Appendices

Appendix A

Summary of Slowsand Filter Assembly

Appendix A

Slowsand Filtration/Reverse Osmosis Pilot Study

Summary of Slowsand Filter Assembly (Requirements, Procurement, Quality Assurance/Quality Control, and Placement)

Introduction

Reclamation's August 2000 report, *Alternatives for Using Central Arizona Project Water in the Northwest Tucson Area, Appendix E – Water Treatment Alternatives* (Reclamation, 2000), discusses the conceptual design and benefits of using slowsand filtration and presents costs for construction and operation and maintenance. Table E-2 in that appendix lists the design criteria for the slowsand filter. These specifications were selected in large part from experience gained with an existing slowsand filtration (SSF) plant in Salem, Oregon. The Reclamation, 2000, appendix E conceptual design specifications relevant to the sand filter bed and underdrain gravel system proposed for the pilot study are as follows:

Table A-1.—Design criteria for slowsand filter sand and gravel (Reclamation, 2000, table E-3)

	Thickness (feet) [minute]	Hydraulic loading rate (gpm/ft^2)[1]	Particle size range (millimeters) [inches]	Coefficient of uniformity[2] (D_{60}/D_{10})
Sand Filter Bed	3.0 (1.5)	0.112	0.27 – 0.33 D_{10} [0.0106 – 0.013]	<2.5
Gravel Underdrain	1.5	—	19 [¾]	NA[3]

[1] Gallons per minute per square foot.

[2] The ratio between the particle diameter sieve sizes through which 60 percent and 10 percent finer than the sample (by weight) passes based on the cumulative gradation curve (a measure of how uniform or poorly graded a granular soil is. The ratio number increases with more particle size variation; particles of all the same size have COU=1).

[3] Not applicable.

Such a narrow size range (generally between U.S. standard sieves #50 and #60) and, thus, small coefficient of uniformity (COU), was specified to reduce headloss and the chance for segregation during shipment and placement. A more uniform sand has higher porosity (void fraction) and lower resistance to flow than a less uniform sand.

Additional sand requirements include durability and inertness in contact with Central Arizona Project (CAP) water. A cursory Internet search of water treatment filter media materials and past experience confirmed that the industry standard is silica sand, although certain geomembrane and artificial packing materials are sometimes used for SSF. Silica sand was selected for the pilot study.

For the pilot SSF tank diameter of 16 feet, a 3-foot filter bed thickness requires 603 cubic feet or about 22 cubic yards (yd^3). This was the volume quoted to prospective suppliers. In some cases, certain suppliers worked in terms of tons and cost per ton. A general rule-of-thumb figure given from several companies for comparable silica sand was 1.35 tons/yd^3. The amount solicited from a number of suppliers was 30 tons of sand.

Procuring Sand Filter and Underdrain Materials

It was expected in the pilot study planning stage that the sand and gravel materials would be available locally, with an estimated cost of around $500. In reality, because of the stringent sand specifications, this assumption was incorrect—the cost was much higher. Oglebay-Norton Industrial Sands, Inc., a parent company of Colorado Silica Sand, Inc., supplied the specified sand at a cost of $2,356 (including shipping) from San Juan Capistrano, California.

The following section summarizes the search for a suitable sand supplier and those companies contacted in Tucson, Phoenix, and outside Arizona.

Finding a supplier began by searching the yellow pages in Netscape for sand and gravel companies around Tucson. Out of 23 Tucson area companies, those with name recognition and/or closest to Twin Peaks Pumping Plant were contacted. The results follow:

- ☐ Pioneer Landscape – Only carry mortar and concrete sand, not special gradations.
- ☐ San Xavier Rock and Materials – Checked to see if they had anything similar; they could not produce it, and they did not have it.
- ☐ Tucson Ready Mix, Inc. – Did not carry anything but concrete and mortar-type sands and would not alter production to produce only 22 yd^3.
- ☐ Sonoron Landscape Materials – Similar response as that of Pioneer Landscape.
- ☐ Cemex USA – Had a stock of sand-equivalent size (#75/80) but would not produce such a small quantity (it was not economically justified); a fax was sent to the company with the desired specification, but there was no return message.

Following these results, it became apparent that the sand would probably be unobtainable from a local Tucson company because of the stringent gradation and uniformity requirements. Although there were other sand and gravel companies in Tucson, they were not contacted because the same reply was anticipated. Those companies that could produce the sand would not because they could not justify altering their batch plant production schedule for a relatively small quantity. Other companies simply did not carry this specialized sand. The focus then shifted toward Phoenix and other more distant potential suppliers.

The following Phoenix suppliers were contacted, but none were able or willing to supply the specified filter sand for similar reasons.

- ☐ Sand Specialties.
- ☐ Airblast Abrasives & Industrial Coatings.
- ☐ United Metro – Did not carry special filter sand.
- ☐ Pep Industrial Sand Filters – Did not carry sand that fine.
- ☐ Sunstate – Only carry mortar and plaster sand types.
- ☐ Marvel Building and Masonry Supply – Does carry 100-pound sacks of "Silica 60" at about $7.50/sack, but not in bulk. Provided this sand was suitable, about 621 bags were required, costing about $4,500 (not including shipment costs).
- ☐ Paragon Casa Grande – Only carry small bags of sand. Recommended Oglebay-Norton, Inc., in California.

An expanded Internet search ensued using a broader keyword list (mortar sand, plaster sand, filter media, sandblasting, wastewater treatment, column packing, etc.), as well as local inquiries to several acquaintances outside of Reclamation with experience in water treatment. Former City of Phoenix 91st Avenue Wastewater Treatment Plant engineer R. Wass provided the URLs for several sand suppliers.

Two of those contacted could supply the sand—the Parry Company in Ohio and the George L. Throop Co. of Pasadena, California. Internet e-mail inquiries were sent to these companies and others outlining the exact sand specification and required volumes needed for the pilot project.

The Parry Company quoted $55.00/ton bulk to make the sand or 3,000-pound "Supersacks" at $95.00 per supersack. Needing 21 supersacks for the pilot project, their fax quote amounted to 1,995.00 or, if in bulk, 31 tons would cost $1,705.00. These prices were competitive, but the costs for shipment to Tucson ($6,000) were considered prohibitive. D. Meredith, the company representative, mentioned he thought the desired sand gradation would be too fine for filtering river water and would clog in a short time; he recommended an effective diameter of 0.65 millimeter (mm) is more useful.

George L. Throop Co. quoted a price of $2,560.60. However, freight costs were an additional $2,500.

Other companies contacted by e-mail included USFilter.com (does not market slow sand filters and does not use that fine a gradation of sand, and would use different technology for RO pretreatment); RainforRent; US Silica Sands, Inc.; National Filter Media Co.; Browns Hill Sand Co.; Foster-Dixiana (they supply golf course bunker sand with 75 percent of the sand within the #60 sieve size); AGSCO Corporation (can supply a 0.3 mm silica sand), Manly Bros. of Indiana, Inc.; Southern Products & Silica Co., Inc.; ABCO – Atlantic Distribution Network; and Northern Filter Media International (A Northern Gravel Co.). The last five companies were returned through the Thomas Register, but only Agsco and Manley replied back. Manley Bros. spokesman P. Scott mentioned the availability of a #50 - #70 product, which could be rescreened.

One Tucson company, which was not contacted initially, was Granite Construction Company. Back in July and August, 1999, Reclamation's Water Treatment Engineering and Research Group member Qian Zhang, for the Southern Arizona Regional Water Management Study slowsand filter budget estimates, had received quotes from R. Mackey of Asphalt Sand & Gravel and from Granite. These quotes for sand were based on quantities of 40,000 to 50,000 tons of sand, the amount estimated for the full-scale slowsand filtration/reverse osmosis (SSF/RO) plant.

Mr. Mackey (now with Granite Construction Co.) was contacted August 2001 regarding these past quotes from Mr. Zhang. Mr. Mackey explained, from his recollection, that the sand and gravel quotes of 1999 (e.g., $19 per ton) were based on large estimated quantities (40,000 tons shown for the sand on a fax quote of August 10, 1999). Mr. Mackey further explained that the plant had just started up then (1999) and that they had found a good continuous sand layer at the site and thought that they could supply those large quantities at those low prices. Mr. Mackey mentioned that Granite would not now produce just 30 tons of the specified pilot study sand for those low prices (e.g., $19 per ton). He went on to say that Reclamation would probably pay 4 to 5 times as much for the small quantity of 31 tons, and that they would probably have to go to a west coast supplier to find such specialized filter sand.

After deciding on the sand supplier (Oglebay-Norton Industrial Sands, Inc.), a gravel underdrain supplier had to be located next. Eight potential suppliers in Tucson were contacted by phone. The following companies, with their stock availability and prices, follow. The target quantity for the SSF/RO pilot was 11 cubic yards.

- ☐ Catalina Rock & Sand – Going out of business (have no gravel left).
- ☐ Pioneer Landscape Materials – Only have a ¾-inch minus (70 percent fines) or a ¾-inch screened gravel with 30 percent fines. The ¾-inch minus is $22 per ton.
- ☐ Tucson Ready Mix, Inc. – Only carry 1¼-inch crushed rock.
- ☐ Sonoran Landscape Materials – Similar to Pioneer Landscape.
- ☐ Aggregate Materials – Carry ¾-inch screened and crushed limestone or granite. The ⅜-inch gravel is $16 per yd^3, and gray limestone ¾-inch gravel is $15.50 per yd^3. The delivery charge is $50. For 4 yd^3 of ⅜-inch pea gravel and 4 yd^3 of ¾-inch gravel, the total is $222.50.
- ☐ San Xavier Rock & Materials – Carry a washed, ¾-inch aggregate rock "57 rock" used for concrete at $13.25 per ton. The total price was $179.00 for rock plus $100.00 for shipment to the Twin Peaks Pumping Plant.
- ☐ Calmet/Cemex – A specialist (S. Freestone) in the Aggregate Department quoted $17.10 per ton of ¾-inch crushed and washed rock "67 rock" (ASTM C-33 #67) delivered for a total of $213.75. This rock had 15 percent fracture faces, and 85 percent was natural gravel clasts.
- ☐ Granite Construction Co. – Representative R. Mackey quoted $17 per ton with delivery to the pumping plant. The rock is a washed ¾-inch gravel. For 16.5 tons, a total price of $280.50 was quoted.

For the SSF/RO pilot project, 1-inch, ¾-inch, and ⅜-inch pea gravel was bought from Calmet/Cemex.

Quality Assurance and Quality Control

Due to the strict sand specification requirements desired for the SSF/RO pilot project (table A-1), some quality assurance/quality control measures were undertaken to ensure that the sand purchased from Oglebay-Norton Industrial Sands, Inc., was a suitable sand filtration pre-treatment media for reverse osmosis (RO) treatment. These measures included both written and verbal quoted assurances and two sieve analyses from Oglebay-Norton and three internal (Reclamation) gradation sieve analyses.

During production of the sand batch as shipped to the Twin Peaks Pumping Plant, an Oglebay testing analyst ran two sieve analyses on August 10, 2001, to determine the gradation and COU of the sand. A full suite of 16 U.S. standard sieve screens (U.S. Nos. 8 through 270) was used in the gradation tests. These test results show that the two samples meet the design specifications for an effective particle size (D_{10}) range of 0.27-0.33 mm and COU of 2.5 or less.

The D_{10} effective size is 0.27 mm in one sample and 0.31 mm in the second, so both samples meet the specification for gradation. The cumulative weight percent passing the #200 sieve (fines) is 0.1 percent. The low percentage of fines indicates that the sand was clean and well washed prior to shipment. The COU is 1.52 and 1.48 for the two samples and easily meet the design COU of 2.5 or less.

Two representative grab samples were collected by Reclamation's Phoenix Area Office Materials Technician from the extra stockpiles of the silica sand. These samples (referred to as sample Nos. 1 and 2 – Norton Sand on the gradation analysis sheets and corresponding gradation test plots) were tested on September 26, 2001. A six-screen gradation analysis calculated a D_{10} of 0.214 mm and COU of 1.9 for sample No. 1 and a D_{10} of 0.219 mm and COU of 1.8 for sample No. 2. These results are reasonably close to those of Oglebay's and provide an independent validation that the sand Reclamation bought met the requirements.

A sample of sand (No. 3 - natural sand) taken from Tucson's 2000 SSF pilot project (Chowdhury, 2002) was tested for comparison. The gradation curve shows that this sand is much less uniform (COU = 4.2) in particle sizes (better graded with more intermediate sand sizes, more fines, and more medium and coarse sand) than sample Nos. 1 and 2 from the current SSF pilot study. The D_{10} effective size for Sample No. 3 is about 0.22 mm. Sample No. 3 had 0.7 percent fines and 5 percent (by weight) particles passing the #100 sieve compared to sample Nos. 1 and 2 which contained 0.1 percent fines and about 2 percent passing the #100 sieve. The Tucson sand gradation may be more restrictive to flow and prone to clogging and segregation.

Slowsand Filter Assembly and Placement

During the week of July 30, 2001, to August 3, 2001, the Central Arizona Water Conservation District constructed an earthen pad for the slowsand tank foundation. The elevated pad enabled gravity flow to the RO feed tank. The pad measured 4 feet high, approximately 24 to 26 feet in diameter at the upper surface, and approximately 32 feet in diameter at the existing ground surface.

On August 6, 2001, as the slowsand tank sat at Hayden Udall Treatment plant, the sands and gravels that had been used for the previous filtration test (Tucson's 2000 SSF test) were removed. The Town of Marana provided labor and equipment to remove the material from the tank. The material was shoveled into a concrete bucket. The bucket was then dumped into a truck, and the material was hauled to a storage area on the Hayden Udall site.

On August 7, 2001, the tank was loaded onto a lowboy truck and moved to the Twin Peaks Pumping Plant. The tank was then placed on the earthen pad. Again, the Town of Marana provided the labor and equipment to accomplish this. A boom truck was used to place the tank. Also on August 7, the sand filter media arrived from Oglebay-Norton in 3,000-pound "polysacks" by two lowboys. The sand was off-loaded by the boom truck and stored onsite.

On August 8, 2001, the preliminary piping to the slow sand tank was connected. The Town of Oro Valley and Flowing Wells Irrigation District had previously installed pipeline from the CAP Canal at the Twin Peaks Pumping Plant to the earthen pad. Once the piping was connected to the tank and the polyvinyl chloride glue allowed to dry, the tank was partially filled with water, allowing the tank to settle on the pad, as well as to detect any leaks. One load of 8 tons of ⅜-inch gravel (pea gravel) was also delivered and stockpiled onsite.

On August 9, 2001, a supply truck from Reclamation's Denver Office arrived and was off-loaded; the supplies included pumps, valves, hoses, portable tanks, and other items.

On August 13, 2001, a load consisting of 8 tons of 1-inch gravel was delivered and stored onsite. On August 16, the first load, consisting of 8 tons of ¾-inch gravel meeting ASTM C-3367, was delivered from a local supplier, CEMEX.

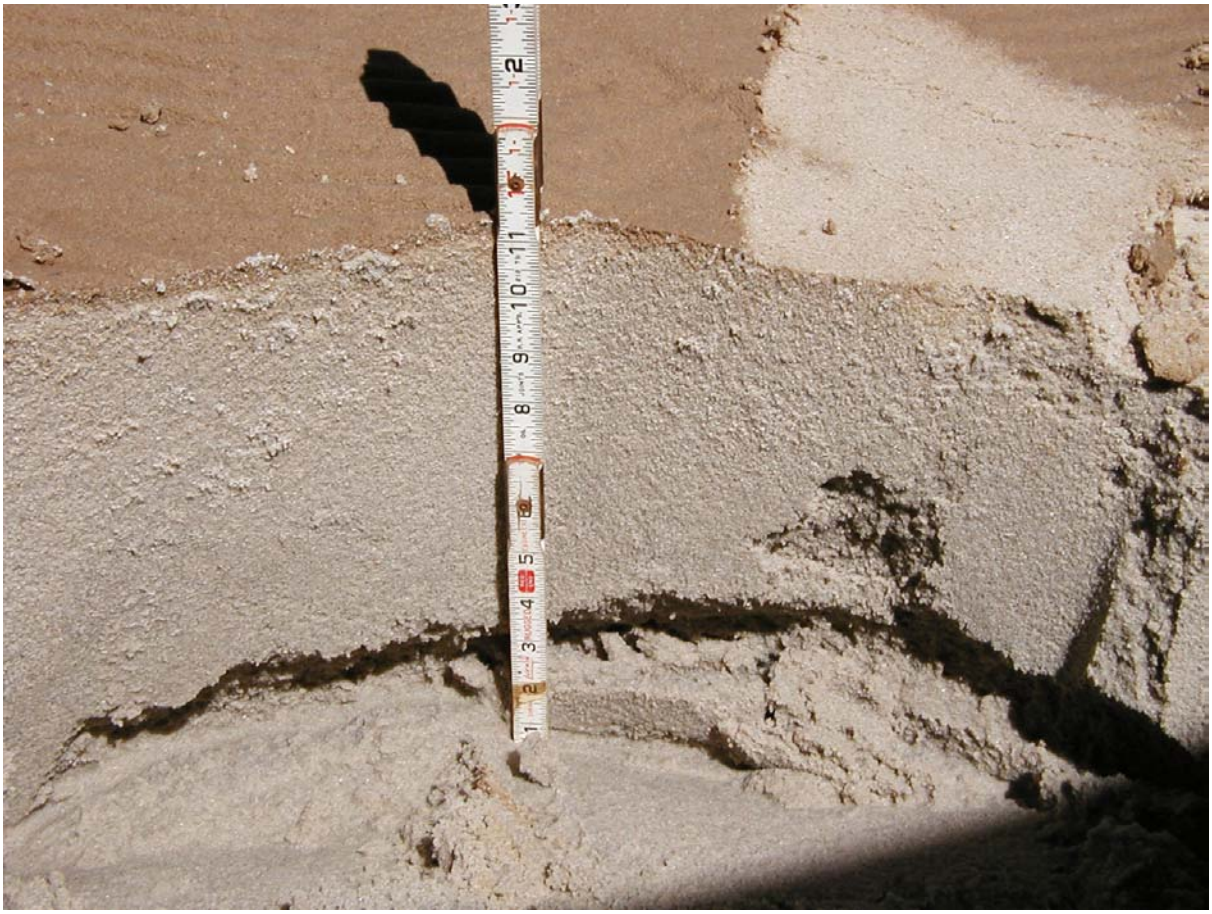
On August 17, 2001, the final load of ¾-inch gravel (7.5 tons) was delivered. At this point, all the filter material was onsite. Also on August 17, the filtering media (silica sand) was installed in the tank. The 1-inch gravel was installed first. The collecter piping was already laying on the tank bottom. The 1-inch gravel was spread evenly around and above the collection piping, taking care not to cause damage. The 1-inch gravel was placed to a thickness of about 6 inches, giving a minimum cover of approximately 1 inch above the collection piping.

Next, about 6 inches of ¾-inch gravel was placed, and above that, about 6 inches of ⅜-inch pea gravel was placed. Each lift was leveled before the next lift was applied. A cloth membrane was then placed on the pea gravel (this is the same membrane that was used previously at the Hayden Udall Treatment Plant during Tucson Water's slowsand testing in 2000).

The filtering sand was then placed in the tank, spread carefully and evenly. An outlet that is within the sand lift was protected by a strainer and a small piece of membrane cloth to keep sand from flowing out. A 3-foot lift of the sand was placed. While the filter media was being placed in the tank, water was introduced into the bottom of the tank through the collector piping. This filling procedure forced air up and kept the filter media saturated as the lifts were being placed. All the gravel and approximately half the sand were saturated by day's end.

On August 20, 2001, the inlet piping was finished, and the filtering media was fully saturated and covered by approximately 6 inches of water.

On August 21, 2001, the slowsand filter was placed into the forward production mode by supplying water from the inlet side at the top of the tank versus the fill procedure, which fed water from the underdrain. CAP water was being filtered, conditioning of the sand had begun, and flow rate calibration was started.



Photograph 1 (#22).—Slowsand Filter – Reverse Osmosis Pilot Study, March 19, 2002.

View of the topmost foot of the exposed sand filter. The brown surface clogging (organic and inorganic) layer or "shmutzdecke" is about 1/16 - 1/8-inch thick. It has been about 2 weeks since the scmutzdecke was last scraped off. The filter was excavated near the south-central portion of the 16-foot-diameter tank. Note that the clogging layer has penetrated the #50-60 mesh silica sand up to about 0.1 foot, but otherwise, there was little to no penetration (contamination) below this zone throughout the 3-foot-thick sand bed. Also note the homogeneous (textureless) structure of the sand. No channeling/piping, fissuring, grain overgrowths, bioturbation, voids, or other features were seen in the sand bed. The void here is a result of sloughing, not an in-place feature.

Photograph 2 (#28).—Slowsand Filter – Reverse Osmosis Pilot Study, March 19, 2002.

The filter fabric was cut open to expose the upper underdrain layer—an approximately 6-inch-thick lift of 3/8-inch gravel. Very little sand had passed through the fabric, although some sand grains were seen about an inch down after digging into the gravel. The fabric was probably not a critical component in the sand filter assembly, but may act as a stabilizer. The sand filter should still be effective even if some of the sand had penetrated the gravel underdrain.

Appendix B

Pilot Test Data: Tables and Figures

Appendix B (RO-Data-Plots-SARWMS.xls) Index

The following tables document SSF-RO pilot test conditions and performances.
These tables are tabs in Excel file "RO-Data-Plots-SARWMS.xls" on CD.

