	48.0 - 48.0	Polymer	5.5 pounds per M.G. net filtered Full						
					Carbon	14.6 pounds per M.G. net filtered Full						
						Sand filtration Pilot						
						Pre-filter line cartridge filter Pilot						
						Acid addition 2SO4; 0.33 mL/L Pilot						
						Antiscalant addition Hexametaphosphate; 1.3 mL/L Pilot						

## Mass Balance Errors

Pressure	RPD	SD	Flow	RPD	SD	TDS	RPD	SD
System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	#VALUE!	#VALUE!	System Inf - Stg 1 Inf	0.0%	0.0%
Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%
Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%
Sys Perm - Avg Stg Perm	-2.0%	16.7%	Sys Perm - Sum Stg Per	28.2%	70.1%	Sys Perm - Avg Stg Perm	-42.5%	32.5%

## Stage Summary

WQP	Stage 1 Influent						Stage 1 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.75	0.08	4	0.67 - 0.83					
pH	6.2	6.6	6.2	1.2	5	4.1 - 7.2	6.0	6.1	0.7	4	5.2 - 6.9
Temp	21.5	21.5	21.5	5.3	5	14.2 - 27.9	21.5	21.5	5.3	5	14.2 - 27.9
Alk	32	336	32	12	4	22 - 49	1	1	2	5	0 - 4
TDS	315	2680	315	88	5	215 - 422	24	13	6	5	6 - 19
TotHard	162	1944	386	517	5	118 - 1309	1	0	0	5	0 - 0
CaHard	148	1766	362	499	5	110 - 1253	2	0	0	5	0 - 1
Turb	0.38	0.38	0.34	0	5	0.20 - 0.55	0.06	0.12	0.14	5	0 - 0
TOC	2.2	23.7	2.1	0.3	5	1.7 - 2.5	0.3	0.3	0.1	5	0.3 - 0.6
UV254	0.052	0.469	0.052	0.006	5	0.047 - 0.059	0.019	0.020	0.005	5	0.015 - 0.027
SUVA	2.45	1.99	2.48	0.22	5	2.22 - 2.76	7.56	7.50	3.01	5	2.68 - 10.80

WQP	Stage 2 Influent						Stage 2 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.65	0.13	4	0.50 - 0.77					
pH	6.2	6.6	6.7	1.5	5	3.9 - 7.7	6.0	6.5	0.8	4	5.4 - 7.3
Temp	21.5	21.5	21.5	5.3	5	14.2 - 27.9	21.5	21.5	5.3	5	14.2 - 27.9
Alk	32	336	133	91	4	65 - 267	1	8	9	5	0 - 23
TDS	315	2680	1095	543	5	630 - 2035	24	70	41	5	36 - 141
TotHard	162	1944	675	374	5	363 - 1309	1	4	5	5	0 - 13
CaHard	148	1766	617	369	5	335 - 1253	2	4	5	5	0 - 13
Turb	0.38	0.38	0.38	0	5	0.30 - 0.48	0.06	0.09	0.04	5	0 - 0
TOC	2.2	23.7	8.1	2.9	5	6.0 - 13.1	0.3	0.4	0.2	5	0.3 - 0.8
UV254	0.052	0.469	0.170	0.059	5	0.117 - 0.260	0.019	0.022	0.003	5	0.017 - 0.024
SUVA	2.45	1.99	2.10	0.16	5.00	1.94 - 2.36	7.56	6.52	2.74	5.00	3.00 - 9.60

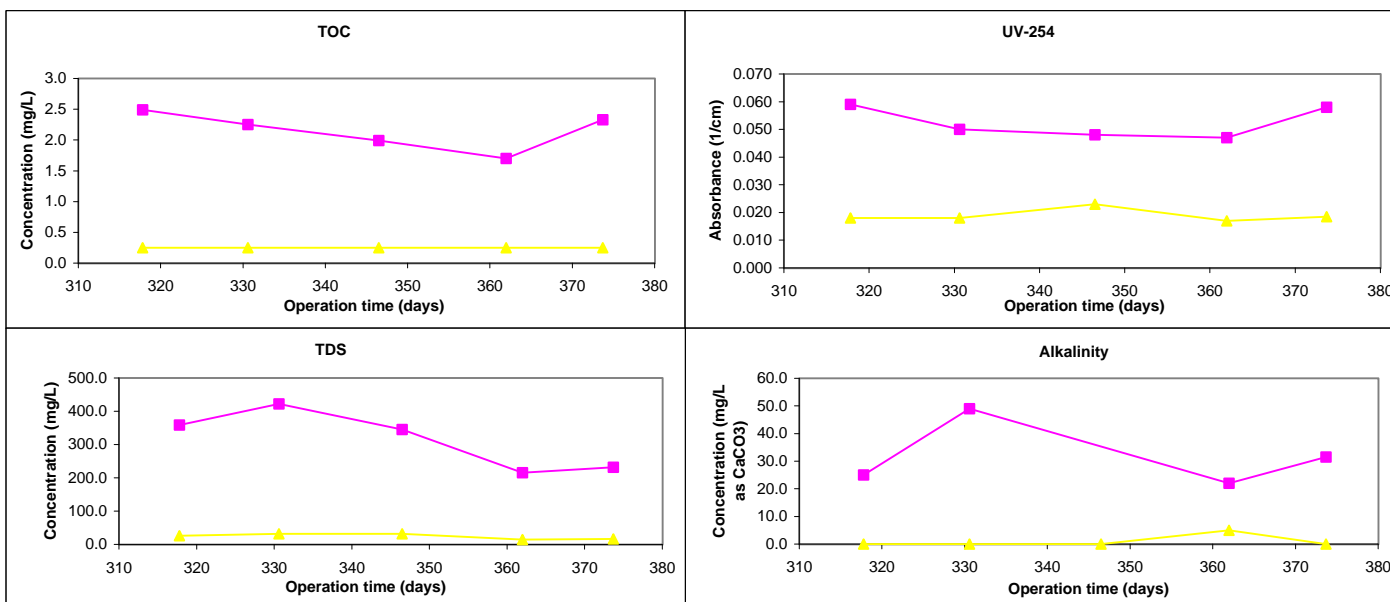
WQP	Stage 3 Influent						Stage 3 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery											
pH											
Temp											
Alk											
TDS											
TotHard											
CaHard											
Turb											
TOC											
UV254											
SUVA											

This was only a two stage study.

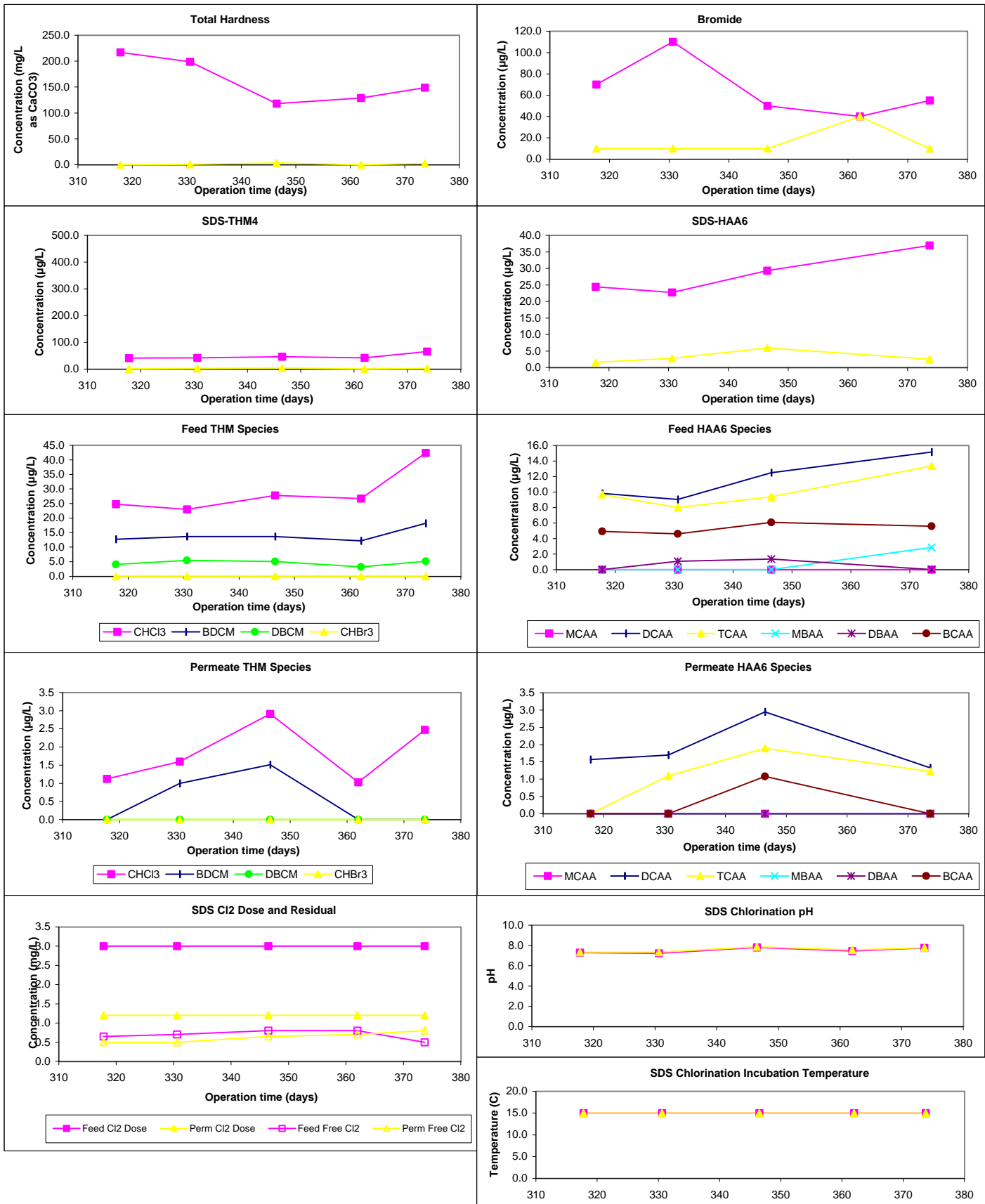
## Chart Legend:

- Feed (System)
- Permeate (System)

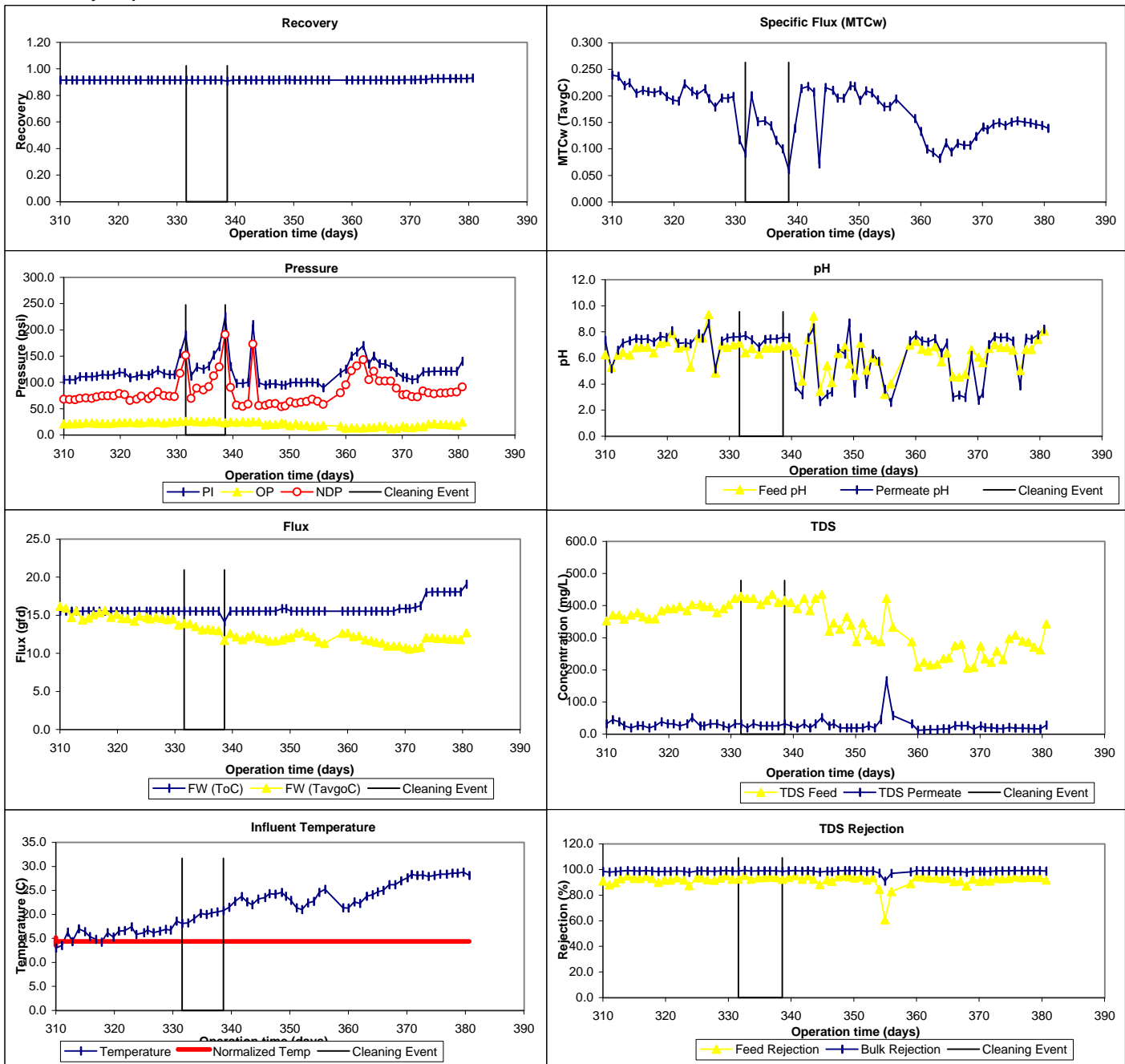
## Water Quality Parameter Graphs



## Water Quality Graphs (Continued)



## Productivity Graphs



## ICR Information

ID / ICR#: MO1010415 / 430  
 ICR Contact: Connie Hull  
 Phone No.: 816 454-7600  
 Period: 7/9/98 - 9/19/98 (72 days)

## Membrane Information

Manufacturer: Hydranautics  
 Trade Name: ESNA  
 Membrane Model: ESNA-4040  
 MWCO: 200-300 Daltons  
 Element Size: 3.94" x 40"  
 Element Area: 85.0 ft<sup>2</sup>  
 Design Flux: 12.0 gfd  
 Mfr. NDP: 75.0 psi  
 Mfr. MTC<sub>w</sub>: 0.140 (gfd/psi)  
 Mfr. Temp: 25.0 °C  
 Maximum Flow: 16.0 gpm  
 Minimum Flow: 4.0 gpm  
 Total Width: 14.0 ft  
 Feed Spacer Thickness: 0.0010 ft  
 840 Element Area: 400.0 ft<sup>2</sup>  
 840 Purchase Price: \$950

## Design Parameters

Norm Temp: 14.4 °C  
 Temp Norm MTC-w: 0.102 TavGC  
 Design Recovery: 0.95  
 Avg Sys Flux F<sub>w</sub>: 15.0 gfd  
 # of Elem in P.V.: 4  
 # Pres Ves in Stg 1: 2  
 # Pres Ves in Stg 2: 1  
 Pres Ves in Stg 3: NA  
 Design Flux: 15.0 gfd  
 Recycle Ratio: 0.00  
 Osmotic P Stage 1: 3.0 psi  
 Osmotic P Stage 2: 22.0 psi  
 Osmotic P Stage 3: NA

## Water Quality Summary

Water Quality Summary												
Summary	Feed (System)				Permeate (System)				Concentrate (System)			
	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max
pH	7.8	1.1	5	7.1 - 9.6	7.6	1.7	5	6.1 - 9.9	8.0	0.7	5	7.4 - 9.0
Temp	25.7	2.2	5	23.4 - 29.0	25.7	2.2	5	23.4 - 29.0	25.7	2.2	5	23.4 - 29.0
Alk	42	7	5	34 - 50	7	3	5	6 - 12	303	170	5	162 - 541
TDS	291	24	5	252 - 314	22	3	5	17 - 25	2918	290	5	2530 - 3240
TotHard	151	23	5	116 - 174	0	0	5	0 - 0	2013	590	5	1185 - 2675
CaHard	138	22	5	105 - 162	0	0	5	0 - 1	1824	536	5	1054 - 2372
Turb	0.49	0.2	4	0.30 - 0.70	0.19	0.2	4	0.05 - 0.50	2.89	2.4	4	0.65 - 6.19
Amm	0.08	0.04	5	0.03 - 0.12	0.05	0.03	5	0.00 - 0.09	0.47	0.15	5	0.2 - 0.6
TOC	3.8	2.6	5	2.1 - 8.1	0.6	0.5	5	0.3 - 1.4	37.7	16.6	5	25.0 - 66.5
UV254	0.057	0.0	5	0.048 - 0.067	0.021	0.0	5	0.019 - 0.026	0.526	0.1	5	0.387 - 0.623
SUVA	1.92	0.86	5	0.68 - 2.75	5.11	2.72	5	1.51 - 8.00	1.54	0.47	5	0.78 - 1.92
Bromide	62	49	5	10 - 110	10	0	5	10 - 10				
TOX	127	33	5	93 - 172	13	0	5	13 - 13				
CHCl3	25.0	11.7	5	9.0 - 42.2	2.5	1.4	5	1.2 - 4.6	Mass Balance			
BDCM	14.1	5.9	5	5.4 - 21.3	0.9	0.8	5	0.0 - 1.8	Closure Errors (%)			
DBCM	5.9	3.0	5	1.5 - 9.3	0.0	0.0	5	0.0 - 0.0	WQP	Count	Avg	SD/RD
CHBr3	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	Alk	5	-123	154
THM4	45.0	20.3	5	15.9 - 72.8	3.4	1.5	5	1.2 - 5.0	TDS	5	-33	9
MCAA	12.0	12.0	5	0.0 - 27.4	5.1	8.0	5	0.0 - 19.1	TotHard	0	n/a	n/a
DCAA	12.2	3.0	5	8.3 - 16.0	1.0	1.4	5	0.0 - 2.6	CaHard	3	-29	62
TCAA	8.3	4.4	5	1.1 - 12.3	0.7	0.7	5	0.0 - 1.4	Turb	4	-174	210
MBAA	1.8	2.4	5	0.0 - 4.7	2.7	3.8	5	0.0 - 7.5	Amm	4	-15	98
DBAA	4.5	6.4	5	1.4 - 16.0	0.0	0.0	5	0.0 - 0.0	TOC	5	-14	27
BCAA	5.2	0.6	5	4.7 - 6.3	0.0	0.0	5	0.0 - 0.0	UV254	5	-3	12
TBAA	1.4	3.2	5	0.0 - 7.2	0.0	0.0	5	0.0 - 0.0				
CDBAA	4.2	3.0	5	0.0 - 8.2	0.5	1.0	5	0.0 - 2.3	TDS	74	-35	16
DCBAA	9.3	1.8	5	6.9 - 11.8	1.6	2.3	5	0.0 - 5.6	Comments:			
HAA5	38.7	18.7	5	26.7 - 71.7	9.6	5.3	5	6.2 - 19.1				
HAA6	43.9	19.3	5	31.4 - 78.0	9.6	5.3	5	6.2 - 19.1				
HAA9	58.9	18.7	5	46.5 - 91.8	11.7	4.4	5	7.9 - 19.1				
SDS Conditions					Pretreatment Information							
WQP	Avg	SD	Count	Min - Max	Process	Description	Scale					
Res (0)	0.85	0.19	10	0.50 - 1.00	Lime Softening, Ca(OH)2	1802 pounds per M.G. net filtered as Ca(OH)	Full					
Temp (°C)	20.0	0.0	10	20.0 - 20.0	Ferric Sulfate, Fe2(SO4)3	107.8 pounds per M.G. net filtered as Fe	Full					
pH (unit)	8.0	0.0	10	8.0 - 8.0	Potassium Perm., KMnO4	1.9 pounds per M.G. net filtered as KMnO4	Full					
Time (hr)	48.0	0.0	10	48.0 - 48.0	Polymer	5.5 pounds per M.G. net filtered	Full					
					Carbon	14.6 pounds per M.G. net filtered	Full					
						Sand filtration	Pilot					
						Pre-filter line cartridge filter	Pilot					
						Acid addition 2SO4; 0.33 mL/L	Pilot					
						Antiscalant addition se SI 300; 4.0 mg/L	Pilot					

## Mass Balance Errors

Pressure	RPD	SD	Flow	RPD	SD	TDS	RPD	SD
System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	-54.0%	51.0%
Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%
Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%
Sys Perm - Avg Stg Perr	0.0%	0.0%	Sys Perm - Sum Stg Per	0.0%	0.0%	Sys Perm - Avg Stg Perm	-40.7%	27.6%

## Stage Summary

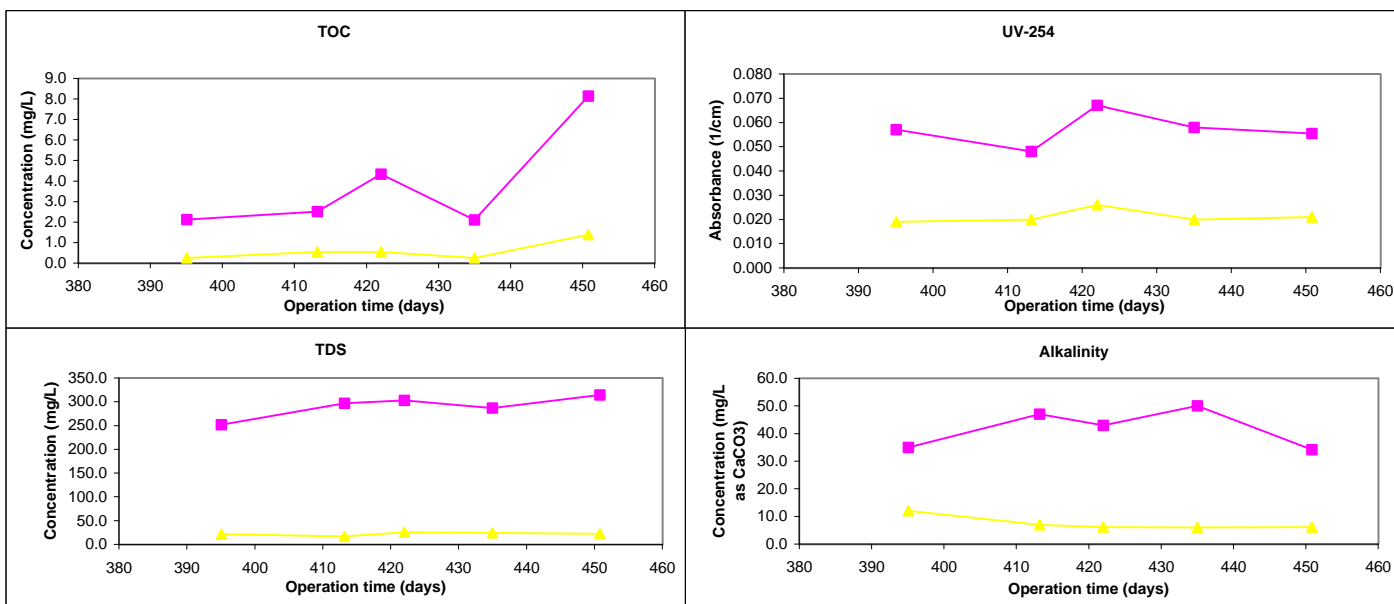
WQP	Stage 1 Influent						Stage 1 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.68	0.09	5	0.61 - 0.82					
pH	7.8	8.0	7.8	1.1	5	7.1 - 9.6	7.6	7.6	1.7	5	6.1 - 9.6
Temp	25.7	25.7	25.7	2.2	5	23.4 - 29.0	25.7	25.7	2.2	5	23.4 - 29.0
Alk	42	303	46	8	5	35 - 53	7	8	7	5	0 - 18
TDS	291	2918	869	684	5	252 - 1942	22	14	3	5	8 - 17
TotHard	151	2013	399	240	5	116 - 610	0	1	1	5	0 - 3
CaHard	138	1824	360	215	5	105 - 542	0	1	1	5	0 - 3
Turb	0.49	2.89	0.91	1	4	0.40 - 1.80	0.19	0.11	0.06	4	0 - 0
TOC	3.8	37.7	8.0	7.1	5	2.1 - 19.6	0.6	0.5	0.6	4	0.3 - 1.4
UV254	0.057	0.526	0.111	0.054	5	0.048 - 0.158	0.021	0.025	0.003	5	0.020 - 0.028
SUVA	1.92	1.54	1.84	0.68	5	0.81 - 2.69	5.11	NA	NA	4	NA
WQP	Stage 2 Influent						Stage 2 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.72	0.10	5	0.55 - 0.78					
pH	7.8	8.0	8.1	0.9	5	7.3 - 9.3	7.6	7.4	1.0	5	6.3 - 8.5
Temp	25.7	25.7	25.7	2.2	5	23.4 - 29.0	25.7	25.7	2.2	5	23.4 - 29.0
Alk	42	303	139	70	5	95 - 262	7	14	7	5	8 - 21
TDS	291	2918	1583	516	5	765 - 1969	22	54	12	5	46 - 75
TotHard	151	2013	1036	399	5	405 - 1369	0	2	1	5	2 - 4
CaHard	138	1824	935	357	5	367 - 1261	0	2	1	5	2 - 4
Turb	0.49	2.89	1.12	1	4	0.40 - 2.82	0.19	0.11	0.06	4	0 - 0
TOC	3.8	37.7	19.1	12.4	5	7.3 - 39.4	0.6	1.1	0.7	5	0.3 - 2.0
UV254	0.057	0.526	0.257	0.077	5	0.153 - 0.330	0.021	0.025	0.003	5	0.021 - 0.028
SUVA	1.92	1.54	1.60	0.52	5.00	0.76 - 2.10	5.11	3.87	3.73	5.00	1.40 - 10.40
WQP	Stage 3 Influent						Stage 3 Permeate				
	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery											
pH											
Temp											
Alk											
TDS											
TotHard											
CaHard											
Turb											
TOC											
UV254											
SUVA											

This was only a two stage study.