SARWMS Slowsand - Reverse Osmosis 2001-2002

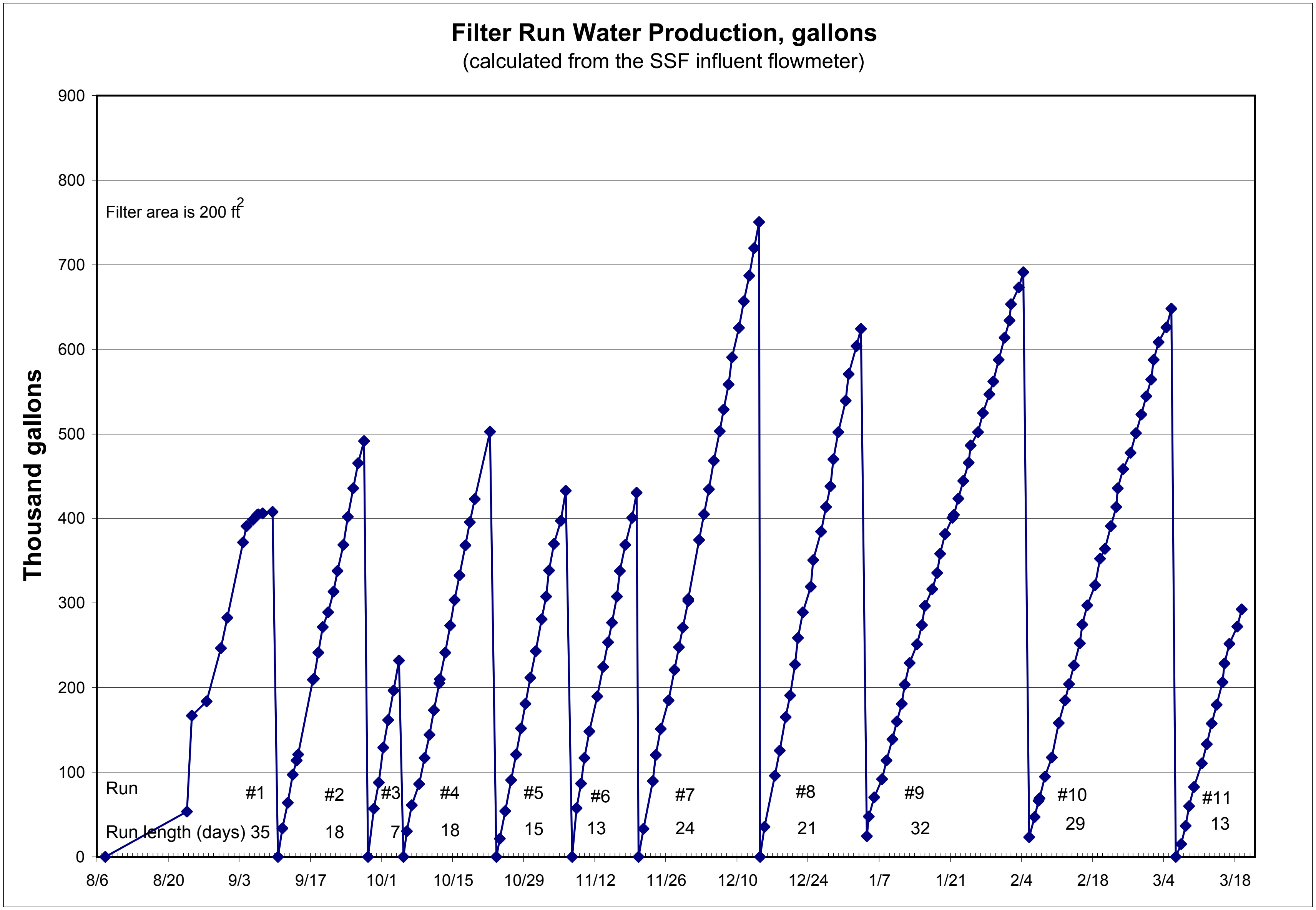


Figure B-1 of 37 - FilterRun-gal

SARWMS Slowsand - Reverse Osmosis 2001-2002

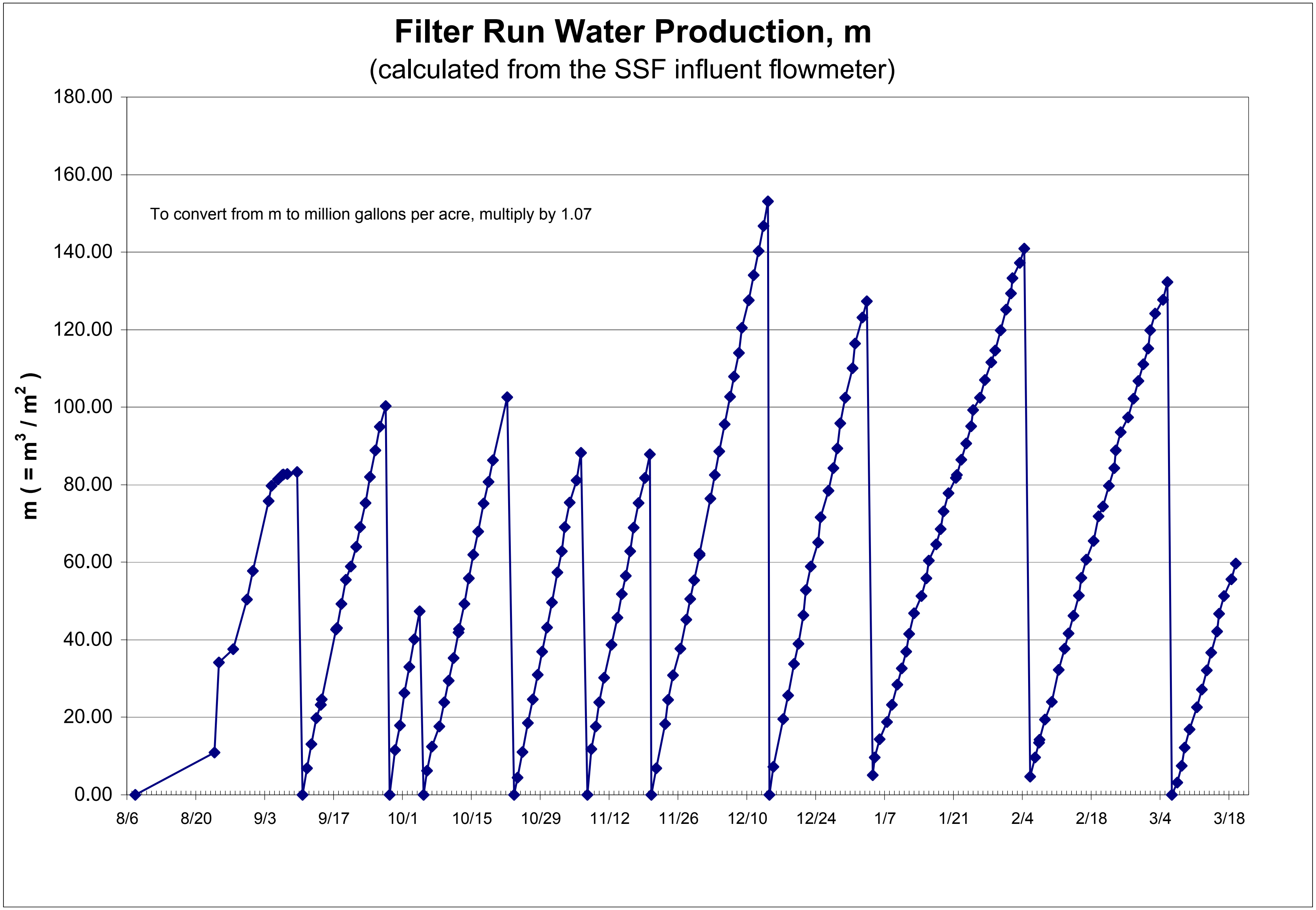


Figure B-2 of 37 - FilterRun-m

SARWMS Slowsand - Reverse Osmosis 2001-2002

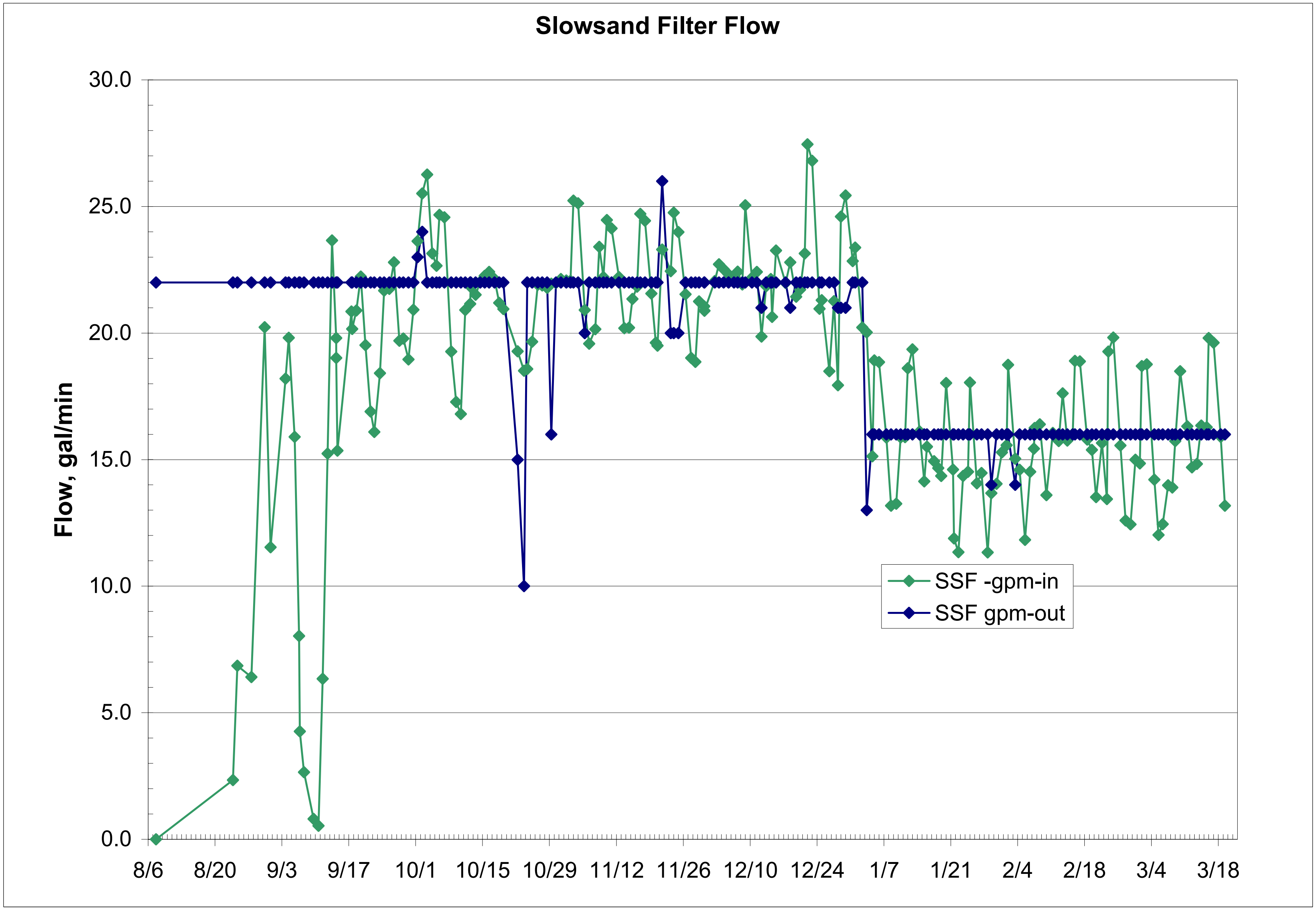


Figure B-3 of 37 - SSF-Flow

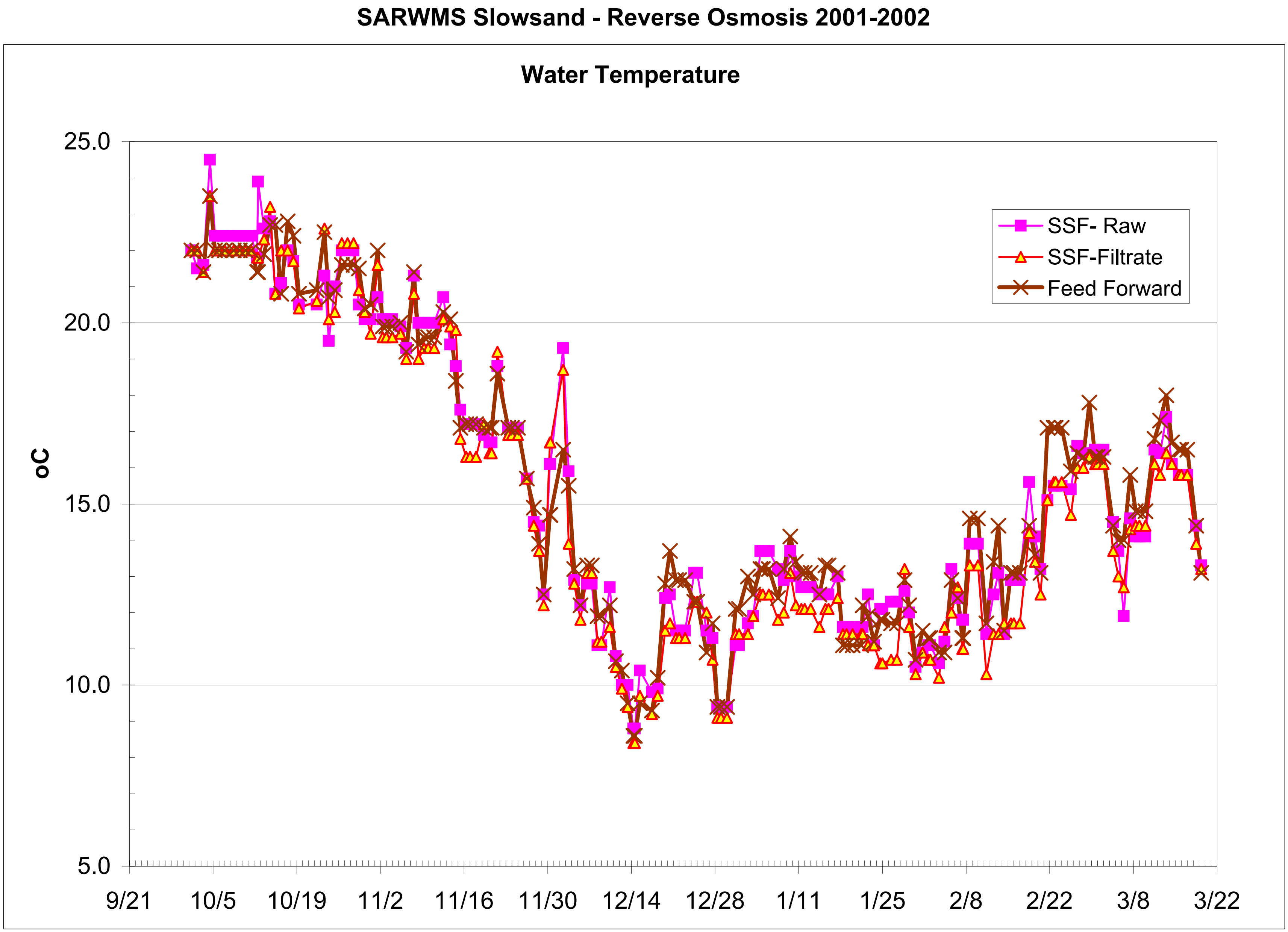


Figure B-4 of 37 - T

SARWMS Slowsand - Reverse Osmosis 2001-2002

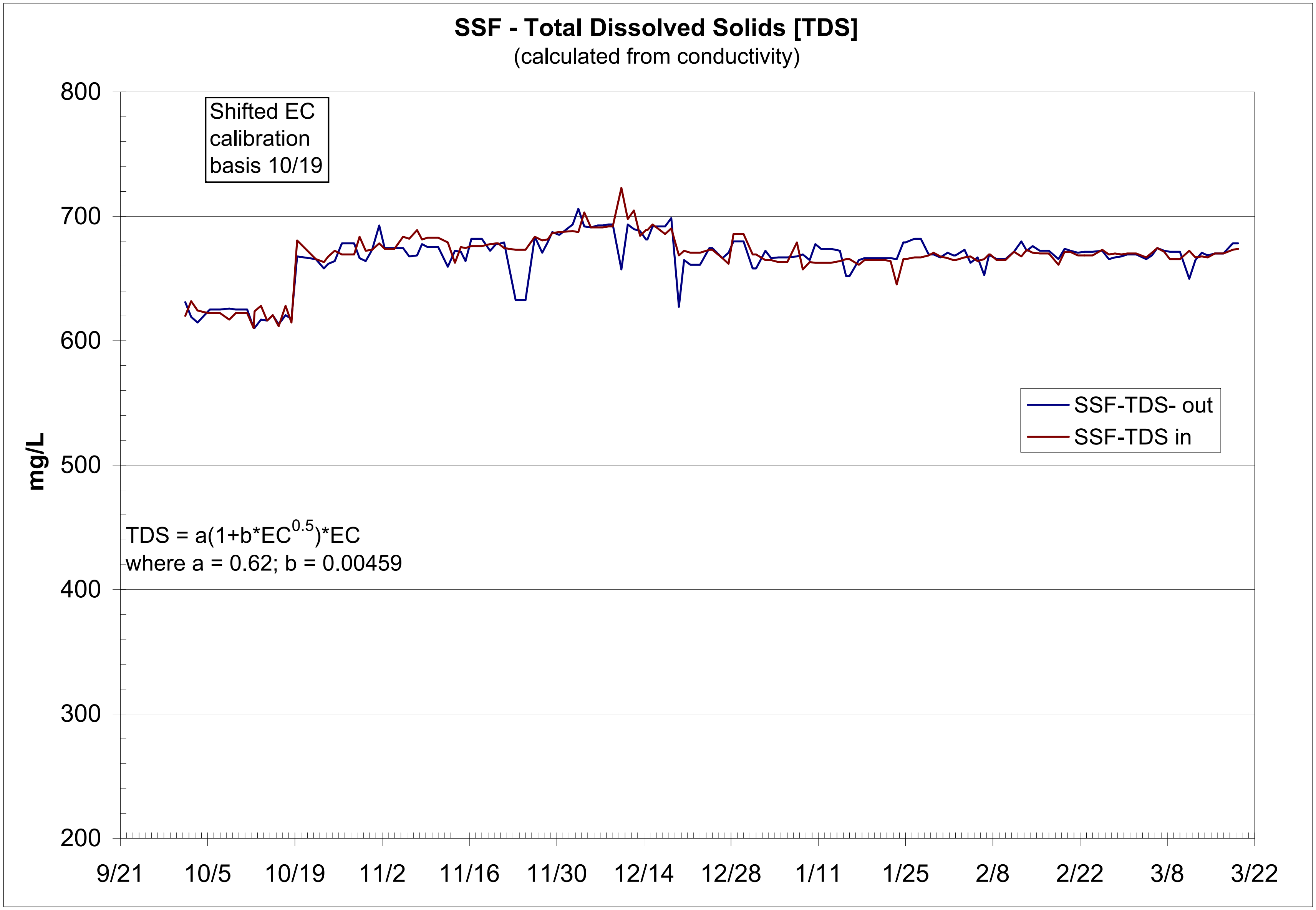


Figure B-5 of 37 - SSF-TDS

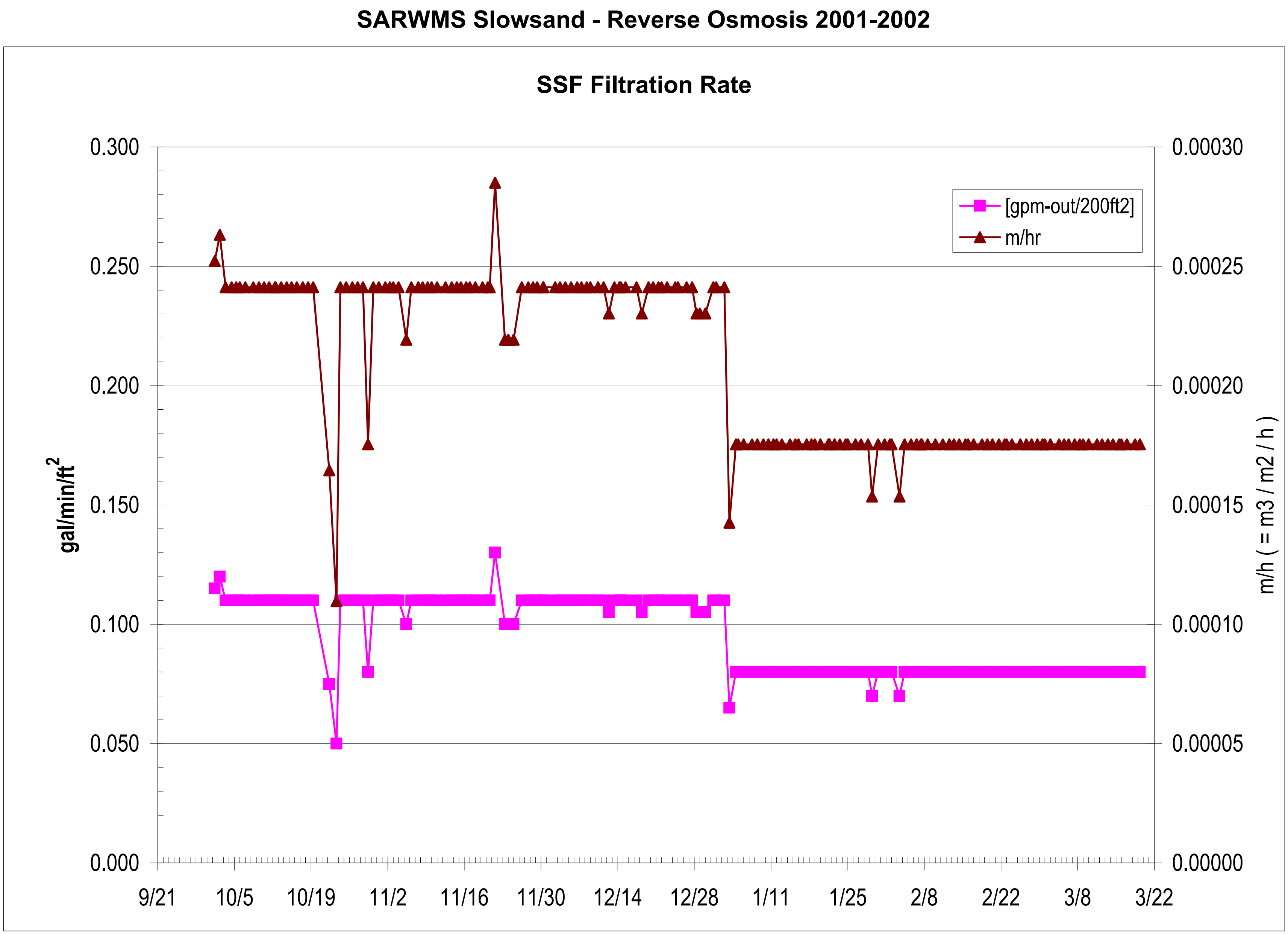


Figure B-6 of 37 - SSF-Flux

SARWMS Slowsand - Reverse Osmosis 2001-2002

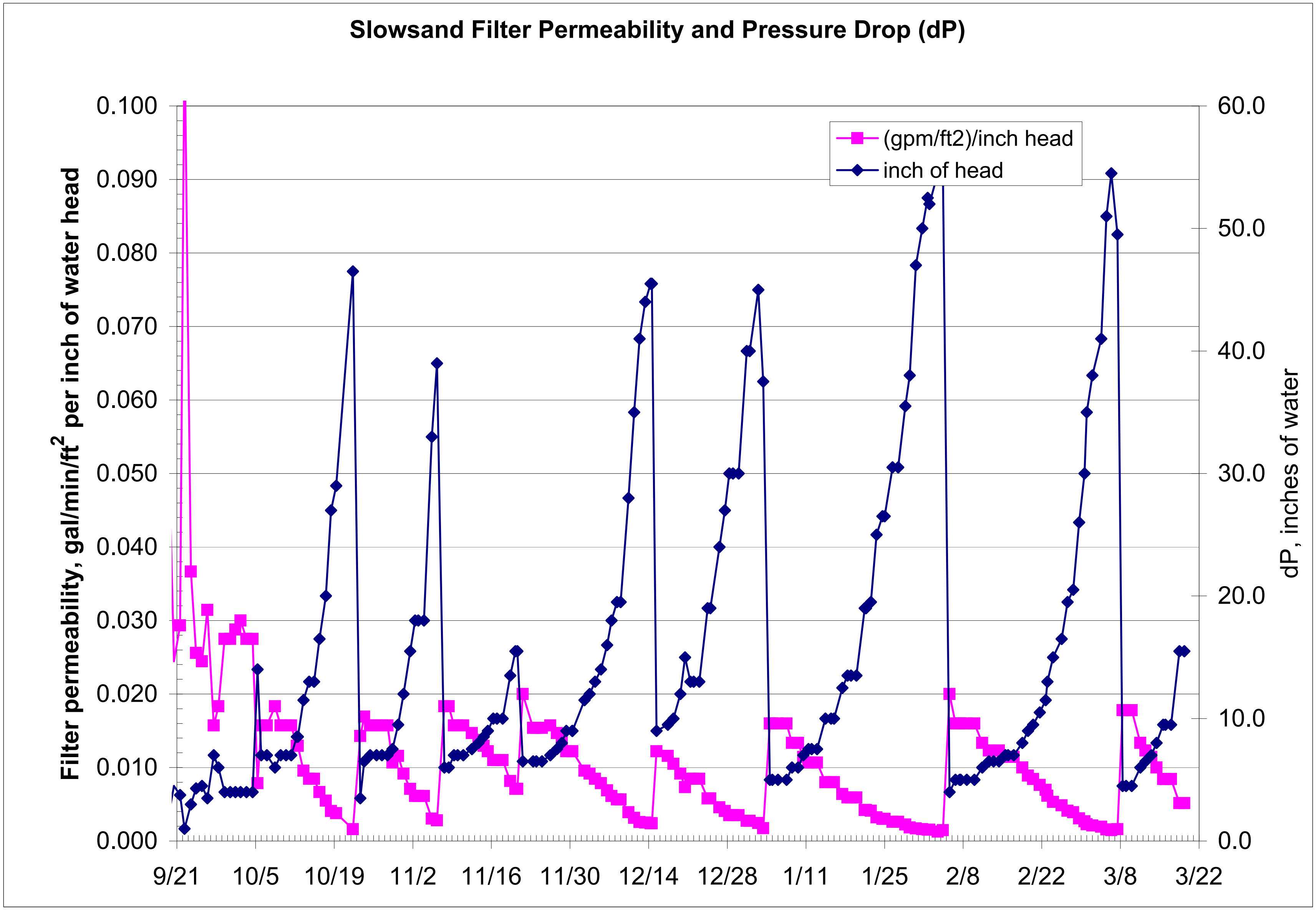


Figure B-7 of 37 - SSF-Perm&dP

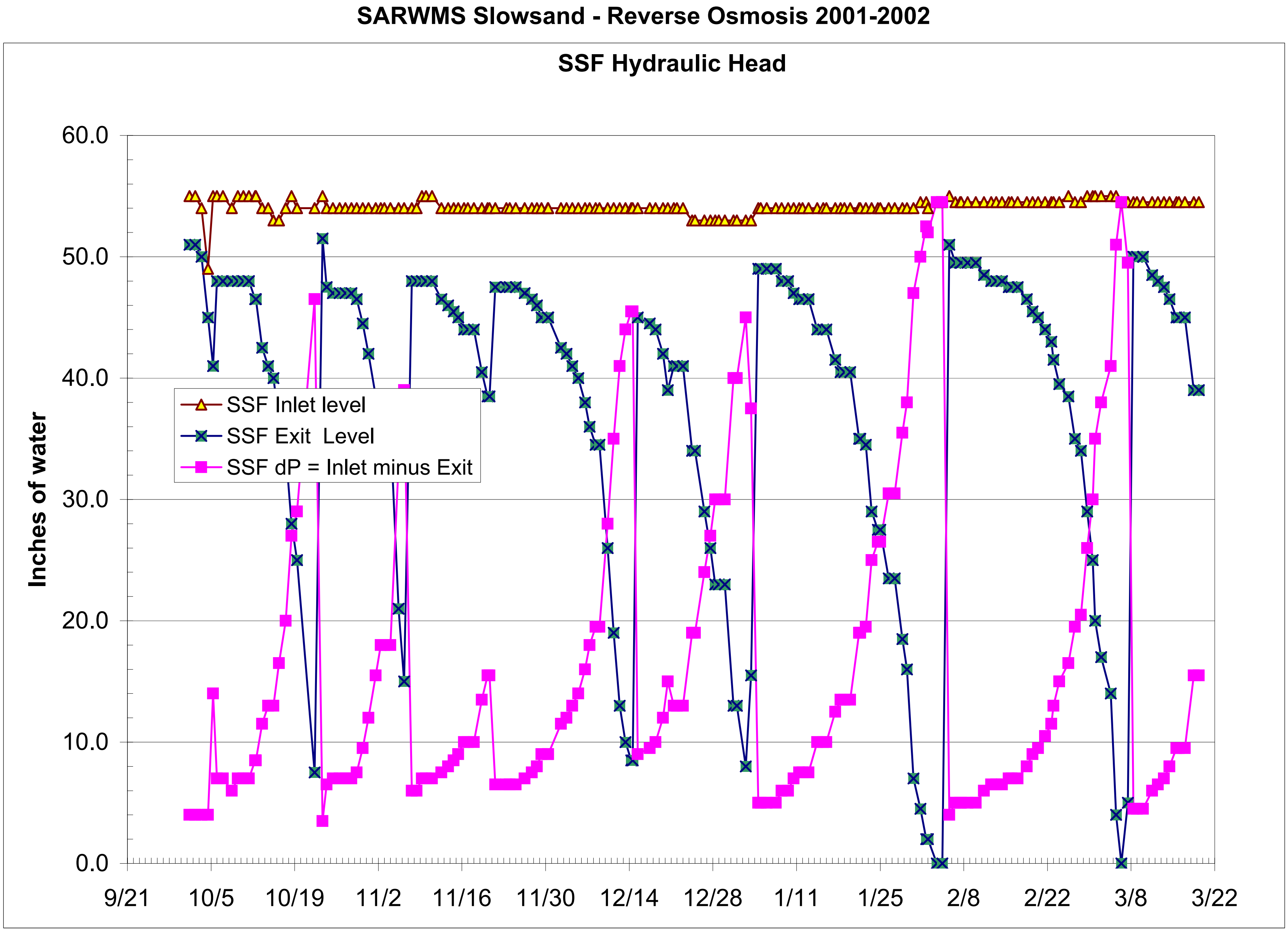


Figure B-8 of 37 - SSF-head

SARWMS Slowsand - Reverse Osmosis 2001-2002

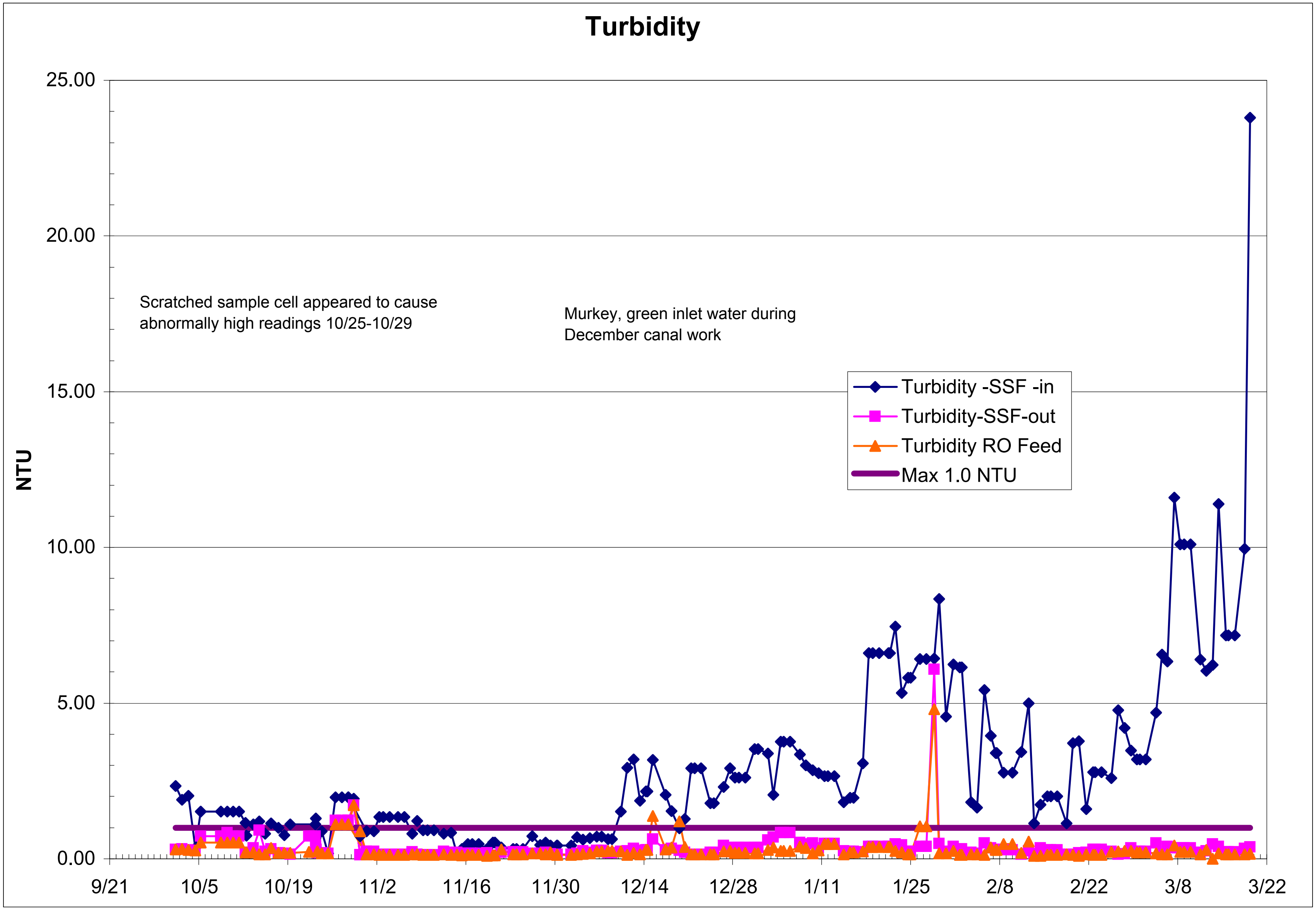


Figure B-9 of 37 - Turb

SARWMS Slowsand - Reverse Osmosis 2001-2002

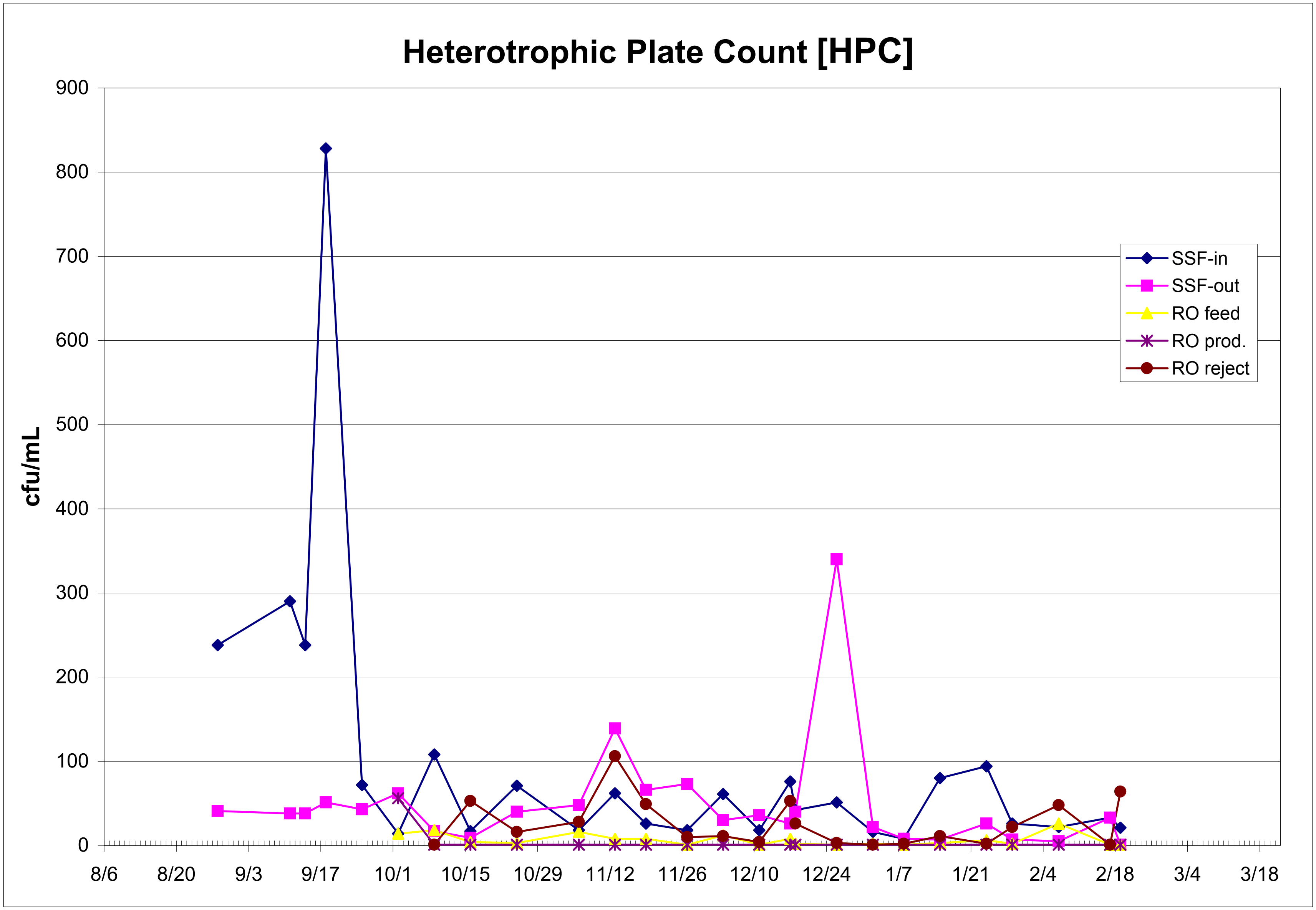


Figure B-10 of 37 - HPC

SARWMS Slowsand - Reverse Osmosis 2001-2002

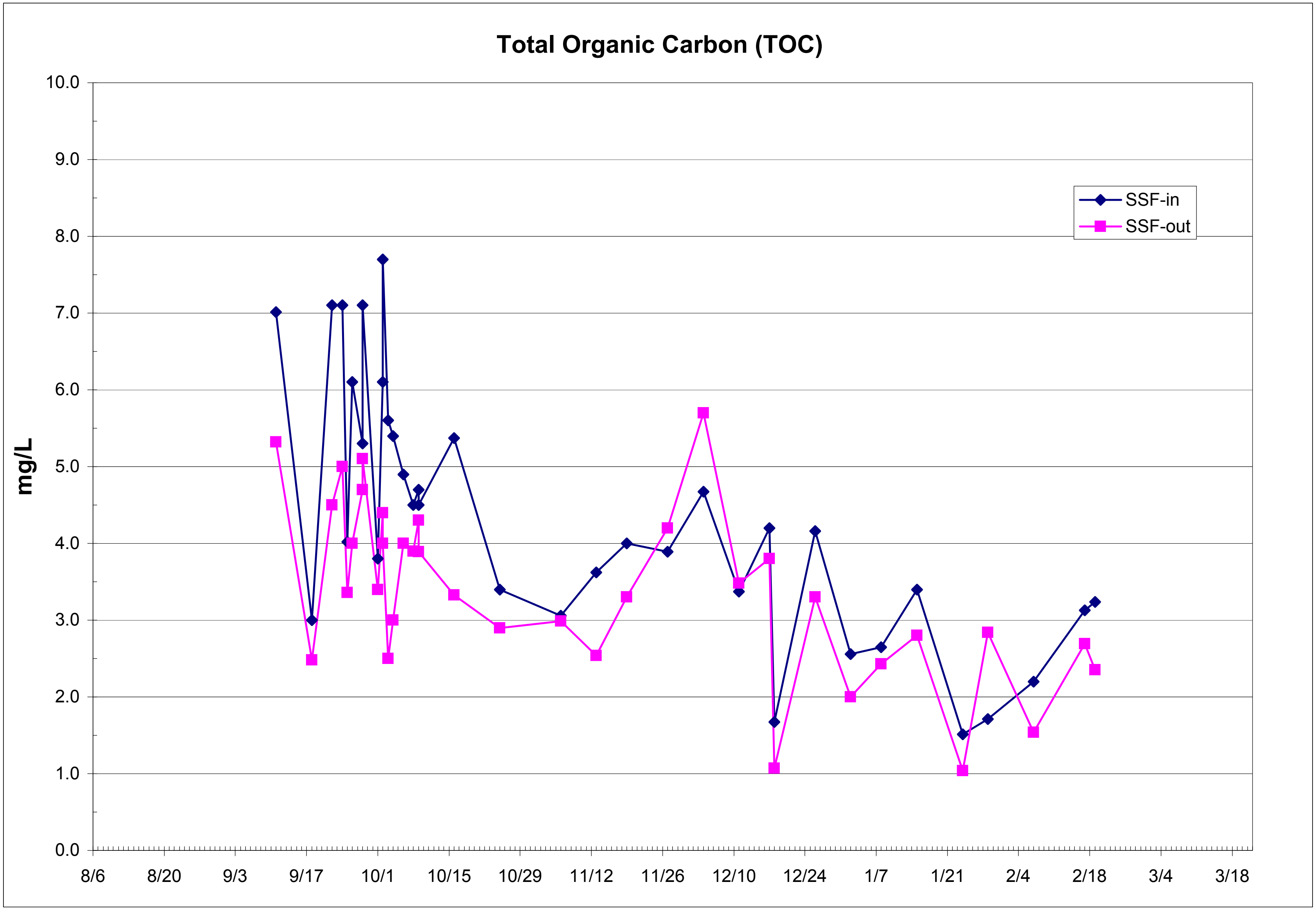


Figure B-11 of 37 - TOC

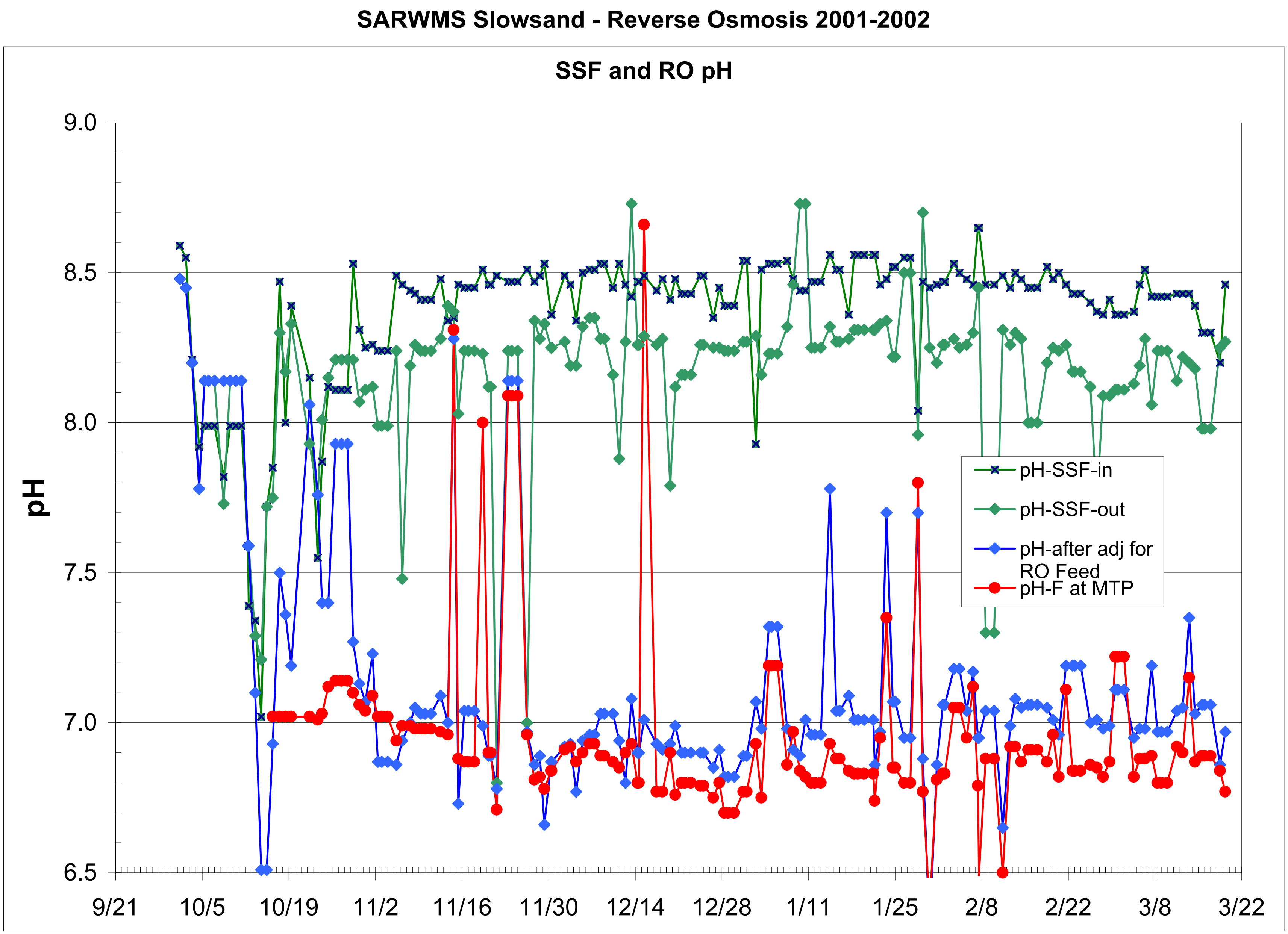


Figure B-12 of 37 - pH

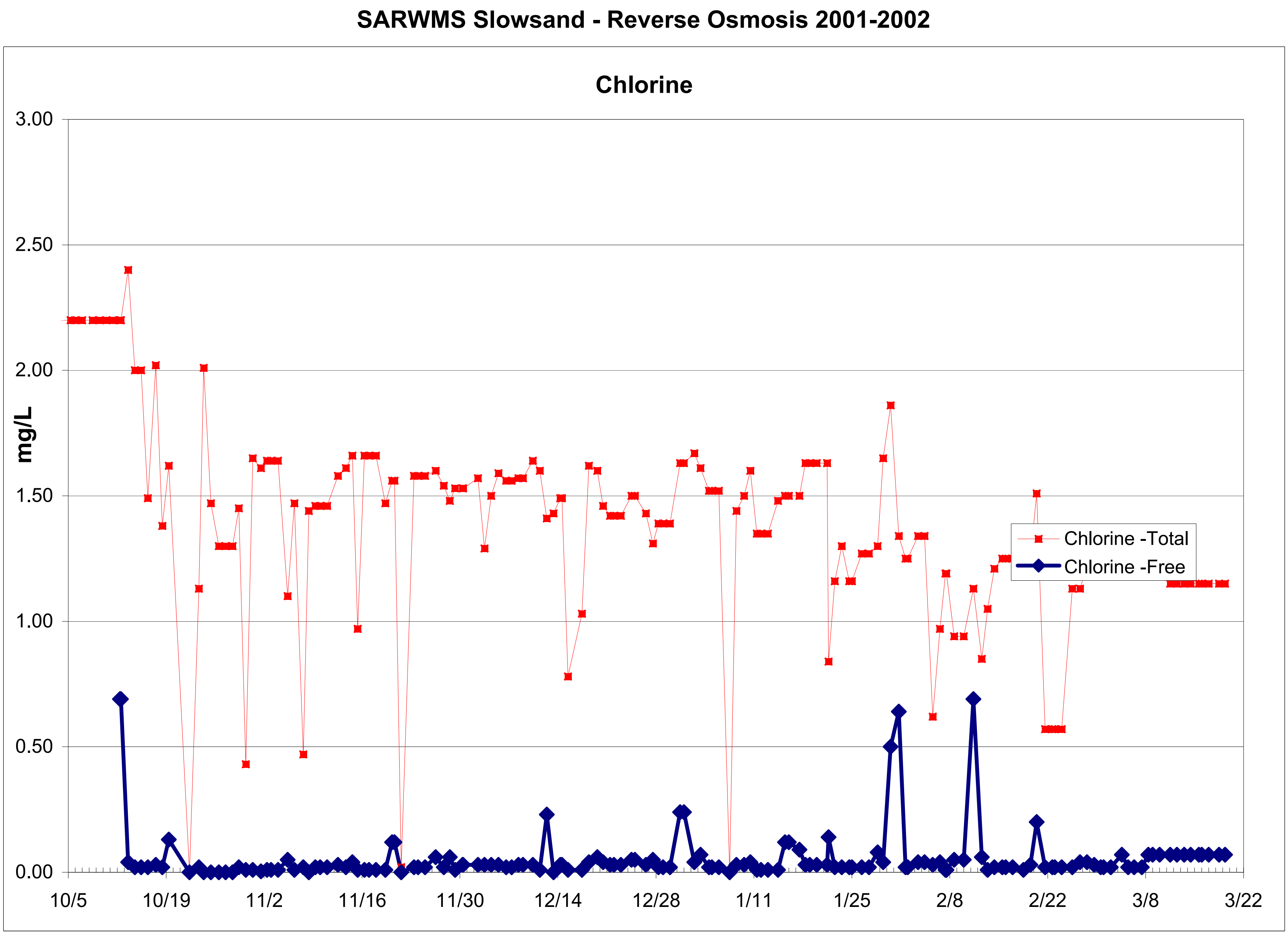


Figure B-13 of 37 - Cl2

SARWMS Slowsand - Reverse Osmosis 2001-2002

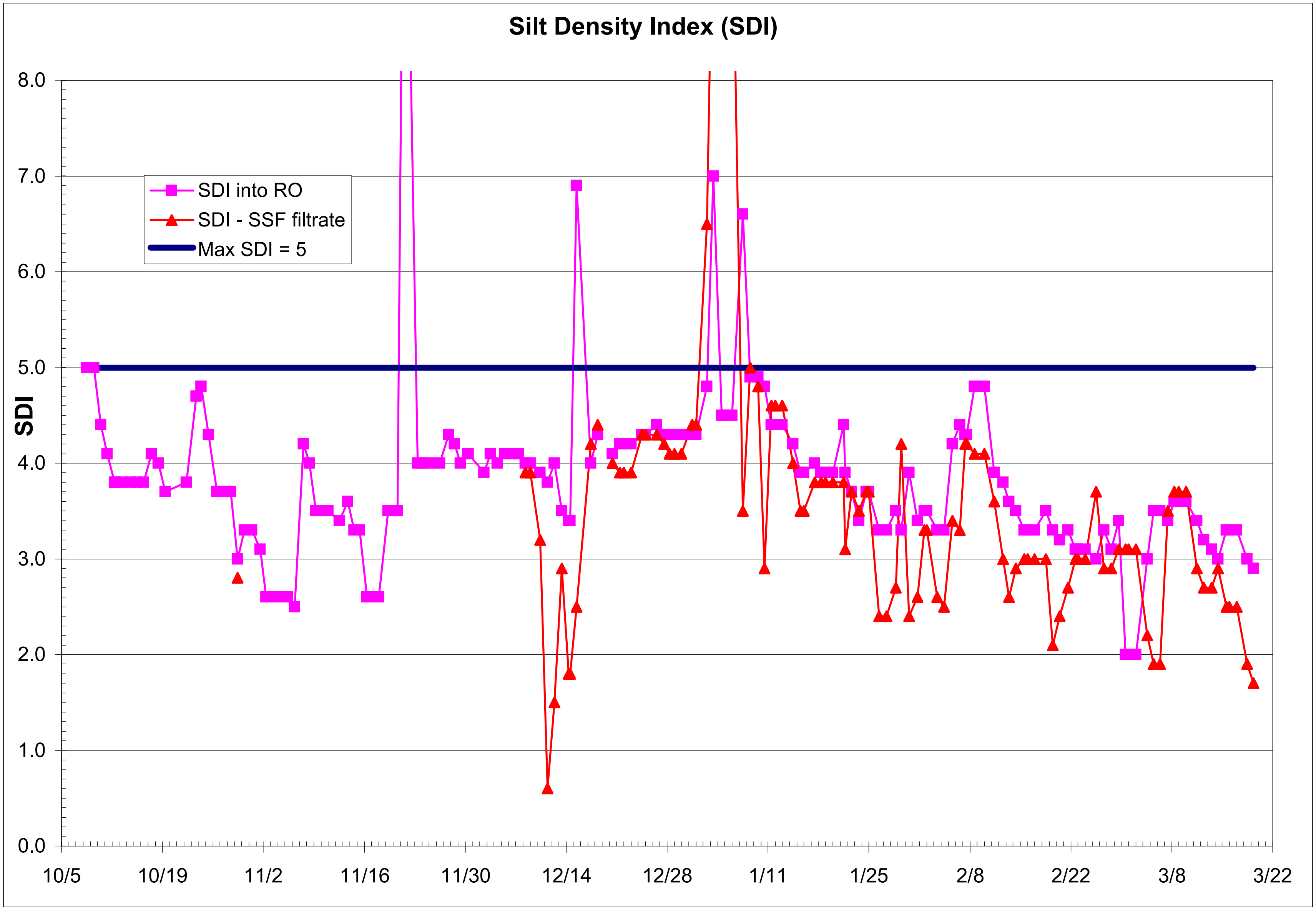


Figure B-14 of 37 - SDI

SARWMS Slowsand - Reverse Osmosis 2001-2002

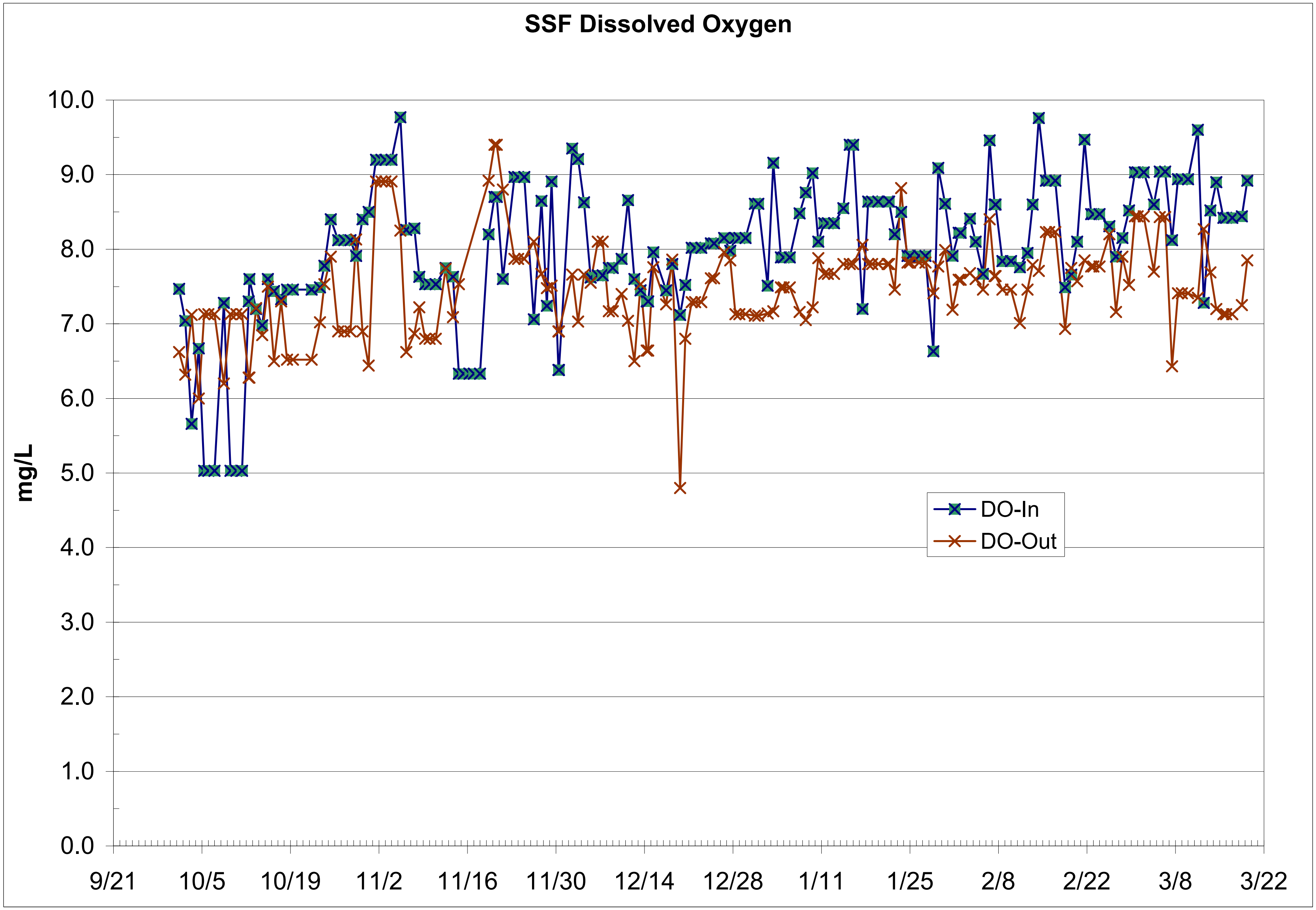


Figure B-15 of 37 - SSF-DO

SARWMS Slowsand - Reverse Osmosis 2001-2002

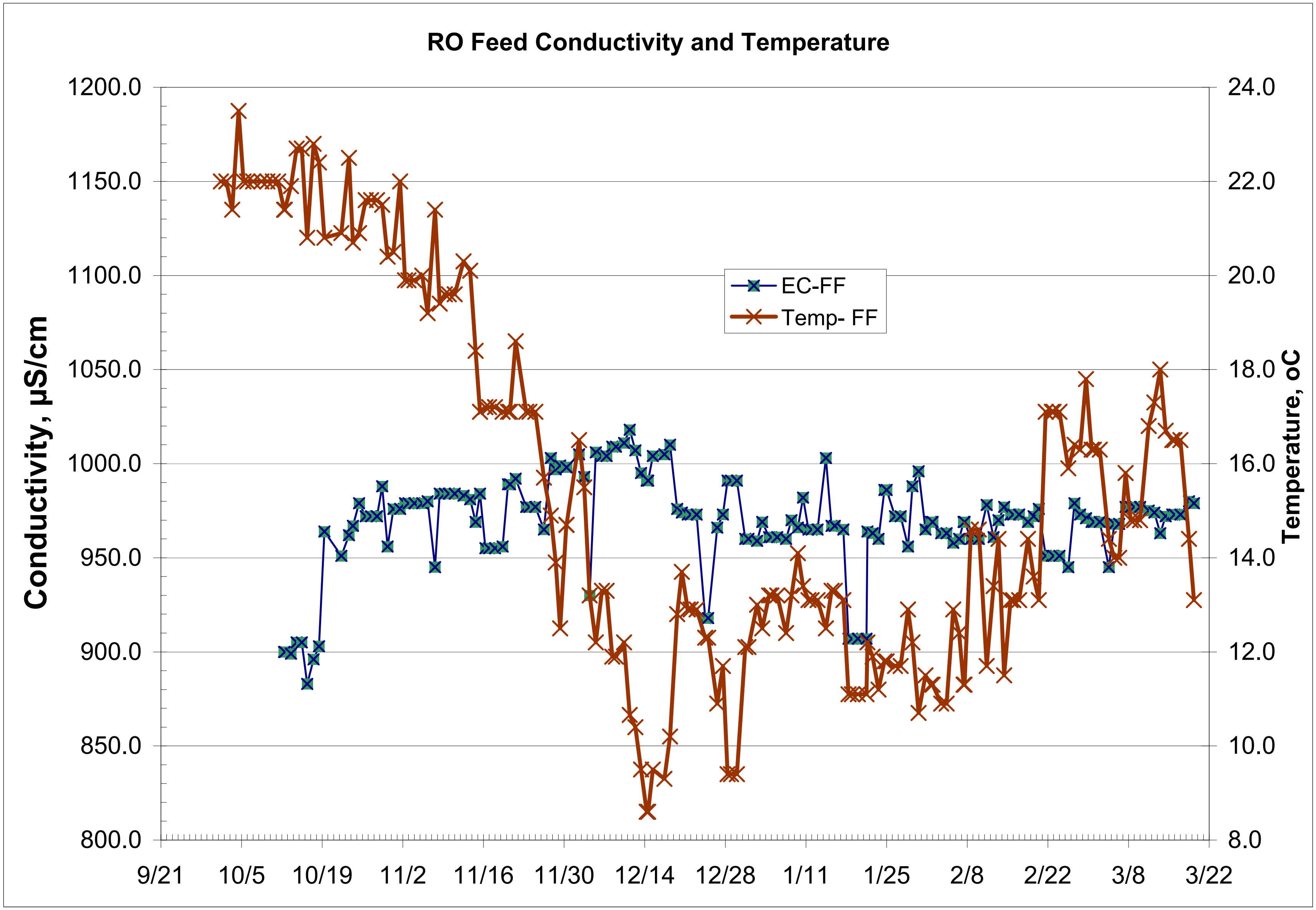


Figure B-16 of 37 - FF-EC,T

SARWMS Slowsand - Reverse Osmosis 2001-2002

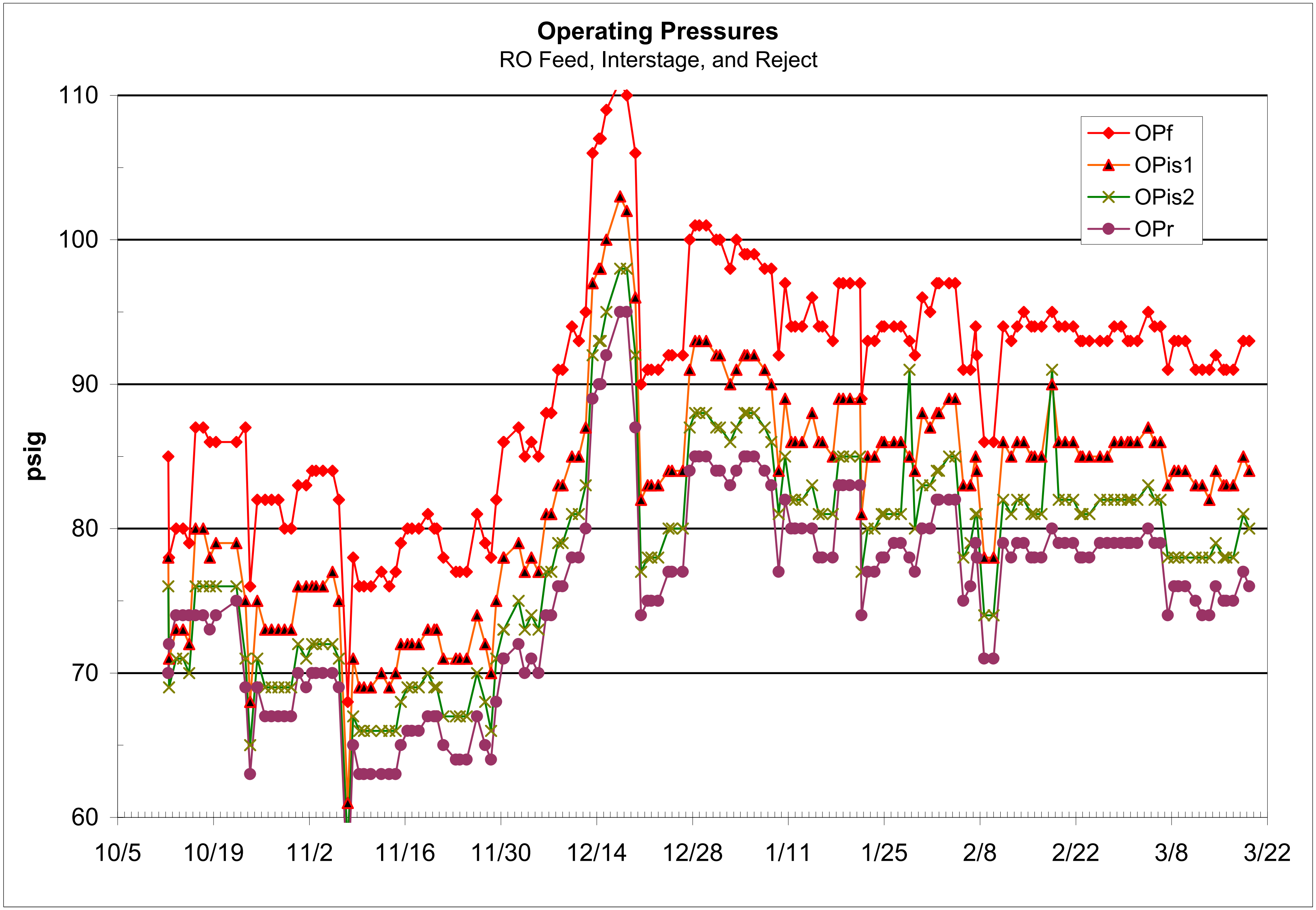


Figure B-17 of 37 - OP-1

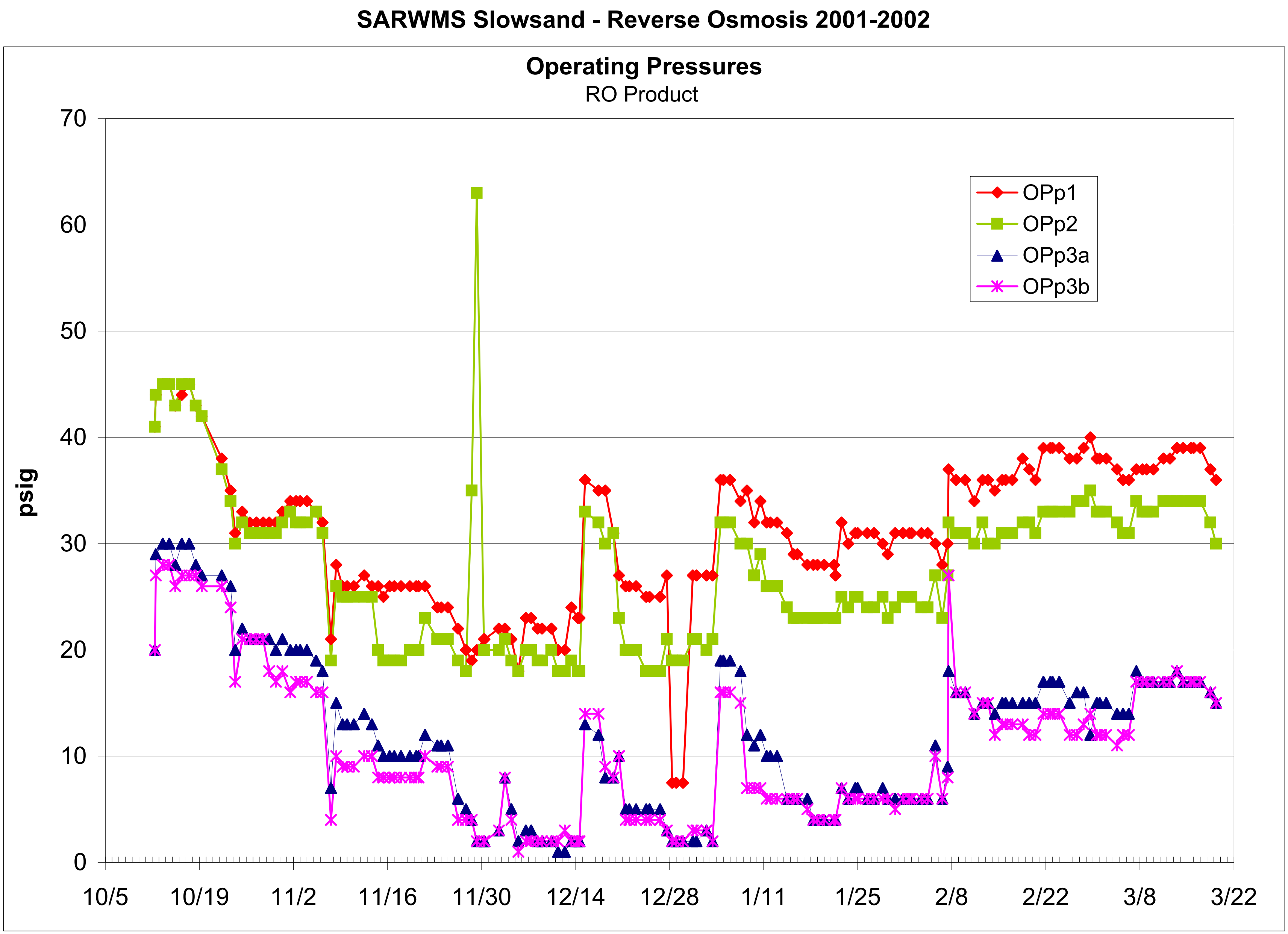


Figure B-18 of 37 - OP-2

SARWMS Slowsand - Reverse Osmosis 2001-2002

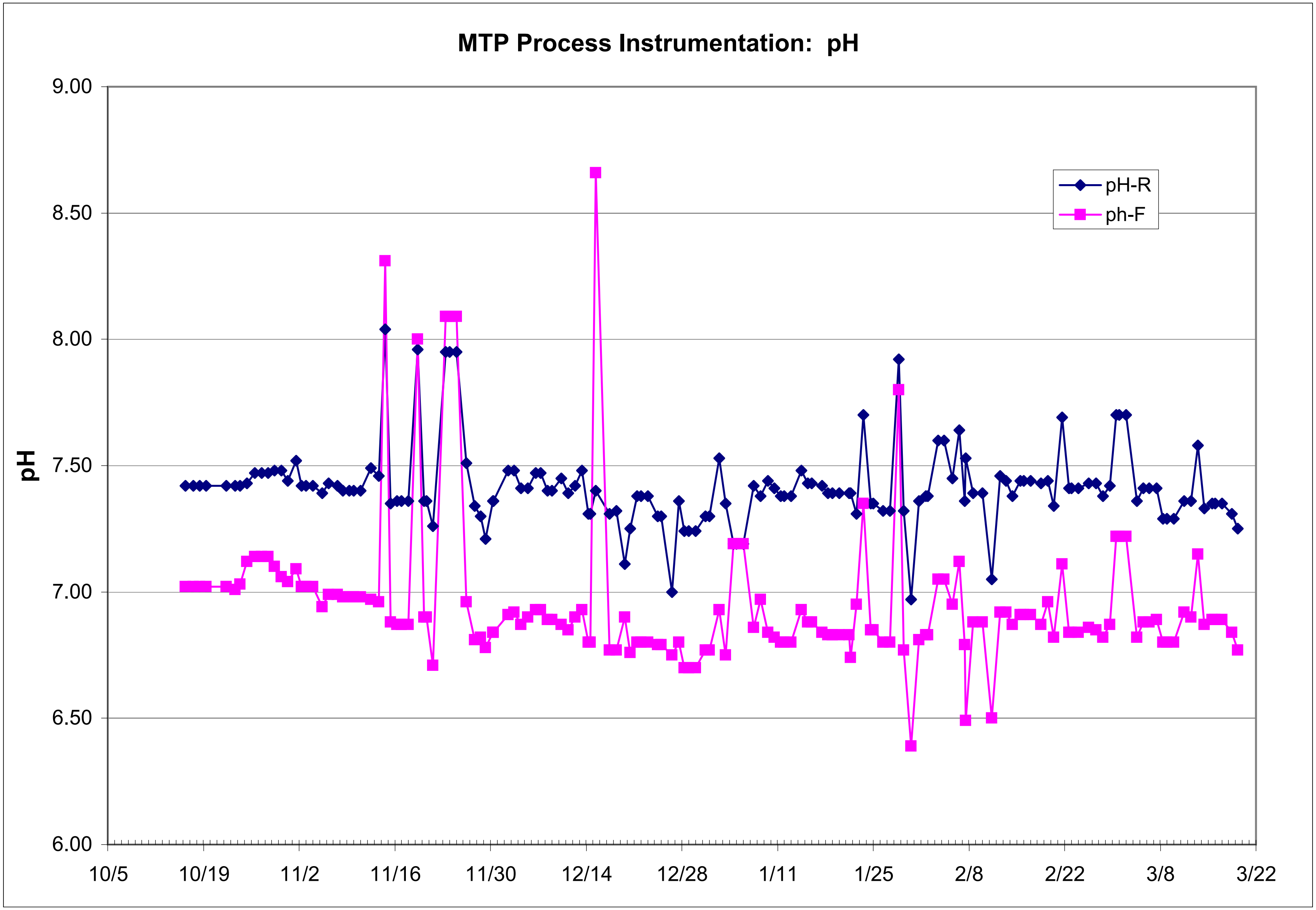


Figure B-19 of 37 - MTP-pH

SARWMS Slowsand - Reverse Osmosis 2001-2002

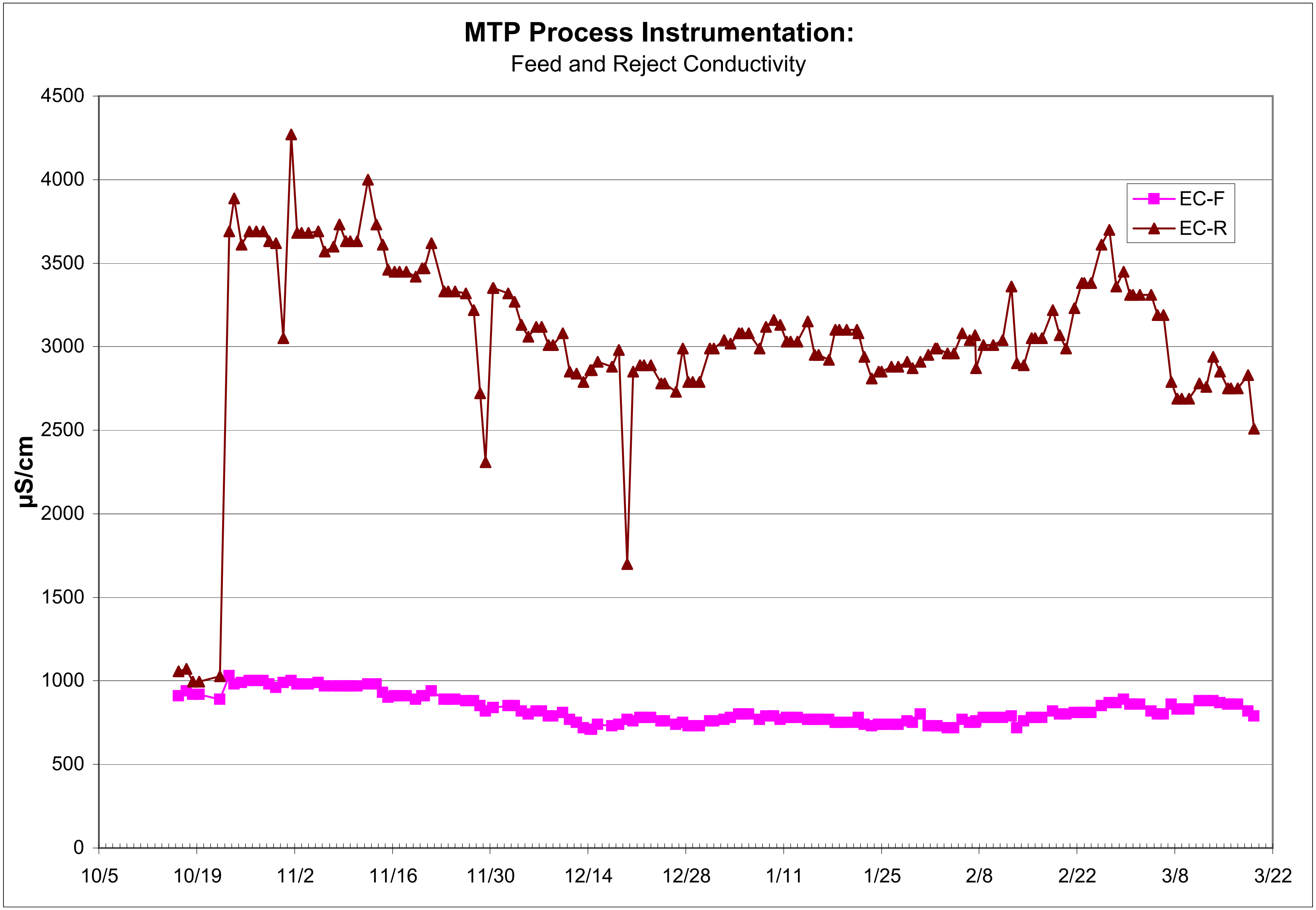