## Chart Legend:

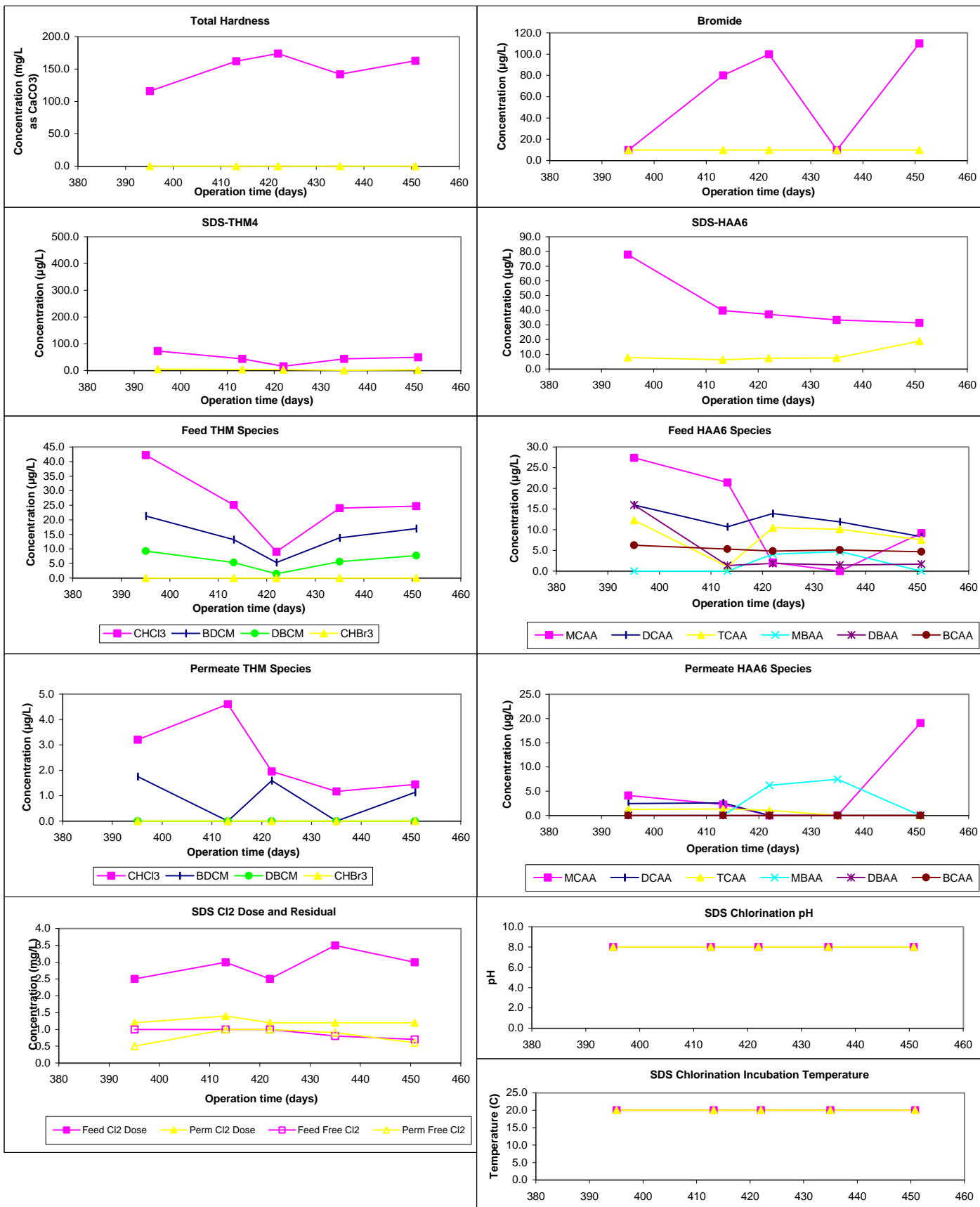
- Feed (System)
- Permeate (System)

## Water Quality Parameter Graphs

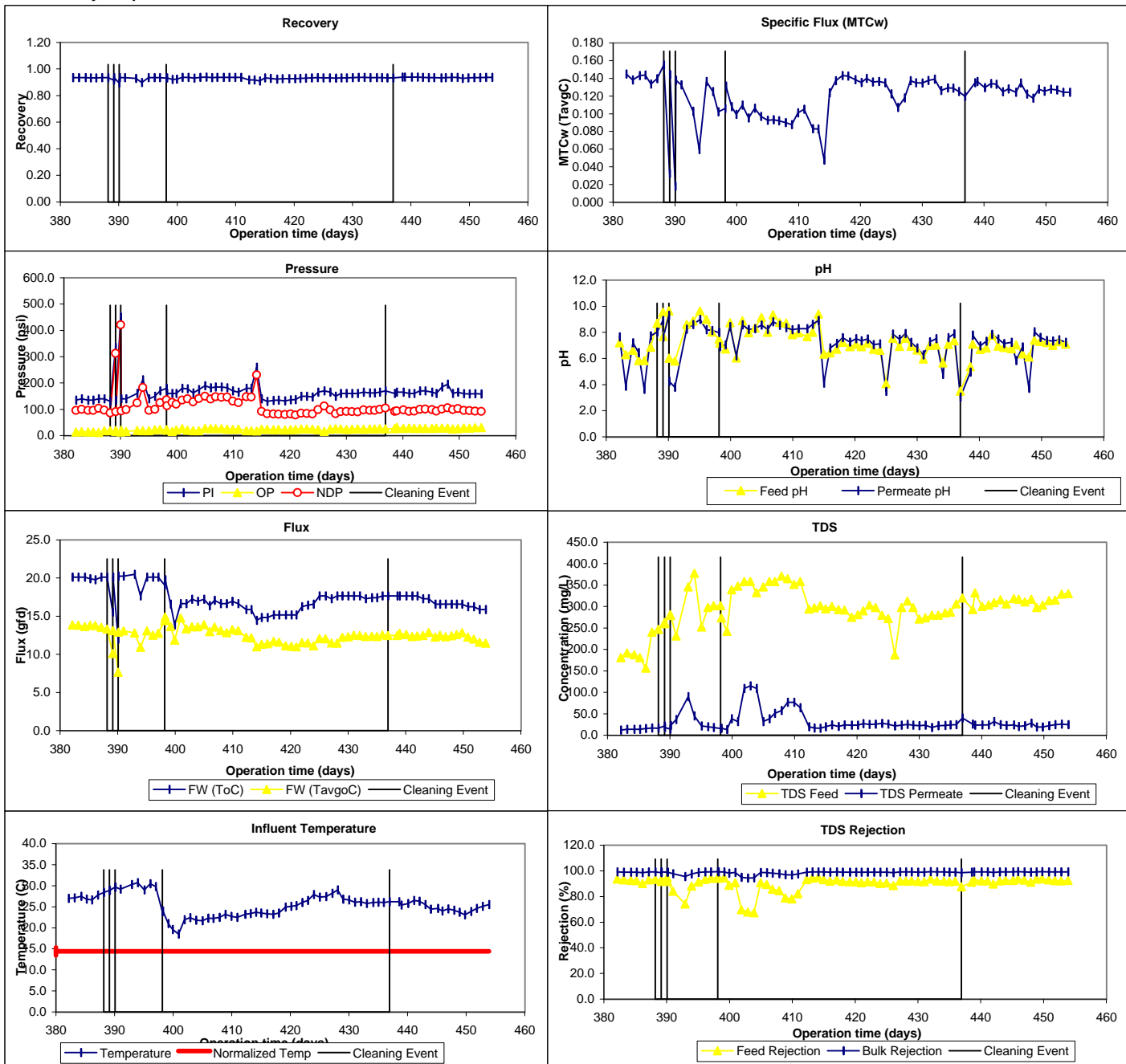




## Water Quality Graphs (Continued)



## Productivity Graphs



## ICR Information

ID / ICR#: MO1010415 / 430  
 ICR Contact: Connie Hull  
 Phone No.: 816 454-7600  
 Period: 9/20/98 - 12/24/98 (95 days)

## Membrane Information

Manufacturer: Hydranautics  
 Trade Name: ESNA  
 Membrane Model: ESNA-4040  
 MWCO: 200-300 Daltons  
 Element Size: 3.94" x 40"  
 Element Area: 85.0 ft<sup>2</sup>  
 Design Flux: 12.0 gfd  
 Mfr. NDP: 75.0 psi  
 Mfr. MTC<sub>w</sub>: 0.140 (gfd/psi)  
 Mfr. Temp: 25.0 °C  
 Maximum Flow: 16.0 gpm  
 Minimum Flow: 4.0 gpm  
 Total Width: 14.0 ft  
 Feed Spacer Thickness: 0.0010 ft  
 840 Element Area: 400.0 ft<sup>2</sup>  
 840 Purchase Price: \$950