Figure B-20 of 37 - MTP-EC F,R

SARWMS Slowsand - Reverse Osmosis 2001-2002

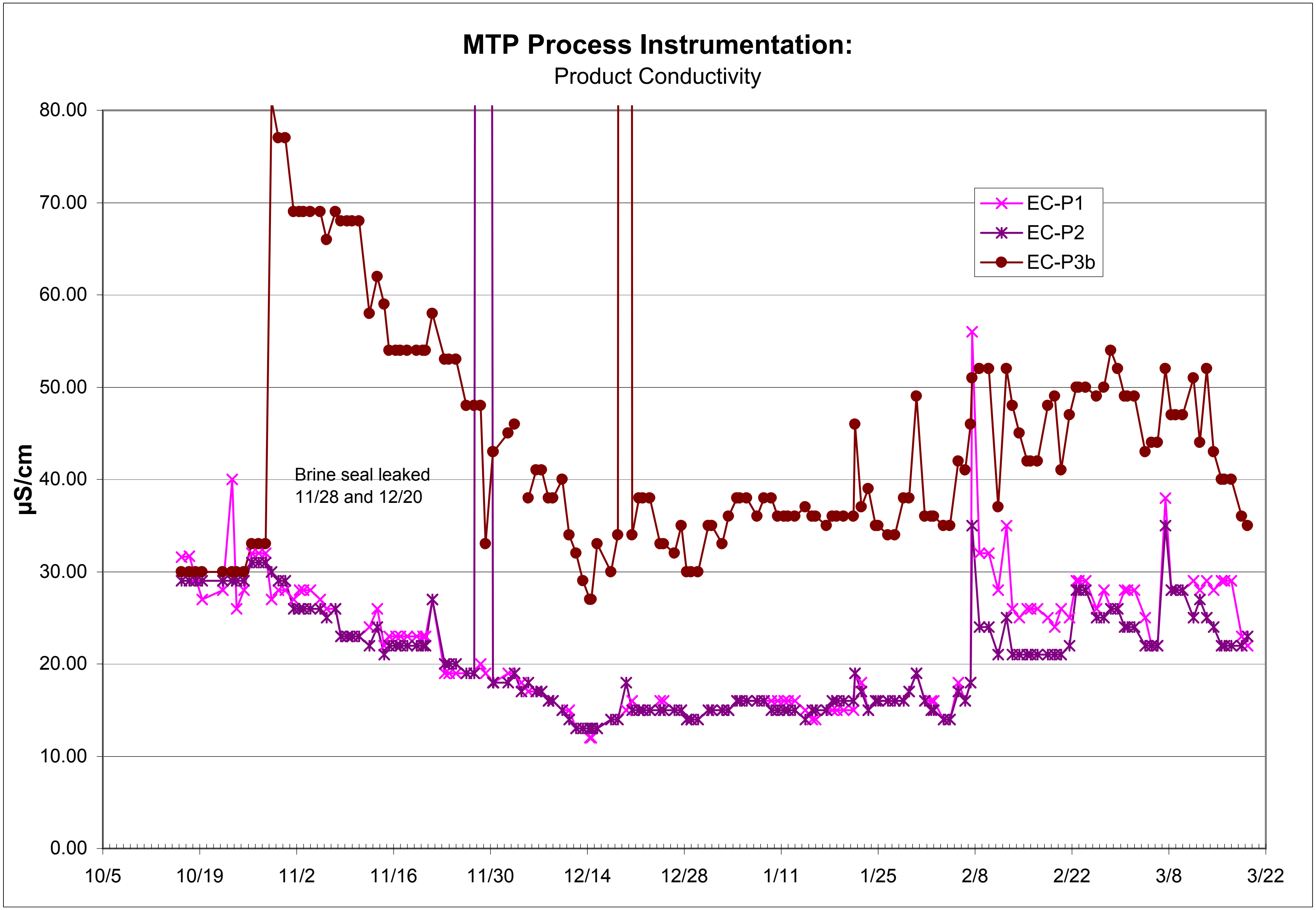


Figure B-21 of 37 - MTP-EC P

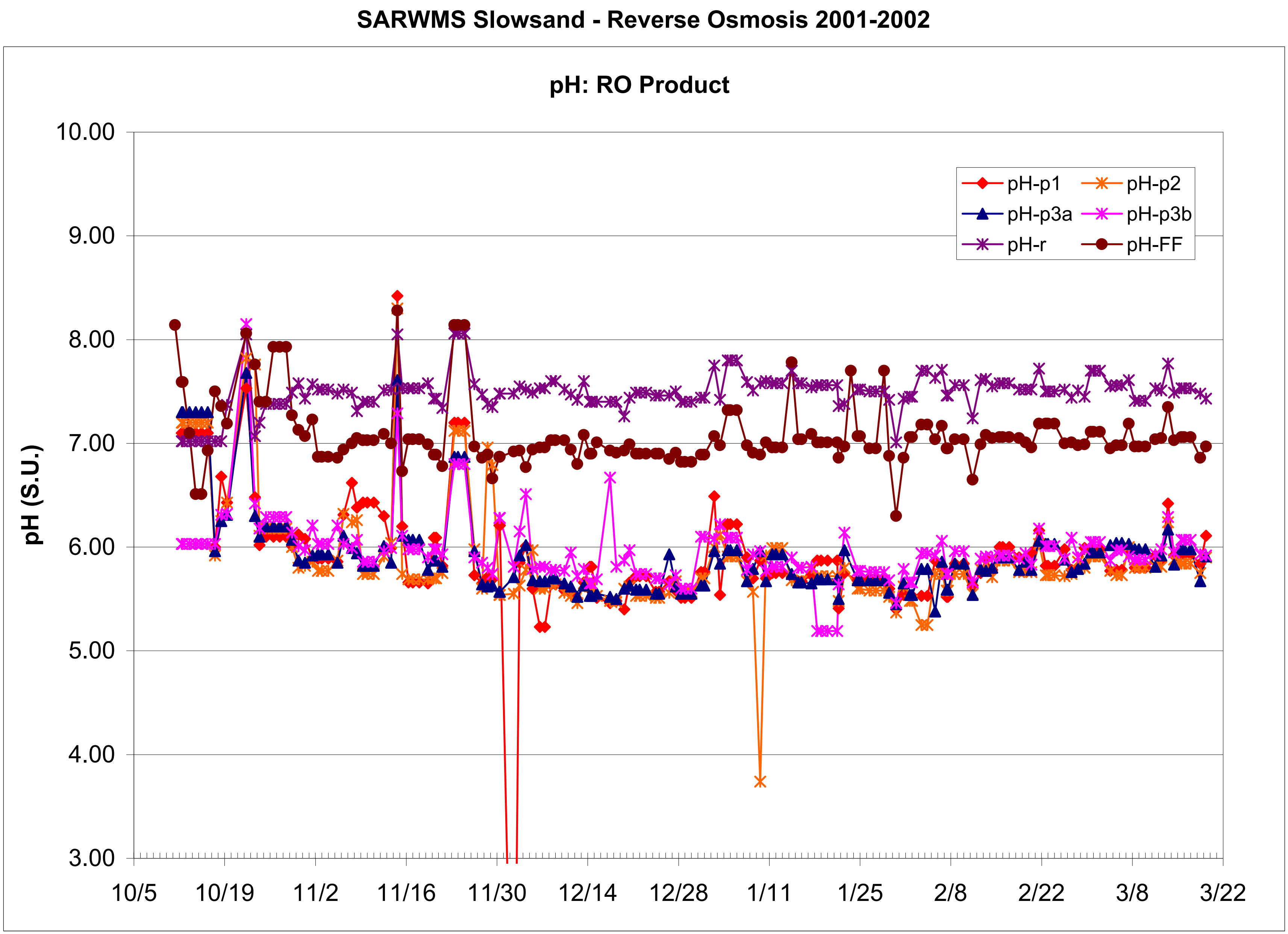


Figure B-22 of 37 - pH-p

SARWMS Slowsand - Reverse Osmosis 2001-2002

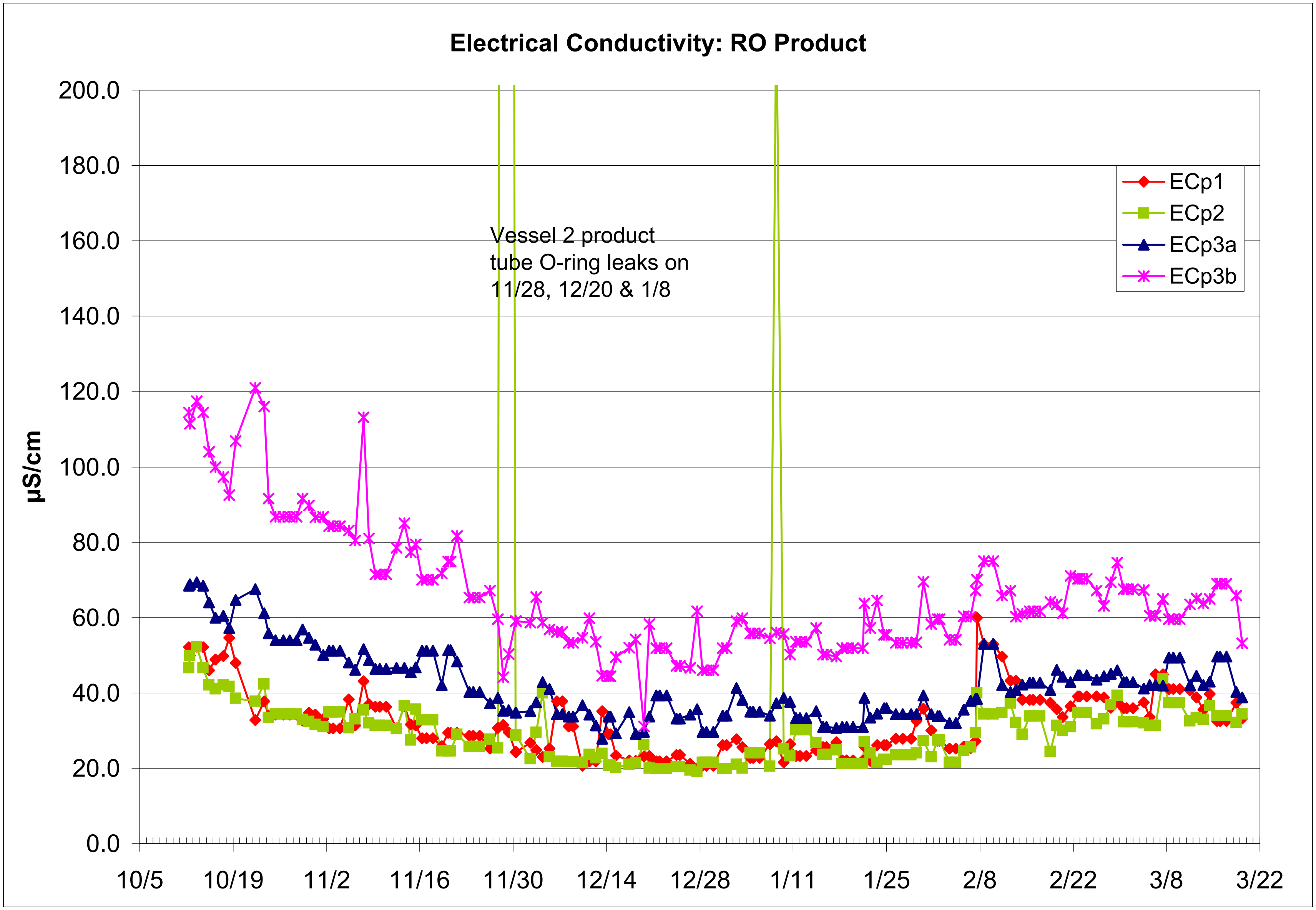


Figure B-23 of 37 - EC-p

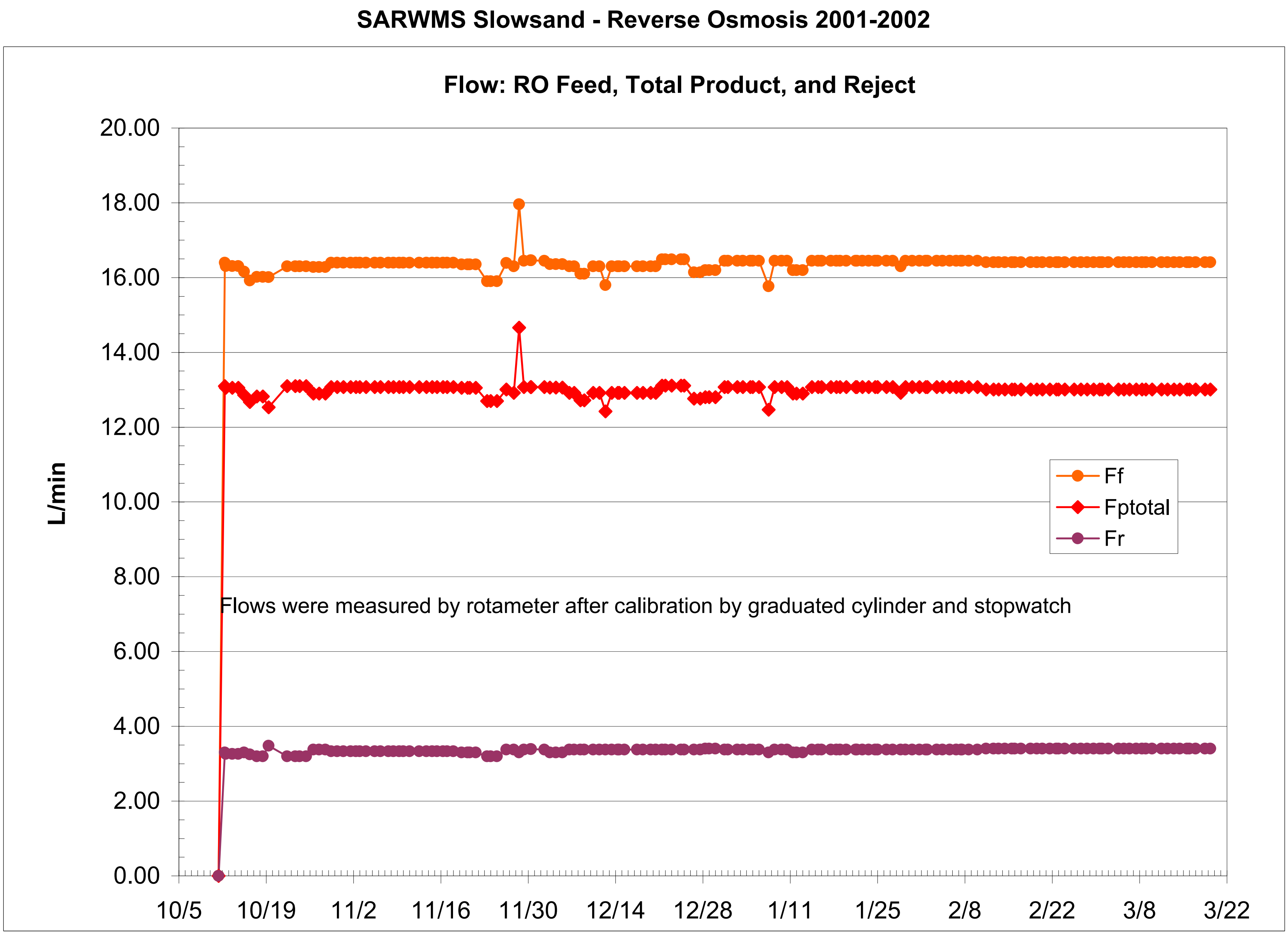


Figure B-24 of 37 - RO flow

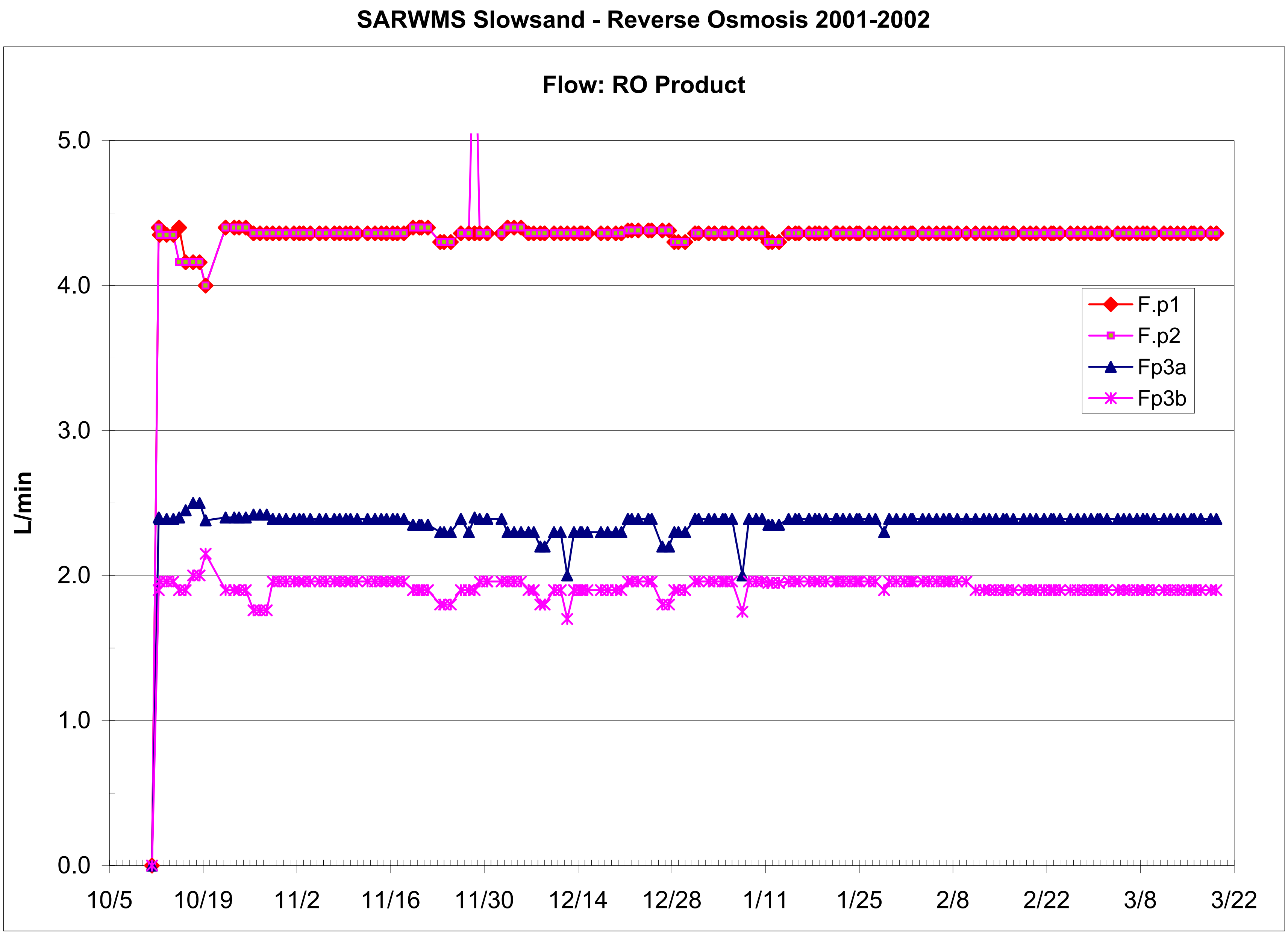


Figure B-25 of 37 - RO prod Flow

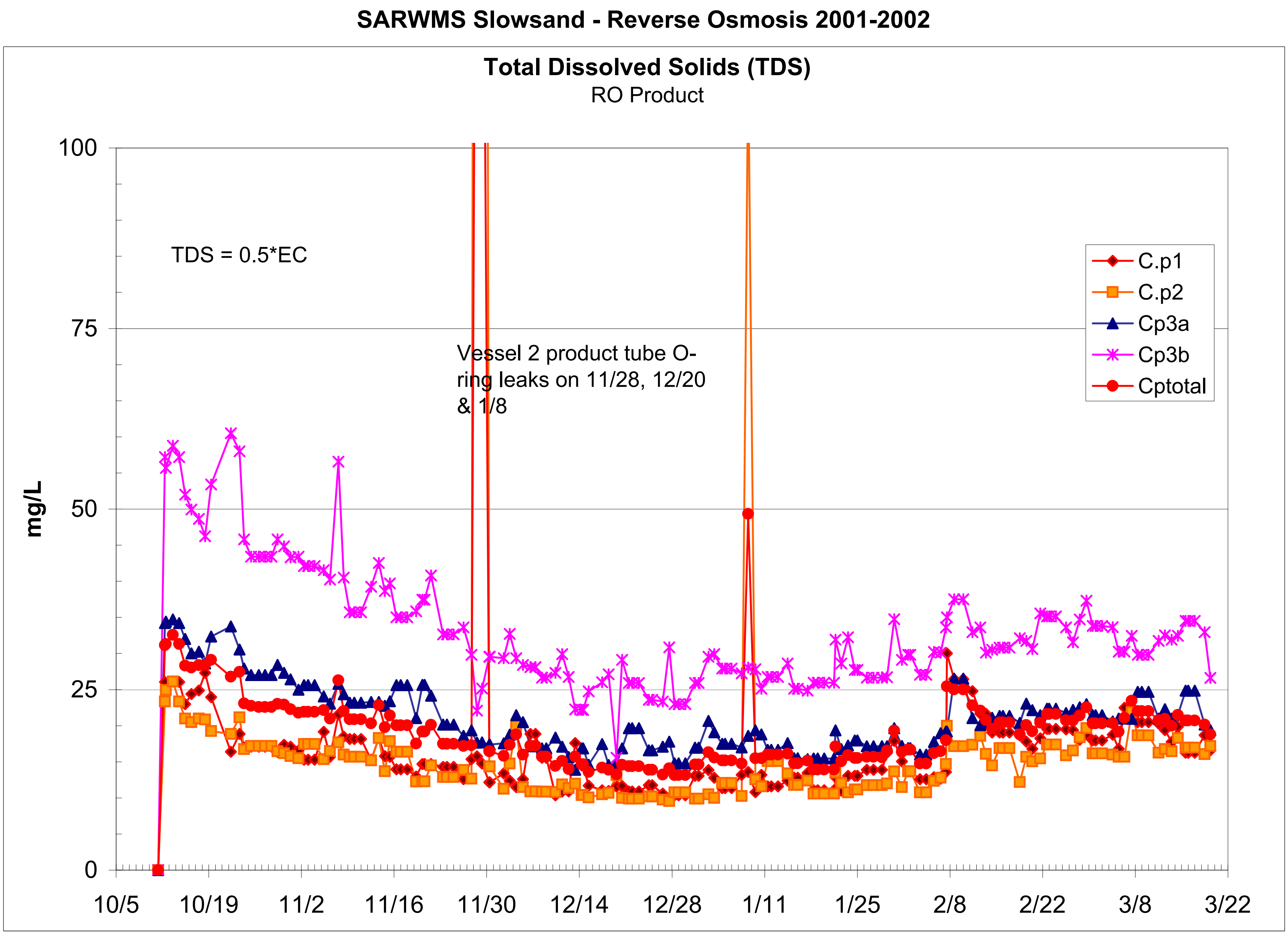


Figure B-26 of 37 - TDS - Product

SARWMS Slowsand - Reverse Osmosis 2001-2002

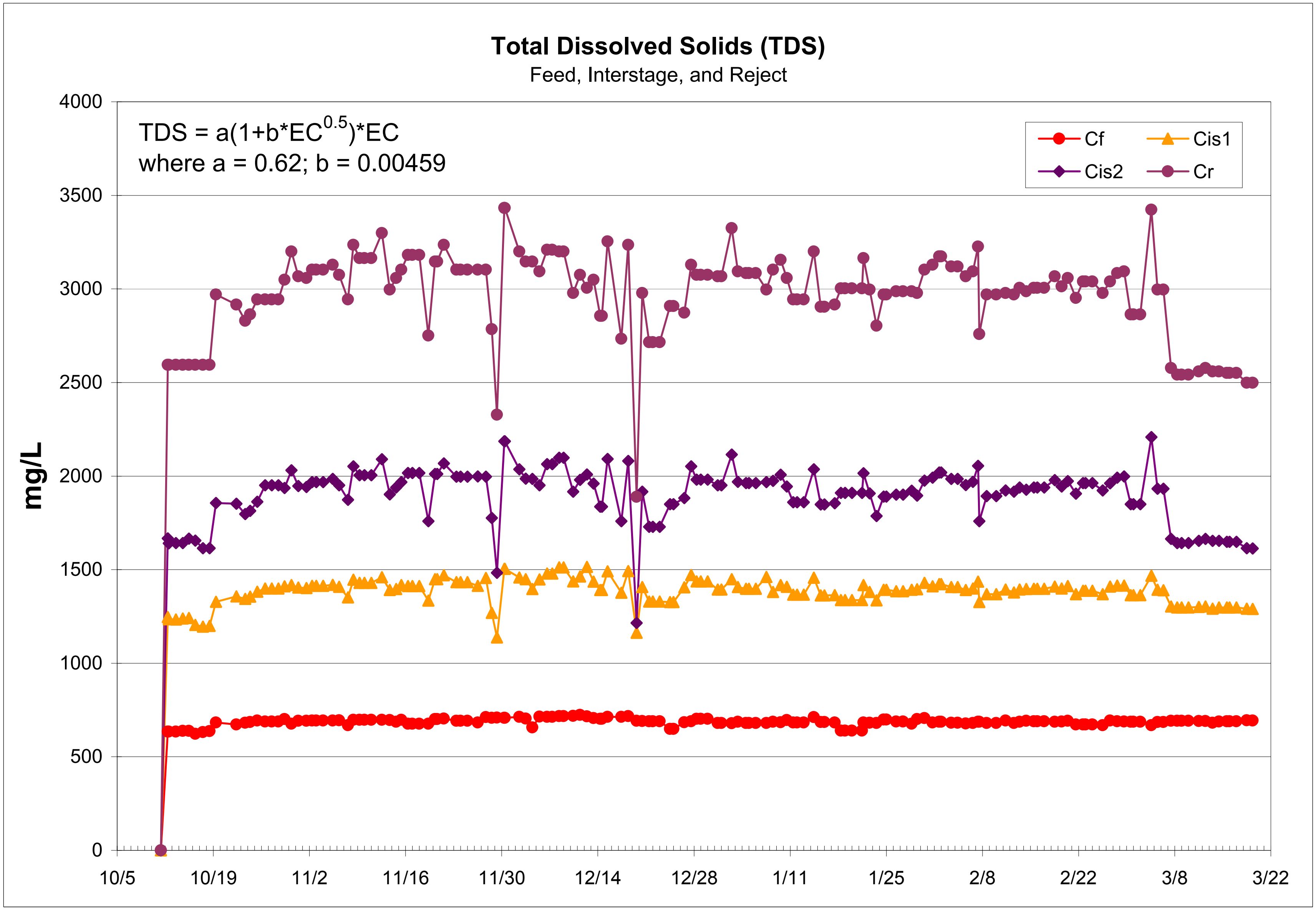


Figure B-27 of 37 - TDS-Conc

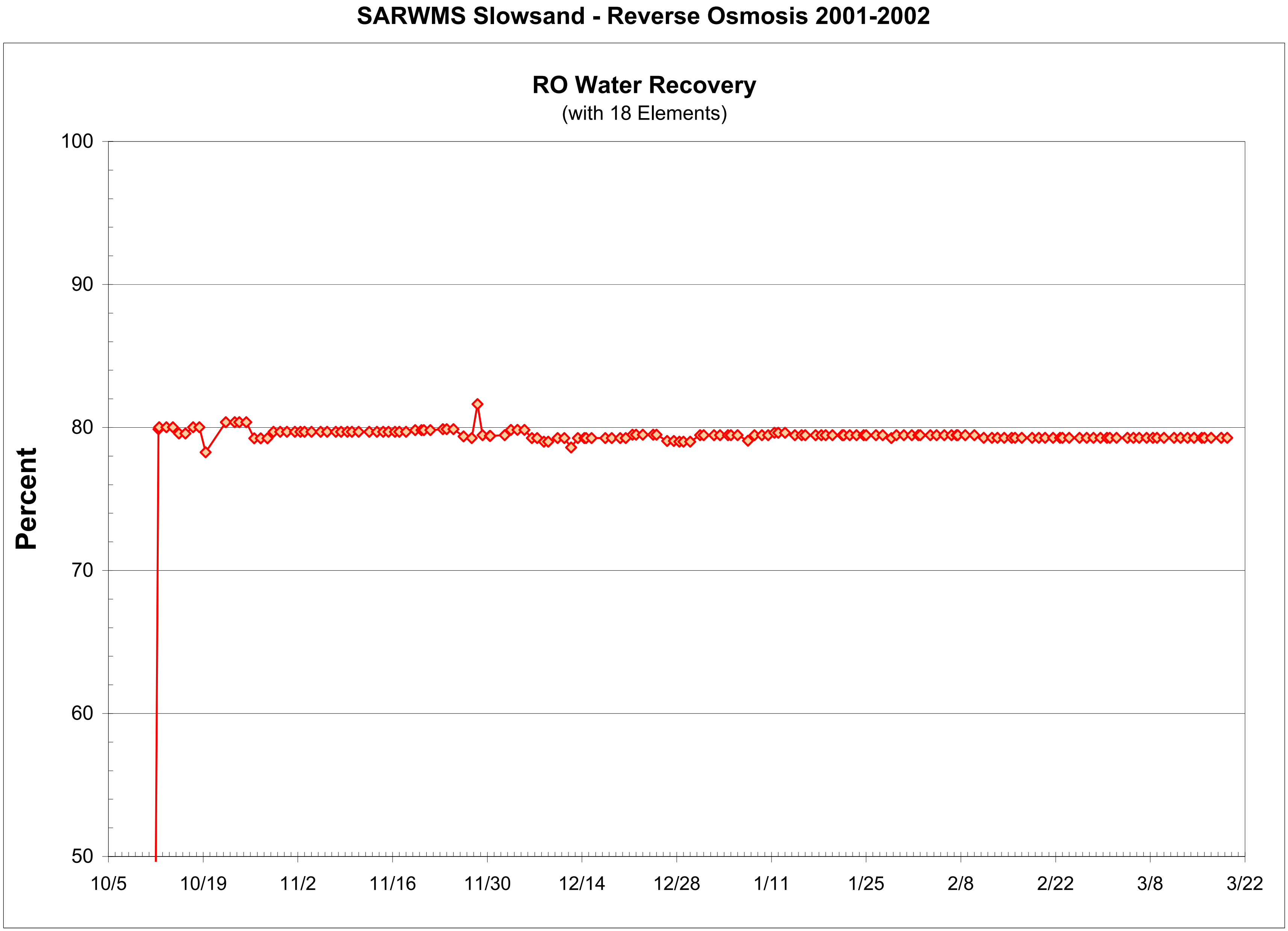


Figure B-28 of 37 - Recovery

SARWMS Slowsand - Reverse Osmosis 2001-2002

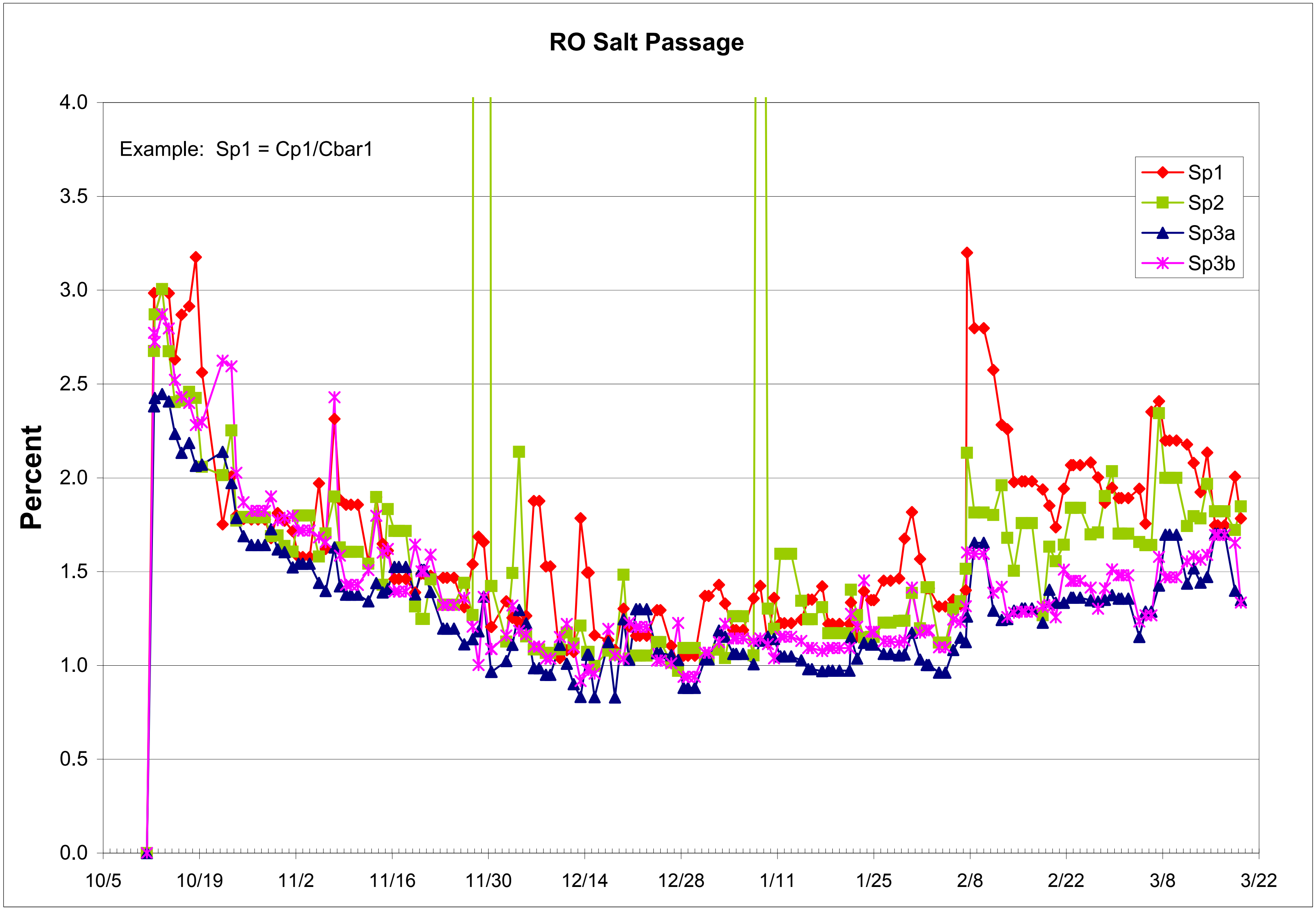


Figure B-29 of 37 - Salt Pass

SARWMS Slowsand - Reverse Osmosis 2001-2002

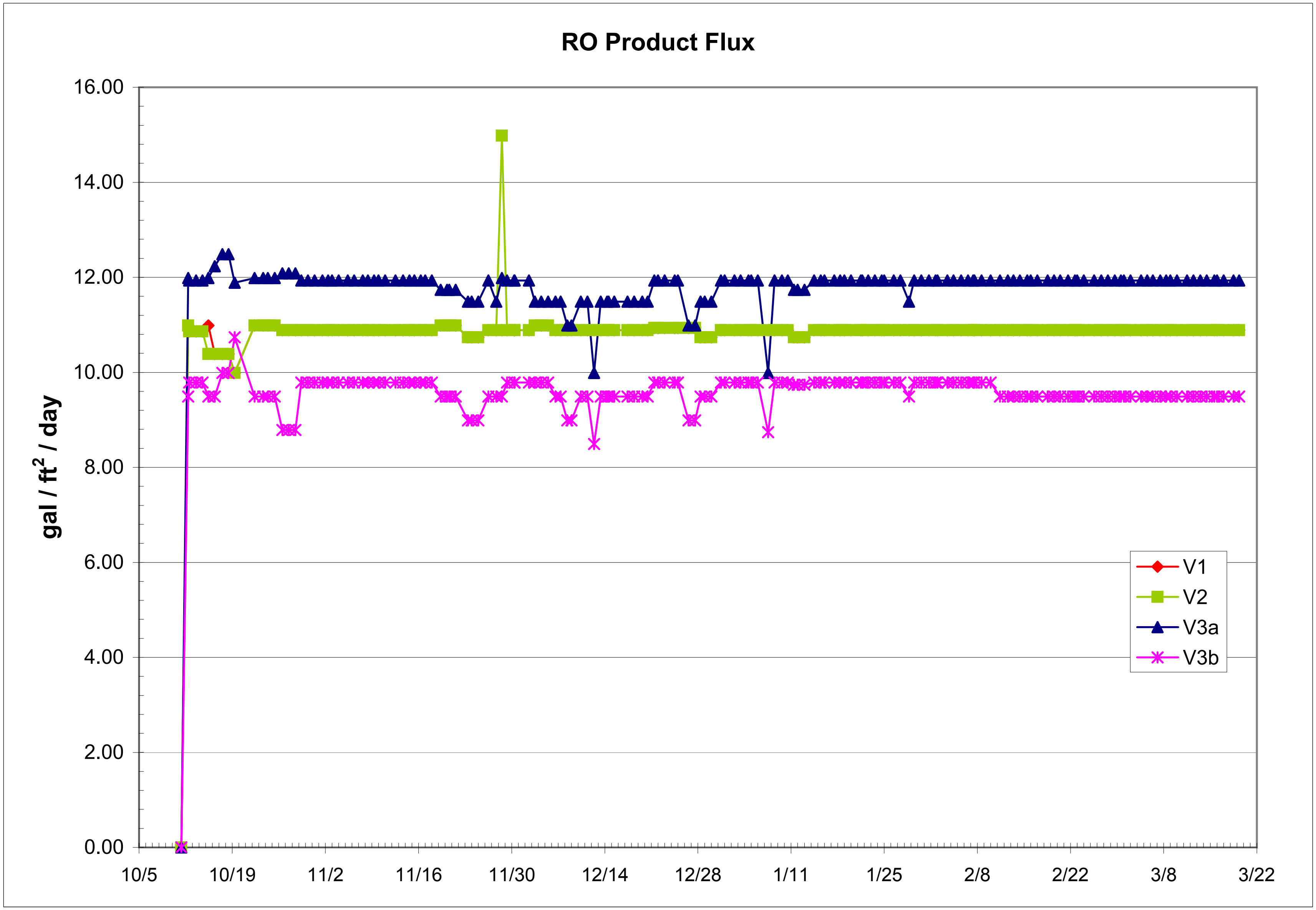


Figure B-30 of 37 - FLUX

SARWMS Slowsand - Reverse Osmosis 2001-2002

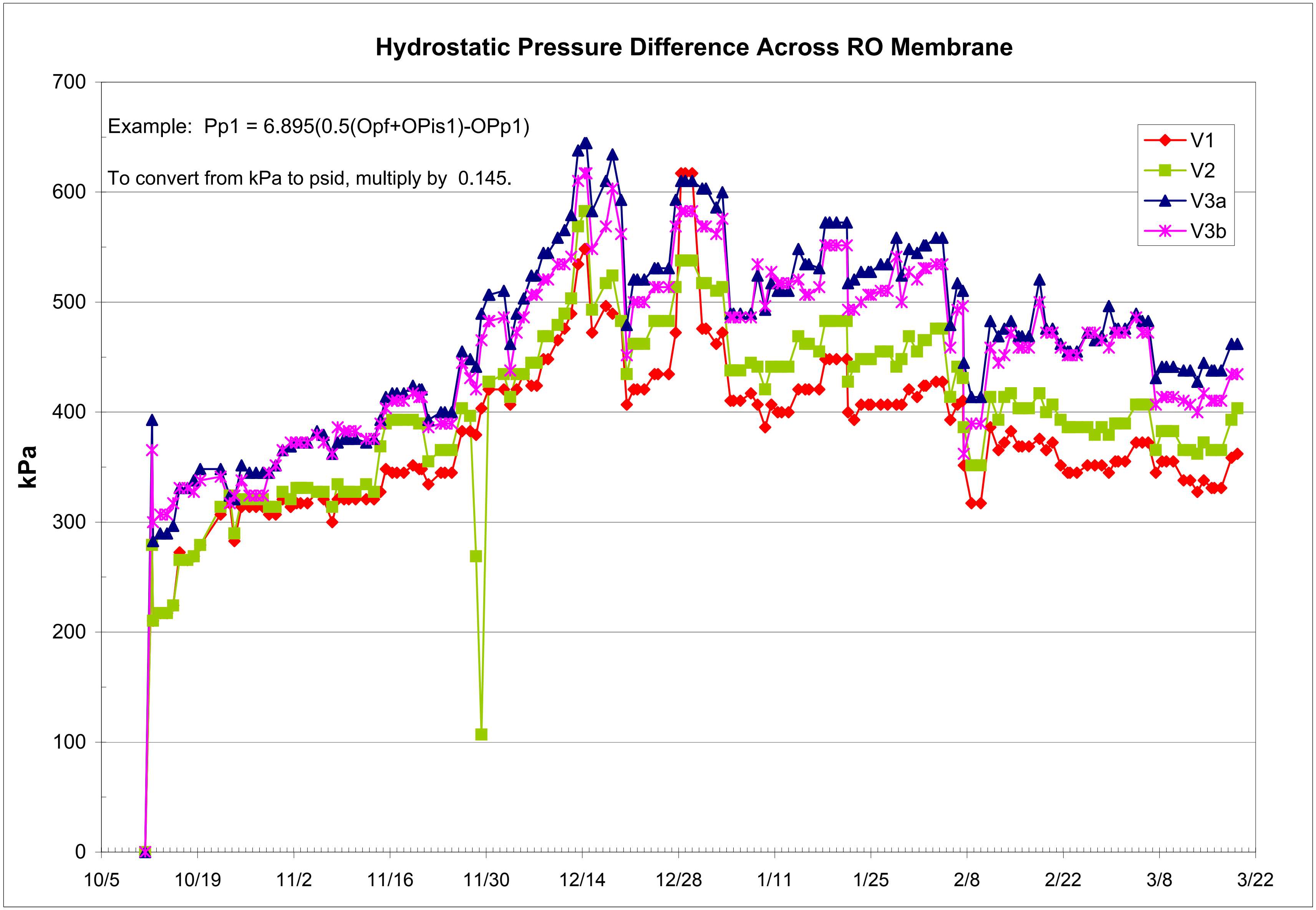


Figure B-31 of 37 - Net Press

SARWMS Slowsand - Reverse Osmosis 2001-2002

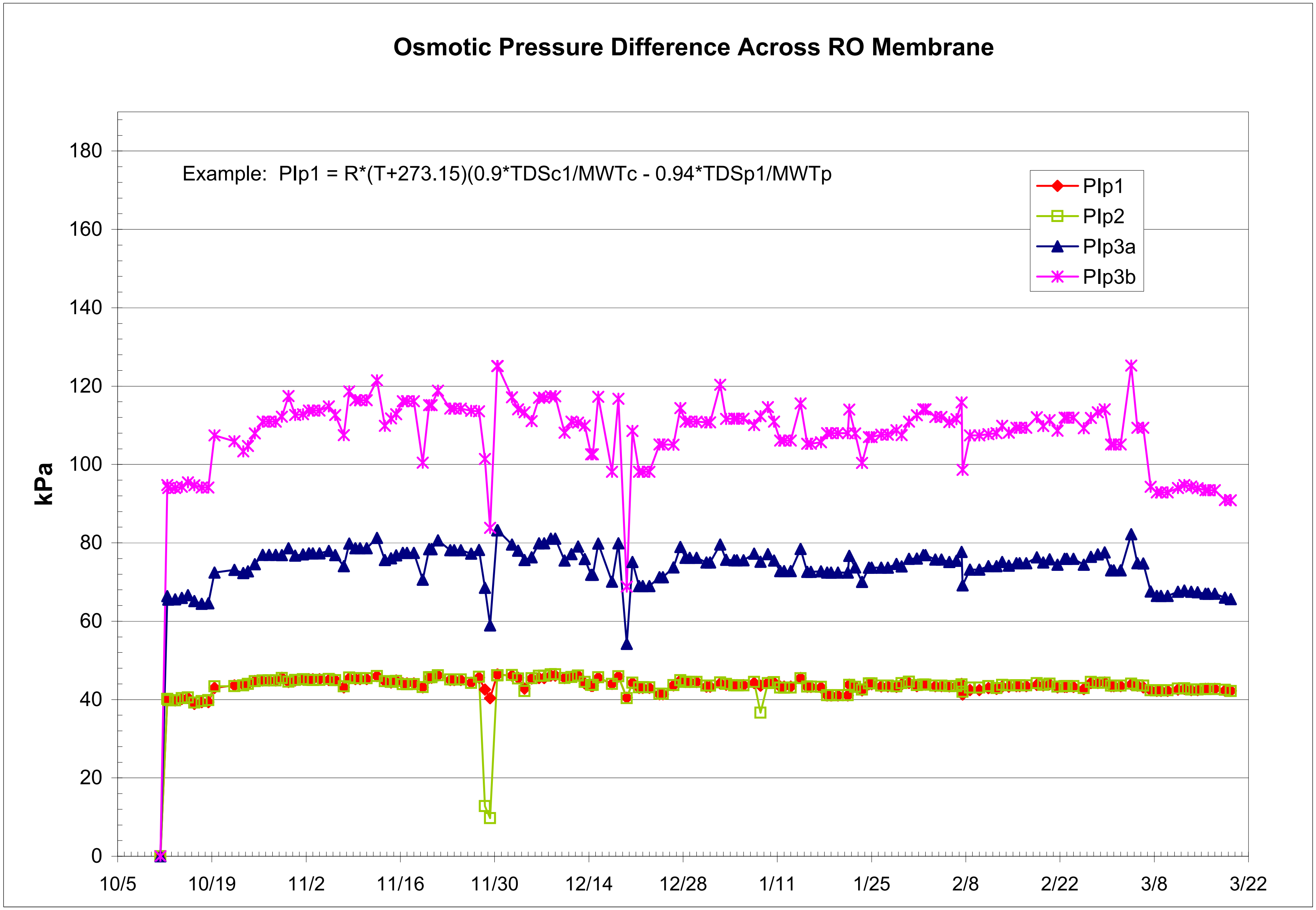


Figure B-32 of 37 - pi

SARWMS Slowsand - Reverse Osmosis 2001-2002

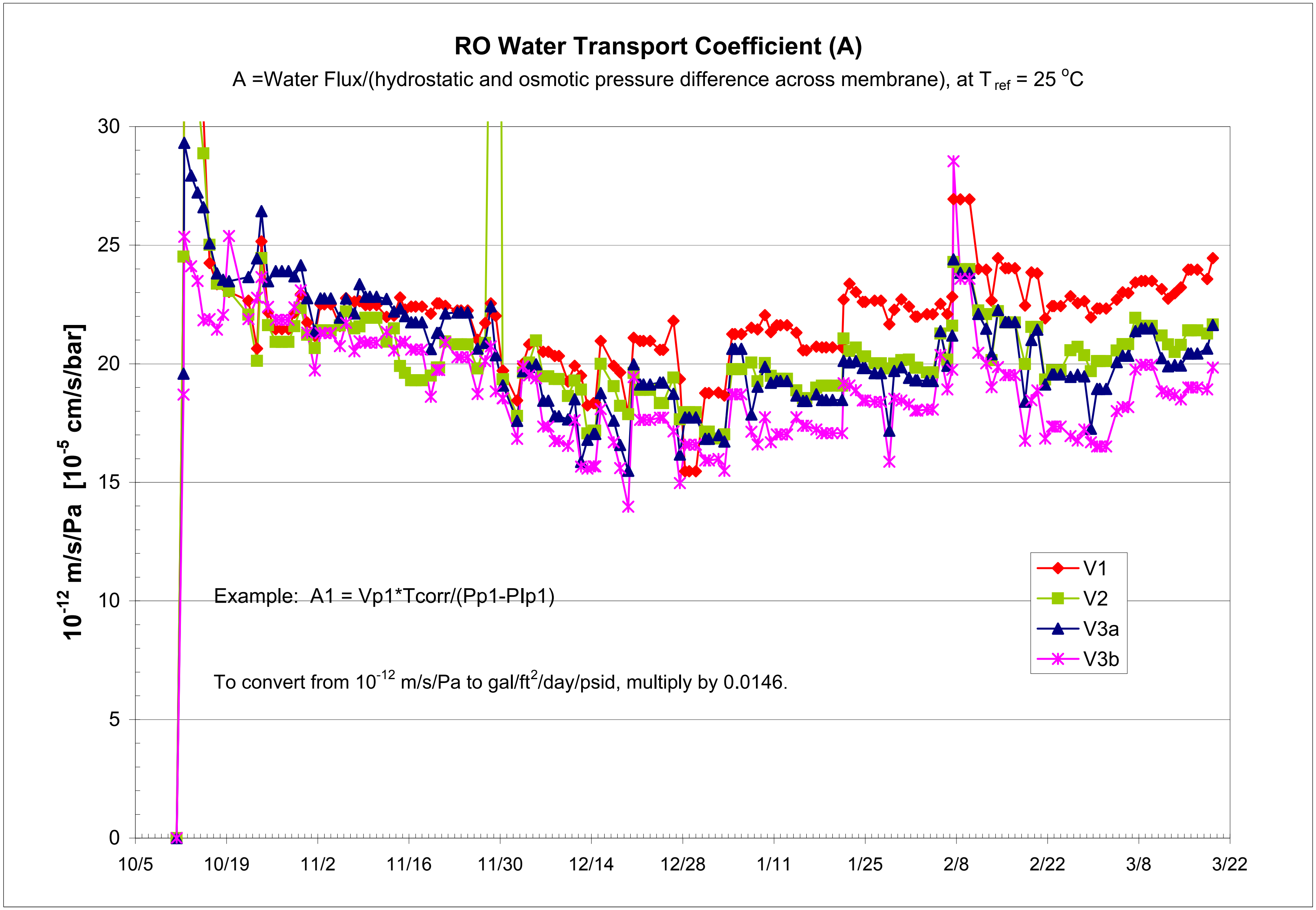


Figure B-33 of 37 - A

SARWMS Slowsand - Reverse Osmosis 2001-2002

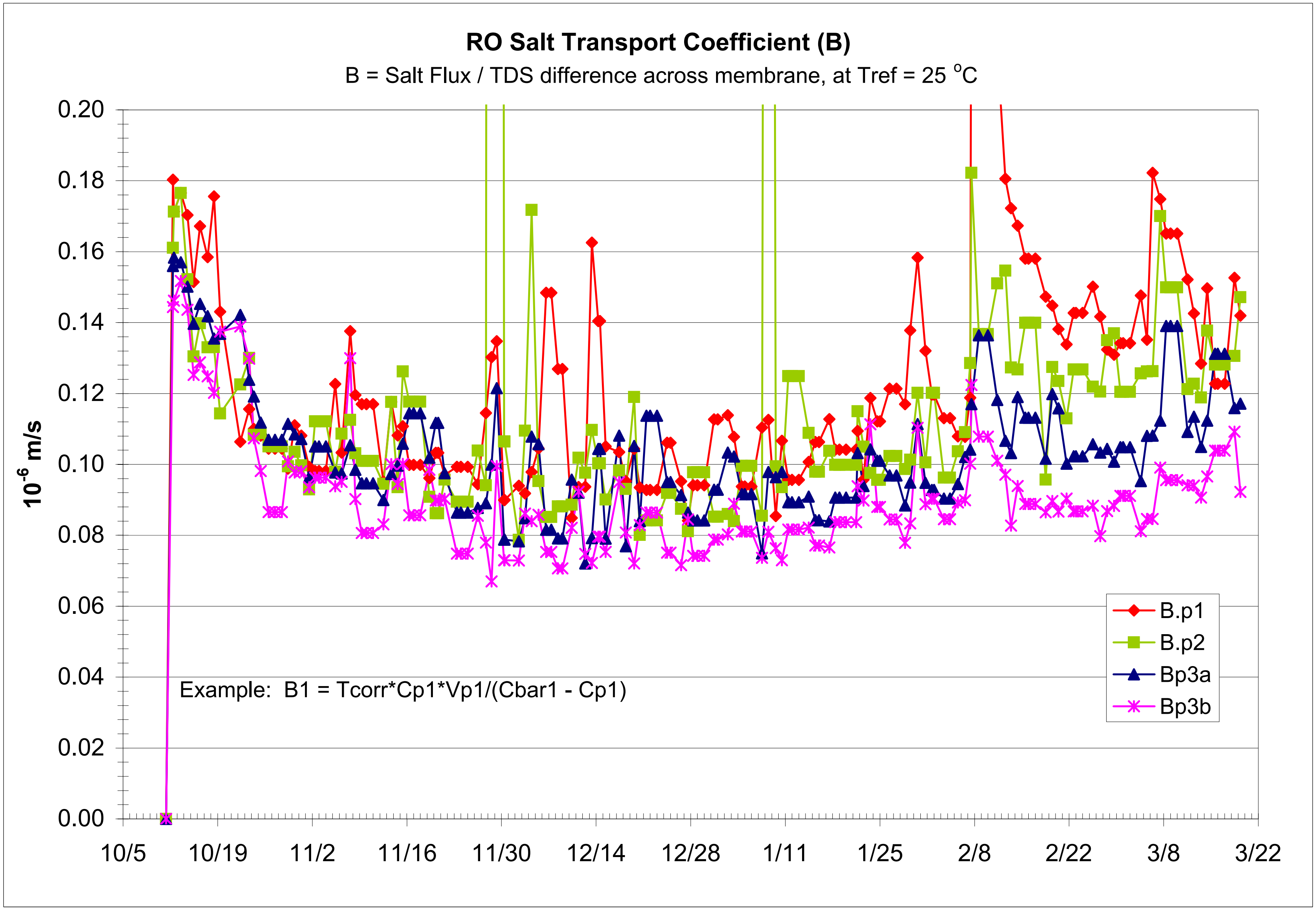


Figure B-34 of 37 - B

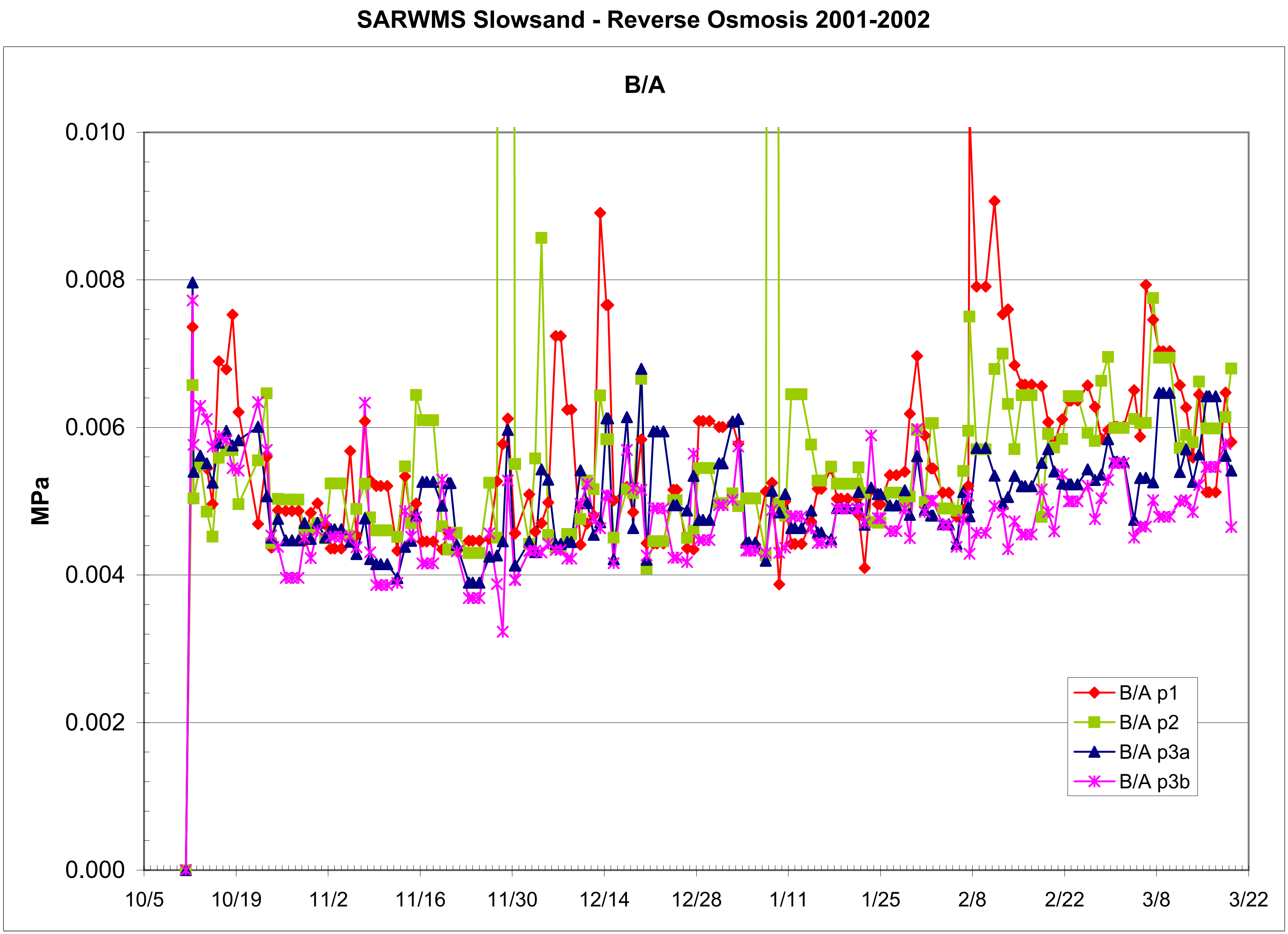


Figure B-35 of 37 - B A

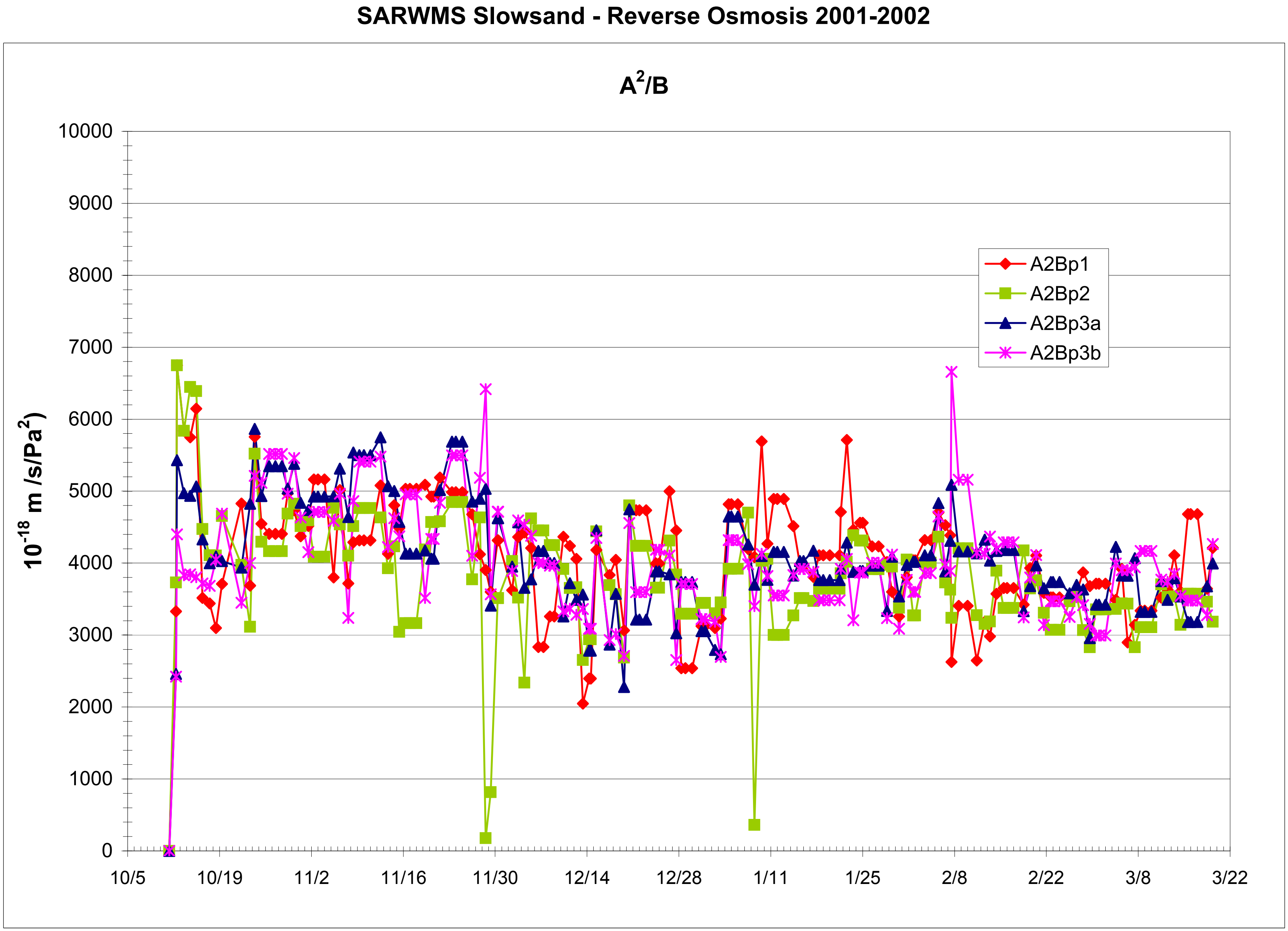


Figure B-36 of 37 - A2B

SARWMS Slowsand - Reverse Osmosis 2001-2002

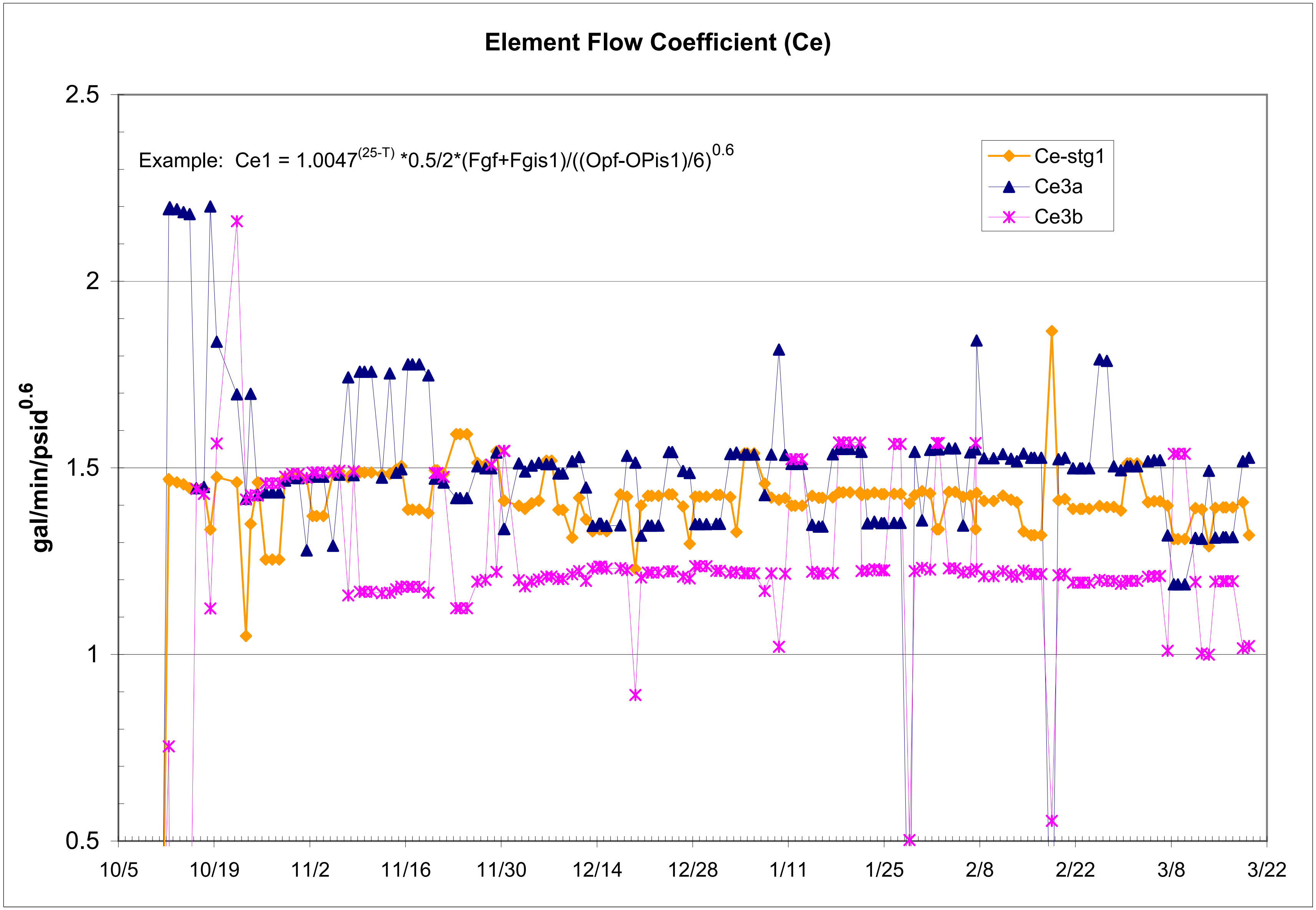


Figure B-37 of 37 - Ce

Appendix C

Chemical Balances and Removals

Appendix C

Table of Contents for Chemical Balances and Removals

Table C- 1 --Chemical Balances and Removals Intro

Introduction and interpretive comments for chemical balances and removals

Dissolved Oxygen (mg/L)	E360.1	Turner Labs
HPC CFU/mL	SM 9215 B	Precision Labs
Alkalinity	M2320 B	Turner Labs
Bicarbonate (as CaCO3, mg/L)	M2320 B	Turner Labs
Carbonate (as CaCO3, mg/L)	M2320 B	Turner Labs
Total (as CaCO3, mg/L)	M2320 B	Turner Labs
Aluminum AL (Dissolved) (mg/L)	E 200.7	Turner Labs
Barium Ba (mg/L)	E 200.7	Turner Labs
Bicarbonate - HCO3 (mg/L)	calc from Alk	=0.61xBicarbonate Alkalinity
Bromide Br (mg/L)	E 300	Turner Labs
Calcium Ca (mg/L)	E 200.7	Turner Labs
Copper Cu (mg/L)	E 200.7	Turner Labs
Chloride Cl (mg/L)	E 300	Turner Labs
Fluoride Fl (mg/L)	E 300	Turner Labs
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	SM 2340 B	Turner Labs: = 2.5 x Ca + 4.1 Mg
Hardness, Calcium Calc.(as CaCO3, mg/L)	SM 2340 B	Turner Labs: = 2.5 x Ca
Iron Fe (Dissolved) (mg/L)	E 200.7	Turner Labs
Magnesium Mg (mg/L)	E 200.7	Turner Labs
Manganese Mn (mg/L)	E 200.7	Turner Labs
Potassium K (mg/L)	E 200.7	Turner Labs
Silica Si02 (mg/L)	M4500-SI D	Turner Labs
Sodium Na (mg/L)	E 200.7	Turner Labs
Strontium Sr (mg/L)	E 200.7	Turner Labs
Sulfate SO4 (mg/L)	E 300	Turner Labs
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	E 415.1	TestAmerica
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	E 415.1	Turner Labs
Total Dissolved Solids TDS (mg/L)	SM1030F	=HCO3+ Ca+F+Mg+K+SiO3+Na+SO4
Tot. Dis. Solids TDS (Residue @180 C) (mg/L)	M2540C	Turner Labs
THM (µg/L)	EPA 551.1	ATEL Labs
Trihalomethane Formation Potential (THMFP µg/L)		
Chloroform	E 524.2	ATEL Labs
Bromoform	E 524.2	ATEL Labs
Bromodichloromethane	E 524.2	ATEL Labs
Dibromochloromethane	E 524.2	ATEL Labs
Total THMFP (µg/L)	E 524.2	ATEL Labs
Lab pH (S.U.)	SM 4500 HB	Turner Labs
Lab Conductivity EC (µmho/cm at 25 C)	M2510 B	Turner Labs
UV 254 nm absorbance	SM 5910B	ATEL Labs

Turner Laboratories Inc. 2445 North Coyote Dr. Suite 104, Tucson, AZ. 85745 520-882-5880
Aqua Tech Envioronmental Laboratories, Inc
  1776 Marion-Waldo Rd, Box 436, Marion OH 43301-0436
  2700 E Bilby Rd Blds A Tucson AZ 85706 -520-573-6565

RO mass balance deviation (MBD) of solute:

For the ideal situation, MBD is zero.