## Design Parameters

Norm Temp: 14.4 °C  
 Temp Norm MTC-w: 0.102 TavGC  
 Design Recovery: 0.95  
 Avg Sys Flux F<sub>w</sub>: 15.0 gfd  
 # of Elem in P.V.: 4  
 # Pres Ves in Stg 1: 2  
 # Pres Ves in Stg 2: 1  
 Pres Ves in Stg 3: NA  
 Design Flux: 15.0 gfd  
 Recycle Ratio: 0.27  
 Osmotic P Stage 1: 3.1 psi  
 Osmotic P Stage 2: 22.0 psi  
 Osmotic P Stage 3: NA

## Water Quality Summary

Summary	Feed (System)				Permeate (System)				Concentrate (System)			
	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max
pH	6.8	0.9	5	5.9 - 8.3	5.9	0.4	5	5.3 - 6.3	6.0	1.8	5	3.7 - 7.4
Temp	12.6	7.1	5	6.0 - 22.5	12.6	7.1	5	6.0 - 22.5	12.6	7.1	5	6.0 - 22.5
Alk	28	19	5	5 - 49	1	2	5	0 - 5	88	122	5	0 - 296
TDS	282	48	5	209 - 340	20	3	5	15 - 24	2440	349	5	2180 - 3000
TotHard	150	52	5	90 - 222	0	0	5	0 - 0	1379	259	5	1151 - 1732
CaHard	115	46	5	66 - 184	0	0	5	0 - 0	971	281	5	642 - 1308
Turb	0.43	0.2	5	0.20 - 0.60	0.05	0.0	5	0.05 - 0.05	1.42	1.5	5	0.45 - 4.00
Amm	0.19	0.22	5	0.06 - 0.58	0.05	0.03	5	0.03 - 0.11	0.85	0.51	5	0.4 - 1.7
TOC	2.8	0.8	5	2.1 - 4.2	0.3	0.1	5	0.3 - 0.6	27.5	5.0	5	21.0 - 33.3
UV254	0.062	0.0	5	0.058 - 0.066	0.027	0.0	5	0.022 - 0.036	1.233	1.6	5	0.355 - 4.080
SUVA	2.36	0.49	5	1.58 - 2.93	9.88	3.89	5	3.79 - 14.40	4.76	6.50	5	1.69 - 16.39
Bromide	44	39	5	10 - 102	10	0	5	10 - 10				
TOX	109	45	5	56 - 154	13	0	5	13 - 13				
CHCl3	22.1	7.2	5	13.7 - 30.9	0.7	0.7	5	0.0 - 1.3	Mass Balance Closure Errors (%)			
BDCM	15.5	5.7	5	10.7 - 25.0	0.2	0.5	5	0.0 - 1.1				
DBCM	4.5	1.6	5	2.6 - 6.5	0.0	0.0	5	0.0 - 0.0	WQP	Count	Avg	SD/RD
CHBr3	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	Alk	1	-65	n/a
THM4	42.1	10.5	5	29.9 - 54.3	0.9	1.0	5	0.0 - 2.4	TDS	5	-35	15
MCAA	8.5	10.2	5	0.0 - 24.7	3.9	8.7	5	0.0 - 19.5	TotHard	1	-60	n/a
DCAA	11.8	5.8	5	6.0 - 21.2	1.5	3.4	5	0.0 - 7.7	CaHard	1	-100	n/a
TCAA	11.0	3.0	5	6.7 - 13.7	2.1	3.5	5	0.0 - 8.3	Turb	5	-356	175
MBAA	1.8	4.1	5	0.0 - 9.2	0.0	0.0	5	0.0 - 0.0	Amm	5	-43	107
DBAA	2.2	2.8	5	0.0 - 7.1	0.3	0.6	5	0.0 - 1.4	TOC	5	-10	38
BCAA	5.7	3.7	5	3.7 - 12.3	0.7	1.7	5	0.0 - 3.7	UV254	5	20	40
TBAA	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	TDS <sub>t</sub>	73	-40	17
CDBAA	2.8	2.9	5	0.0 - 6.9	0.0	0.0	5	0.0 - 0.0	Comments:			
DCBAA	28.8	20.1	5	7.3 - 50.9	7.6	15.5	5	0.0 - 35.3				
HAA5	35.3	22.8	5	18.6 - 75.3	7.9	9.7	5	0.0 - 19.5				
HAA6	41.1	26.5	5	22.7 - 87.6	8.6	10.7	5	0.0 - 21.1				
HAA9	72.7	39.4	5	36.9 - 138.4	16.2	24.0	5	0.0 - 56.4				

## SDS Conditions

WQP	Avg	SD	Count	Min - Max
Res (0)	0.64	0.13	10	0.50 - 0.80
Temp (°C)	15.0	0.0	10	15.0 - 15.0
pH (unit)	8.0	0.0	10	8.0 - 8.0
Time (hr)	48.0	0.0	10	48.0 - 48.0

## Pretreatment Information

Process	Description	Scale
Lime Softening, Ca(OH) <sub>2</sub>	1802 pounds per M.G. net filtered as Ca(OH)	Full
Ferric Sulfate, Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	107.8 pounds per M.G. net filtered as Fe	Full
Potassium Perm., KMnO <sub>4</sub>	1.9 pounds per M.G. net filtered as KMnO <sub>4</sub>	Full
Polymer	5.5 pounds per M.G. net filtered	Full
Carbon	14.6 pounds per M.G. net filtered	Full
	Sand filtration	Pilot
	Pre-filter line cartridge filter	Pilot
	Acid addition 2SO <sub>4</sub> ; 0.33 ml/L	Pilot
	Antiscalant addition se SI 300; 4.0 mg/L	Pilot

## Mass Balance Errors

Pressure	RPD	SD	Flow	RPD	SD	TDS	RPD	SD
System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	-96.5%	10.0%
Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%
Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%
Sys Perm - Avg Stg Perr	0.0%	0.0%	Sys Perm - Sum Stg Per	0.0%	0.0%	Sys Perm - Avg Stg Perm	-27.2%	12.6%

## Stage Summary

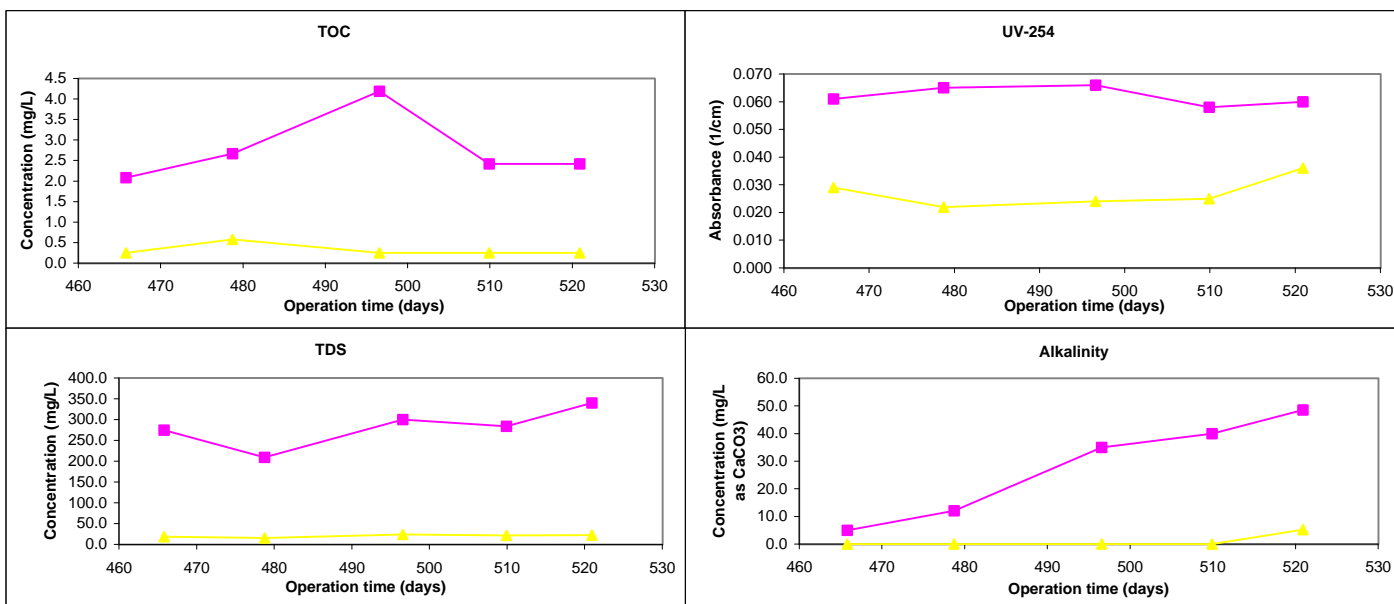
	Stage 1 Influent						Stage 1 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.66	0.02	5	0.64 - 0.69					
pH	6.8	6.0	5.9	1.3	5	4.0 - 7.1	5.9	5.7	0.3	5	5.4 - 6.0
Temp	12.6	12.6	12.6	7.1	5	6.0 - 22.5	12.6	12.6	7.1	5	6.0 - 22.5
Alk	28	88	29	40	5	0 - 97	1	1	1	5	0 - 3
TDS	282	2440	804	104	5	676 - 956	20	13	3	5	10 - 18
TotHard	150	1379	359	146	5	123 - 525	0	1	2	5	0 - 5
CaHard	115	971	253	118	5	88 - 407	0	1	2	5	0 - 4
Turb	0.43	1.42	1.41	2	5	0.25 - 5.00	0.05	0.05	0.00	5	0 - 0
TOC	2.8	27.5	8.6	1.0	5	7.3 - 9.9	0.3	0.4	0.2	5	0.3 - 0.8
UV254	0.062	1.233	0.162	0.025	5	0.130 - 0.190	0.027	0.027	0.004	5	0.022 - 0.032
SUVA	2.36	4.76	1.88	0.17	5	1.74 - 2.16	9.88	9.22	3.45	5	3.68 - 12.80
	Stage 2 Influent						Stage 2 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.77	0.02	5	0.74 - 0.79					
pH	6.8	6.0	6.0	1.5	5	4.0 - 7.4	5.9	6.0	0.8	5	5.3 - 7.3
Temp	12.6	12.6	12.6	7.1	5	6.0 - 22.5	12.6	12.6	7.1	5	6.0 - 22.5
Alk	28	88	56	79	5	0 - 192	1	3	4	5	0 - 8
TDS	282	2440	1512	201	5	1316 - 1737	20	35	7	5	26 - 45
TotHard	150	1379	792	127	5	644 - 982	0	1	1	5	0 - 1
CaHard	115	971	556	143	5	395 - 759	0	1	0	5	1 - 1
Turb	0.43	1.42	2.28	4	5	0.40 - 9.00	0.05	0.05	0.00	5	0 - 0
TOC	2.8	27.5	15.9	2.5	5	12.6 - 19.2	0.3	0.6	0.4	5	0.3 - 1.3
UV254	0.062	1.233	0.295	0.051	5	0.229 - 0.344	0.027	0.030	0.004	5	0.024 - 0.034
SUVA	2.36	4.76	1.85	0.13	5.00	1.71 - 2.05	9.88	6.91	4.26	5.00	2.27 - 12.80
	Stage 3 Influent						Stage 3 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery											
pH											
Temp											
Alk											
TDS											
TotHard											
CaHard											
Turb											
TOC											
UV254											
SUVA											

This was only a two stage study.

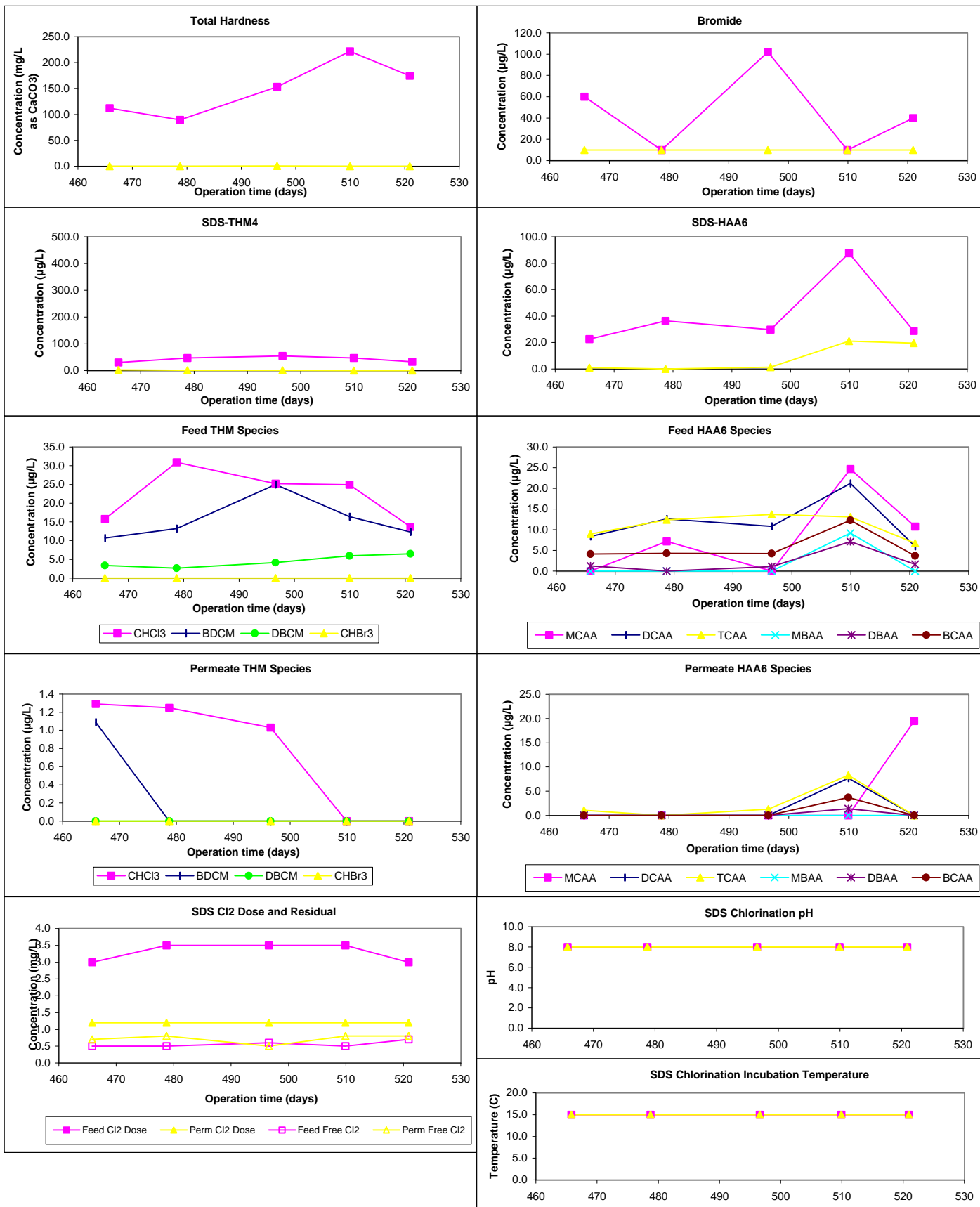
## Chart Legend:

- Feed (System)
- Permeate (System)