This indicates 1) Accurate RO flows, 2) Accurate solute concentration values, and 3) No scaling or leaks.

MBD values between -10% and +10% are probably within expected data scatter.

MBD positive values could indicate solute accumulation and scaling in the RO equipment.

MBD-1 uses the listed RO product values and detection limits for nondetected RO product solutes.

MBD-2 uses zero for nondetected RO product solutes.

Table C- 2 --Chemical Balances and Removals on 8-28-01

RO: Dow FilmTec NF90	RO not in operation		Removal by SSF
RO water recovery			
RO water flux (gal/ft^2/day)			
RO element area measured 4/3/02 (ft^2)			
8/28/2001	SSF feed	SSF outlet	
Parameter			(%)
Flow (L/min)	83.3	83.3	
Dissolved Oxygen (mg/L)			
HPC CFU/mL	238	41	82.8
Alkalinity			
Bicarbonate (as CaCO3, mg/L)	120	120	0.0
Carbonate (as CaCO3, mg/L)	< 1.0	< 1.0	-
Total (as CaCO3, mg/L)	120	120	0.0
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	-
Barium Ba (mg/L)	< 1.0	< 1.0	-
Bicarbonate - HCO3 (mg/L)	73.2	73.2	0.0
Bromide Br (mg/L)	< 1.0	< 1.0	-
Calcium Ca (mg/L)	68	69	-1.5
Copper Cu (mg/L)	< 0.020	< 0.020	
Chloride Cl (mg/L)	66	67	-1.5
Fluoride Fl (mg/L)	0.34	0.36	-5.9
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	280	280	0.0
Hardness, Calcium Calc.(as CaCO3, mg/L)	170	170	0.0
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	-
Magnesium Mg (mg/L)	27	27	0.0
Manganese Mn (mg/L)	< 0.020	< 0.020	-
Potassium K (mg/L)	6.1	6.1	0.0
Silica Si02 (mg/L)	8.0	8.0	0.0
Sodium Na (mg/L)	71	72	-1.4
Strontium Sr (mg/L)	1.5	1.5	0.0
Sulfate SO4 (mg/L)	210	210	0.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	4.6	2.83	38.5
Total Dissolved Solids TDS (mg/L)	522	525	-0.6
Tot. Dis. Solids TDS (Residue @180 C) (mg/L)			
THM (µg/L)	0.7	0.7	0.0
Trihalomethane Formation Potential (THMFP µg/L)			
Chloroform	206	116.0	
Bromoform	< 0.5	< 0.5	
Bromodichloromethane	27.3	36.8	
Dibromochloromethane	1.9	6.7	
Total THMFP (µg/L)	236	159	32.6
Lab pH (S.U.)	7.88	7.90	
Lab Conductivity EC (µmho/cm at 25 C)	953	944.3	
UV 254 nm absorbance	0.028	0.029	-3.6

Table C- 3 --Chemical Balances and Removals on 9-25-01

RO: Dow FilmTec NF90	RO not in operation		Removal by SSF
RO water recovery			
RO water flux (gal/ft^2/day)			
RO element area measured 4/3/02 (ft^2)			
9/25/2001	SSF feed	SSF outlet	
Parameter			(%)
Flow (L/min)	83.3	83.3	
Dissolved Oxygen (mg/L)	8.7	8.2	
HPC CFU/mL	72	43	40.3
Alkalinity			
Bicarbonate (as CaCO3, mg/L)	130	130	0.0
Carbonate (as CaCO3, mg/L)	< 1.0	< 1.0	-
Total (as CaCO3, mg/L)	120	120	0.0
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	-
Barium Ba (mg/L)	< 1.0	< 1.0	-
Bicarbonate - HCO3 (mg/L)	79.3	79.3	0.0
Bromide Br (mg/L)	< 1.0	< 1.0	-
Calcium Ca (mg/L)	74	74	0.0
Copper Cu (mg/L)	< 0.020	< 0.020	
Chloride Cl (mg/L)	66	66	0.0
Fluoride Fl (mg/L)	< 1.0	< 1.0	-
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	300	300	0.0
Hardness, Calcium Calc.(as CaCO3, mg/L)	180	180	0.0
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	-
Magnesium Mg (mg/L)	28	27	3.6
Manganese Mn (mg/L)	< 0.020	< 0.020	-
Potassium K (mg/L)	6.7	6.7	0.0
Silica Si03 (mg/L)	9.3	10	-7.5
Sodium Na (mg/L)	68	74	-8.8
Strontium Sr (mg/L)	1.7	1.7	0.0
Sulfate SO4 (mg/L)	220	220	0.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	4.02	3.36	16.4
Total Dissolved Solids TDS (mg/L)	551	550	0.2
TDS (Residue @180 C) (mg/L)	650	560	13.8
THM (µg/L)	< 0.5	< 0.5	-
Trihalomethane Formation Potential (THMFP µg/L)			
Chloroform	76	68.5	9.9
Bromoform	0.6	0.7	-16.7
Bromodichloromethane	32.8	31.9	2.7
Dibromochloromethane	10.7	12.7	-18.7
Total THMFP (µg/L)	120	114	5.0
Lab pH (S.U.)	7.7	7.7	
Lab Conductivity EC (µmho/cm at 25 C)	920	930	
UV 254 nm absorbance	0.0570	0.0380	33.3

Table C- 4 --Chemical Balances and Removals on 10-25-01

RO: Dow FilmTec NF90						Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water recovery	80.4%								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO water flux (gal/ft^2/day)	10.9											Based on feed conc.	Based on avg. feed reject