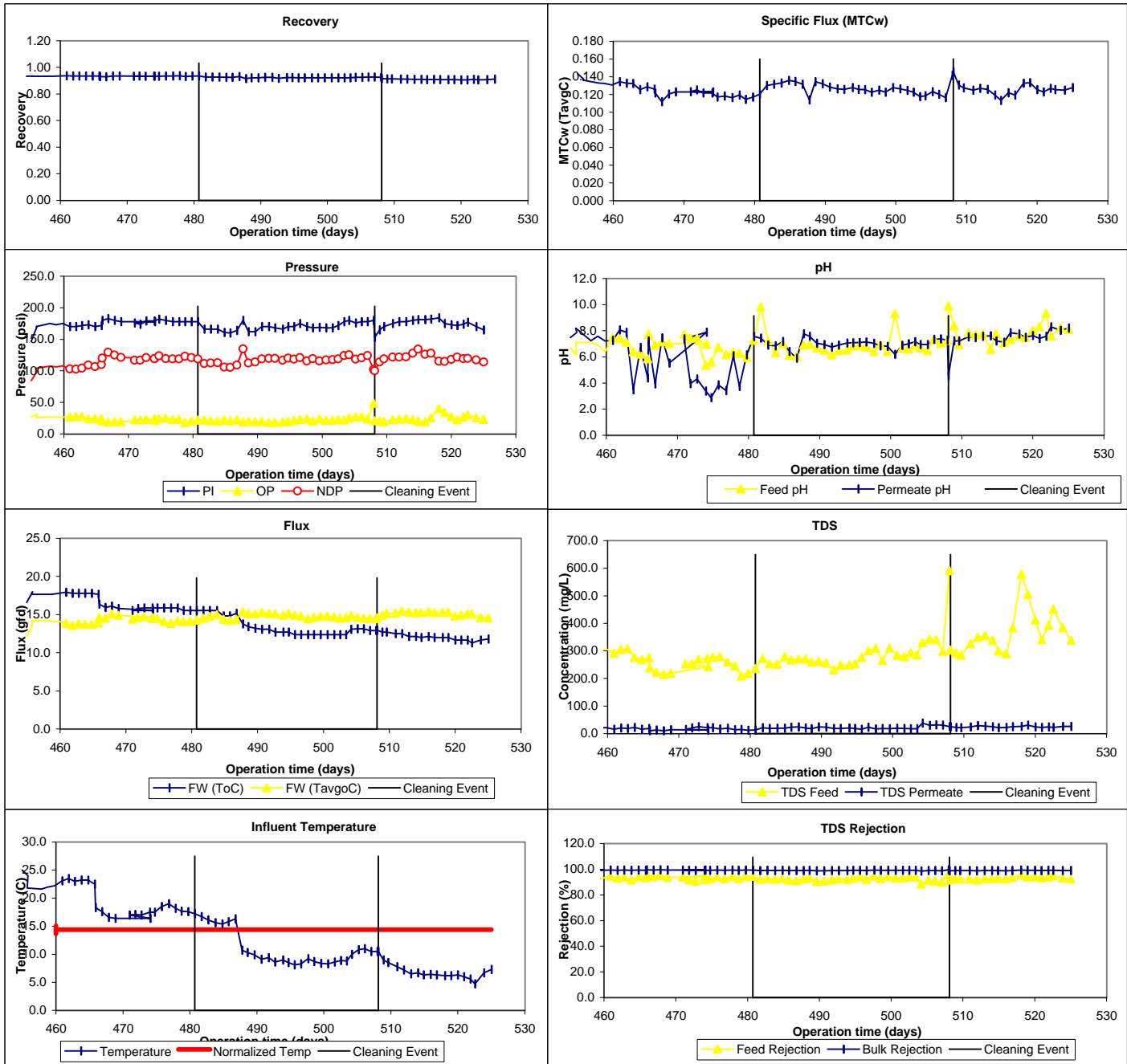
## Water Quality Parameter Graphs



## Water Quality Graphs (Continued)



## Productivity Graphs



## ICR Information

ID / ICR#: MO1010415 / 430  
 ICR Contact: Connie Hull  
 Phone No.: 816 454-7600  
 Period: 1/22/99 - 4/7/99 (75 days)

## Membrane Information

Manufacturer: Hydranautics  
 Trade Name: ESNA  
 Membrane Model: ESNA-4040  
 MWCO: 200-300 Daltons  
 Element Size: 3.94" x 40"  
 Element Area: 85.0 ft<sup>2</sup>  
 Design Flux: 12.0 gfd  
 Mfr. NDP: 75.0 psi  
 Mfr. MTC<sub>w</sub>: 0.140 (gfd/psi)  
 Mfr. Temp: 25.0 °C  
 Maximum Flow: 16.0 gpm  
 Minimum Flow: 4.0 gpm  
 Total Width: 14.0 ft  
 Feed Spacer Thickness: 0.0010 ft  
 840 Element Area: 400.0 ft<sup>2</sup>  
 840 Purchase Price: \$950

## Design Parameters

Norm Temp: 14.4 °C  
 Temp Norm MTC-w: 0.102 TavGC  
 Design Recovery: 0.90  
 Avg Sys Flux F<sub>w</sub>: 15.0 gfd  
 # of Elem in P.V.: 3  
 # Pres Ves in Stg 1: 2  
 # Pres Ves in Stg 2: 1  
 Pres Ves in Stg 3: NA  
 Design Flux: 15.0 gfd  
 Recycle Ratio: 0.34  
 Osmotic P Stage 1: 3.1 psi  
 Osmotic P Stage 2: 22.0 psi  
 Osmotic P Stage 3: NA

## Water Quality Summary

Summary	Feed (System)				Permeate (System)				Concentrate (System)			
	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max	Mean	SD	Count	Min/Max
pH	6.7	0.3	5	6.3 - 7.1	6.3	0.3	5	5.9 - 6.6	7.0	0.3	5	6.7 - 7.6
Temp	7.5	4.2	5	3.7 - 14.1	7.5	4.2	5	3.7 - 14.1	7.5	4.2	5	3.7 - 14.1
Alk	87	18	5	67 - 114	33	9	5	25 - 46	346	83	5	266 - 442
TDS	403	45	5	359 - 472	172	30	5	143 - 218	2323	272	5	1946 - 2666
TotHard	262	10	5	252 - 273	64	18	5	45 - 93	2445	391	5	1913 - 2934
CaHard	148	45	5	69 - 175	40	12	5	28 - 60	1554	229	5	1246 - 1840
Turb	0.13	0.1	5	0.05 - 0.20	0.05	0.0	5	0.05 - 0.05	0.21	0.1	5	0.10 - 0.30
Amm	0.11	0.14	5	0.01 - 0.35	0.05	0.03	5	0.03 - 0.11	0.36	0.34	5	0.1 - 1.0
TOC	3.2	0.5	5	2.8 - 4.0	0.8	0.3	5	0.3 - 1.1	30.0	2.7	5	27.5 - 33.9
UV254	0.067	0.0	5	0.061 - 0.071	0.012	0.0	5	0.010 - 0.015	0.756	0.1	5	0.634 - 0.905
SUVA	2.10	0.22	5	1.71 - 2.29	2.01	1.37	5	0.96 - 4.40	2.51	0.16	5	2.30 - 2.67
Bromide	50	46	5	10 - 108	16	13	5	10 - 40				
TOX	151	38	5	112 - 211	32	14	5	13 - 51				
CHCl3	61.8	27.8	5	33.7 - 90.5	5.2	4.6	5	2.1 - 13.4	Mass Balance Closure Errors (%)			
BDCM	18.7	2.9	5	15.7 - 22.4	8.3	5.6	5	3.3 - 17.0				
DBCM	4.6	0.7	5	3.8 - 5.5	5.1	1.2	5	3.5 - 6.7	WQP	Count	Avg	SD/RD
CHBr3	0.0	0.0	5	0.0 - 0.0	0.2	0.5	5	0.0 - 1.0	Alk	5	-121	27
THM4	85.1	29.7	5	56.2 - 116.6	18.7	11.1	5	9.5 - 37.1	TDS	5	-39	30
MCAA	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	TotHard	5	-11	9
DCAA	38.5	20.2	5	15.3 - 59.3	6.6	4.9	5	2.8 - 14.7	CaHard	5	8	44
TCAA	20.0	2.3	5	17.0 - 22.9	1.8	1.1	5	0.0 - 2.9	Turb	5	-376	290
MBAA	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	Amm	5	-18	144
DBAA	0.7	0.7	5	0.0 - 1.5	1.4	0.6	5	1.0 - 2.4	TOC	5	-7	24
BCAA	8.4	2.6	5	5.6 - 12.1	5.9	4.0	5	2.3 - 12.2	UV254	5	2	6
TBAA	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0	Comments:			
CDBAA	0.0	0.0	5	0.0 - 0.0	0.0	0.0	5	0.0 - 0.0				
DCBAA	8.7	1.5	5	7.7 - 11.5	0.3	0.7	5	0.0 - 1.7	TDSt	70	-111	39
HAA5	59.3	21.7	5	34.5 - 83.7	9.8	6.0	5	5.7 - 20.0				
HAA6	67.7	24.2	5	40.0 - 95.7	15.7	9.9	5	8.6 - 32.1				
HAA9	76.4	25.3	5	48.2 - 107.2	16.0	10.6	5	8.6 - 33.8				

## SDS Conditions

WQP	Avg	SD	Count	Min - Max
Res (0)	0.58	0.08	10	0.50 - 0.70
Temp (°C)	13.0	0.0	10	13.0 - 13.0
pH (unit)	8.0	0.0	10	8.0 - 8.0
Time (hr)	48.0	0.0	10	48.0 - 48.0

## Pretreatment Information

Process	Description	Scale
Flocculation	18 mg/L Fe2(SO4)3; In-line coagulation; 15 min	Pilot
Flocculation	Zenon immersed membrane process tank; 5 min	Pilot
Microfiltration	Zenon immersed membrane	Pilot
Equalization	Liquid volume = 55 gallons	Pilot
Acid addition	93% H2SO4; 0.33 ml/L	Pilot
	Antiscalant addition se SI 300; 4.0 mg/L	Pilot

## Mass Balance Errors

Pressure	RPD	SD	Flow	RPD	SD	TDS	RPD	SD
System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	0.0%	0.0%	System Inf - Stg 1 Inf	-64.1%	21.8%
Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%	Sys Conc - Stg 2 Conc	0.0%	0.0%
Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%	Stg 1 Conc - Stg 2 Inf	0.0%	0.0%
Sys Perm - Avg Stg Perm	0.0%	0.0%	Sys Perm - Sum Stg Per	0.0%	0.0%	Sys Perm - Avg Stg Perm	-7.0%	4.0%

## Stage Summary

	Stage 1 Influent						Stage 1 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.63	0.03	5	0.60 - 0.68					
pH	6.7	7.0	6.9	0.4	4	6.6 - 7.5	6.3	6.4	0.2	4	6.1 - 6.6
Temp	7.5	7.5	7.5	4.2	5	3.7 - 14.1	7.5	7.5	4.2	5	3.7 - 14.1
Alk	87	346	160	34	5	119 - 197	33	30	11	5	21 - 47
TDS	403	2323	1111	97	5	942 - 1179	172	139	23	5	117 - 175
TotHard	262	2445	845	436	5	68 - 1071	64	189	327	5	33 - 774
CaHard	148	1554	536	276	5	43 - 692	40	122	215	5	21 - 507
Turb	0.13	0.21	0.13	0	5	0.10 - 0.25	0.05	0.05	0.00	5	0 - 0
TOC	3.2	30.0	13.2	1.3	5	11.7 - 15.2	0.8	0.9	0.3	5	0.6 - 1.4
UV254	0.067	0.756	0.350	0.111	5	0.254 - 0.540	0.012	0.013	0.002	5	0.011 - 0.016
SUVA	2.10	2.51	2.61	0.56	5	2.17 - 3.56	2.01	1.69	0.57	5	1.04 - 2.61