RO element area measured 4/3/02 (ft^2)	25.4												
Temperature - ^{o}C			20.9										
10/25/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.3	13.1	3.2						80.4%		
Dissolved Oxygen (mg/L)	9.7	9.1	9.3	9.2	9.1								
HPC CFU/mL	71	40	3	< 1	16	43.7							
Alkalinity													
Bicarbonate (as CaCO3, mg/L)	130	120	100	14	460	7.7	16.7	23.1	-1.6	-	80.7%	86.0	92.7
Carbonate (as CaCO3, mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Total (as CaCO3, mg/L)	130	120	100	14	460	7.7	16.7	23.1	-1.6	-	80.7%	86.0	92.7
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	-	-	-	-	-	-	-	-
Barium Ba (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Bicarbonate - HCO3 (mg/L)	79.3	73.2	61	8.54	280.6	7.7	16.7	23.1	-1.6	-	80.7%	86.0	92.7
Bromide Br (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Calcium Ca (mg/L)	66	65	65	< 4.0	290	1.5	0.0	1.5	> 7.5	< 12.4	-	> 93.8	> 96.9
Copper Cu (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	0.021	-	-	-	-	-	-	-	-
Chloride Cl (mg/L)	64	64	65	7.8	310	0.0	-1.6	-1.6	-3.3	-	81.1%	88.0	93.8
Fluoride Fl (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	1.3	-	-	-	-	-	-	-	-
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	280	280	280	< 22	1300	0.0	0.0	0.0	> 2.5	< 8.9	-	> 92.1	> 96.0
Hardness, Calcium Calc.(as CaCO3, mg/L)	160	160	160	< 9.9	720	0.0	0.0	0.0	> 6.7	< 11.7	-	> 93.8	> 96.9
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	< 0.30	< 0.30	< 0.30	-	-	-	-	-	-	-	-
Magnesium Mg (mg/L)	28	28	28	< 3.0	130	0.0	0.0	0.0	> 0.2	< 8.9	-	> 89.3	> 94.5
Manganese Mn (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	-	-	-	-	-	-	-	-
Potassium K (mg/L)	6.3	6.3	6.4	< 5.0	30	0.0	-1.6	-1.6	> -83.7	< 8.0	-	> -14.1	> -52.7
Silica Si03 (mg/L)	8.0	8.0	8.0	0.40	39	0.0	0.0	0.0	> 0.3	< 4.3	-	> 95.0	> 97.5
Sodium Na (mg/L)	84	85	88	7.3	390	-1.2	-3.5	-4.8	6.3	-	78.9%	91.7	95.8
Strontium Sr (mg/L)	1.6	1.6	1.6	< 0.20	9.2	0.0	0.0	0.0	> -22.9	< -12.9	-	> 87.5	> 93.5