	Stage 2 Influent						Stage 2 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery			0.79	0.01	5	0.78 - 0.80					
pH	6.7	7.0	7.1	0.3	5	6.8 - 7.7	6.3	6.3	0.4	5	5.9 - 6.7
Temp	7.5	7.5	7.5	4.2	5	3.7 - 14.1	7.5	7.5	4.2	5	3.7 - 14.1
Alk	87	346	250	58	5	189 - 310	33	48	19	5	31 - 77
TDS	403	2323	1731	174	5	1456 - 1903	172	231	40	5	192 - 291
TotHard	262	2445	1690	251	5	1297 - 1922	64	95	27	5	63 - 135
CaHard	148	1554	1074	147	5	844 - 1206	40	60	18	5	40 - 86
Turb	0.13	0.21	0.17	0	5	0.10 - 0.25	0.05	0.05	0.00	5	0 - 0
TOC	3.2	30.0	21.1	1.6	5	19.1 - 23.7	0.8	1.1	0.3	5	0.7 - 1.4
UV254	0.067	0.756	0.474	0.105	5	0.325 - 0.581	0.012	0.017	0.005	5	0.011 - 0.024
SUVA	2.10	2.51	2.26	0.54	5.00	1.37 - 2.75	2.01	1.49	0.39	5.00	1.03 - 2.03

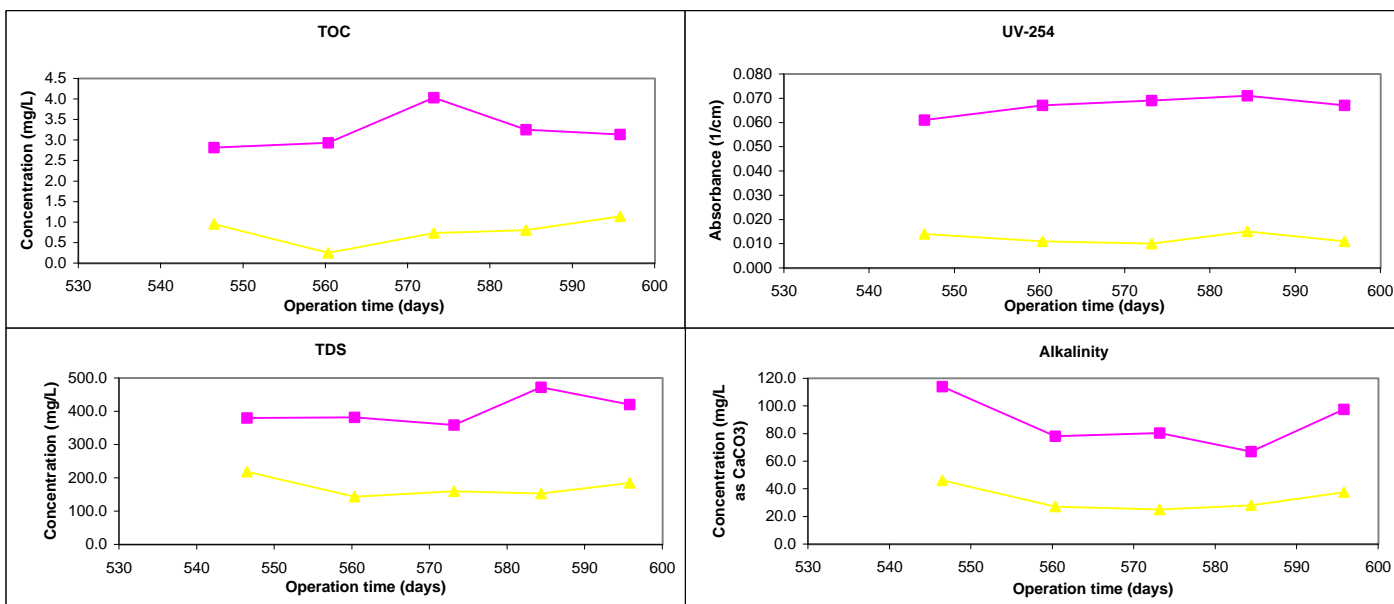
	Stage 3 Influent						Stage 3 Permeate				
WQP	Sys Feed	Sys Conc	Mean	SD	Count	Min/Max	Sys Perm	Mean	SD	Count	Min/Max
Recovery											
pH											
Temp											
Alk											
TDS											
TotHard											
CaHard											
Turb											
TOC											
UV254											
SUVA											

This was only a two stage study.

## Chart Legend:

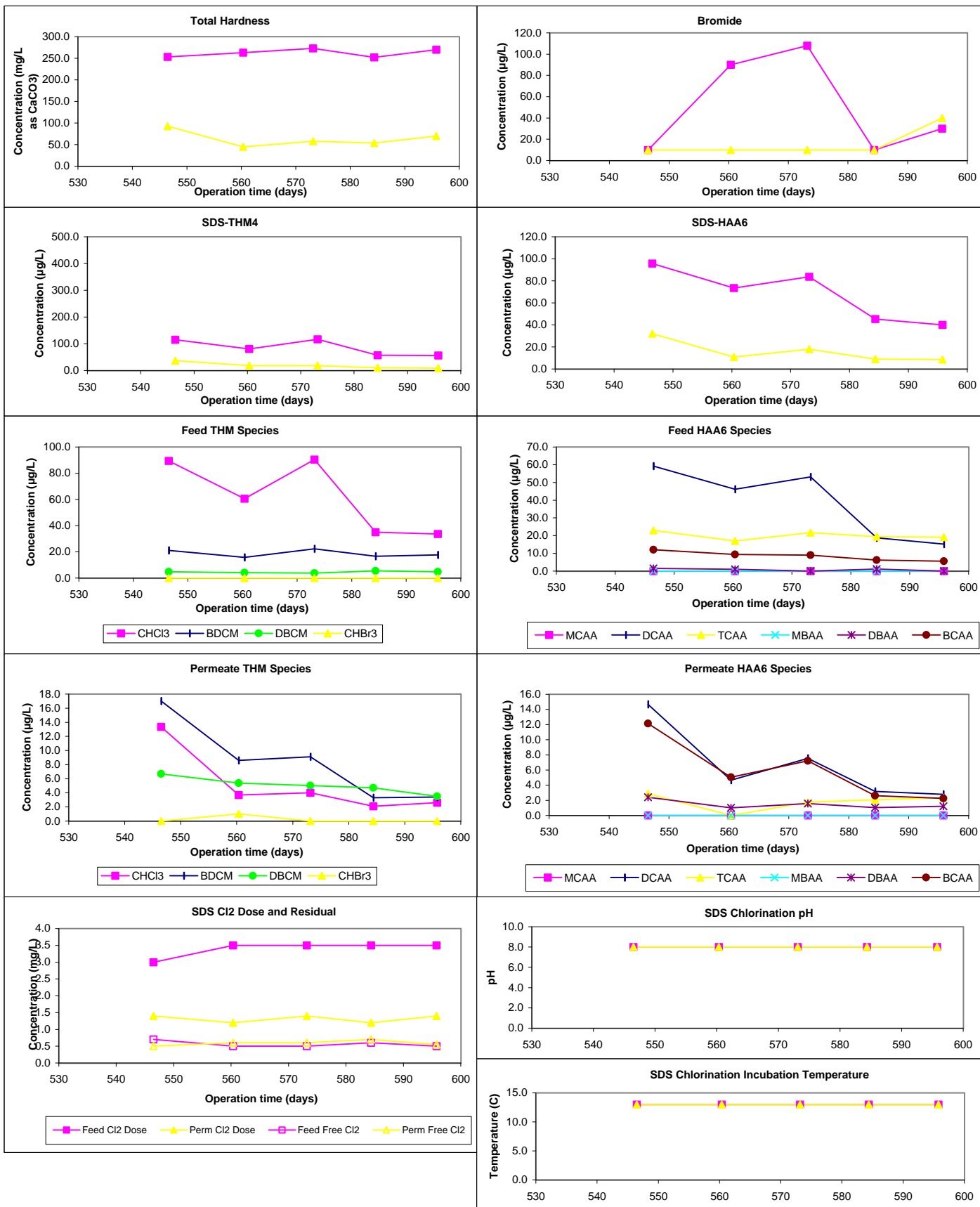
- Feed (System)
- Permeate (System)

## Water Quality Parameter Graphs





## Water Quality Graphs (Continued)



## Productivity Graphs