Sulfate SO4 (mg/L)	220	220	260	< 5.0	1200	0.0	-18.2	-18.2	> 7.8	< 9.4	-	> 98.1	> 99.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L	3.4	2.9	3.0	< 0.50	11	14.7	-3.4	11.8	> 14.6	< 28.0	-	> 83.3	> 91.2
Total Dissolved Solids TDS (mg/L)	555	549	581	< 42	2666	1.1	-5.8	-4.7	> 4.2	< 10.0	-	> 92.8	> 96.3
TDS (Residue @180 C) (mg/L)	800	740	690	130	3000	7.5	6.8	13.8	-0.5	-	80.5%	81.2	89.9
THM (µg/L)	< 1	< 1	< 1	< 1	< 1	-	-	-	-	-	-	-	-
Trihalomethane Formation Potential (THMFP µg/L)													
Chloroform	56.2	89.4	48.8	1.6	45.0	-59.1	45.4	13.2	79.3	-	-8.8%	96.7	98.4
Bromoform	2.2	1.4	0.6	< 0.5	15	36.4	57.1	72.7	> -457.8	< -390.8	-	> 16.7	> 32.0
Bromodichloromethane	31	34.6	25.7	< 0.5	55.5	-11.6	25.7	17.1	> 56.0	< 57.6	-	> 98.1	> 99.0
Dibromochloromethane	20.5	19	10.1	< 0.5	43	7.3	46.8	50.7	> 12.4	< 16.4	-	> 95.0	> 97.5
Total THMFP (µg/L)	110	144	85.2	1.6	158	-30.9	40.8	22.5	62.1	-	46.5%	98.1	99.1
Lab pH (S.U.)	7.6	7.7	6.8	5.2	7.3								
Lab Conductivity EC (µmho/cm at 25 C)	920	920	960	49	3700								
UV 254 nm absorbance	0.023	0.023	0.029	0.004	0.175								

Table C- 5 --Chemical Balances and Removals on 11-19-01

RO: Dow FilmTec NF90						Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water recovery	79.8%								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO water flux (gal/ft^2/day)	10.9											Based on feed conc.	Based on avg. feed reject
RO element area measured 4/3/02 (ft^2)	25.4												
Temperature - ^{o}C			17.1										
11/19/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.35	13.05	3.3						79.8%		
Dissolved Oxygen (mg/L)	9.8	8.5	8.8	8.6	8.5								
HPC CFU/mL	26	66	8	< 1	49	-153.8							
Alkalinity													
Bicarbonate (As CaCO3, mg/L)	120	120	100	6	480	0.0	16.7	16.7	-1.7	-	80.2%	94.0	96.9
Carbonate (As CaCO3, mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Total (As CaCO3, mg/L)	120	120	100	6	480	0.0	16.7	16.7	-1.7	-	80.2%	94.0	96.9
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	-	-	-	-	-	-	-	-
Barium Ba (mg/L)	0.091	0.091	0.090	< 0.020	0.430	0.0	-	-	-	-	-	-	-
Bicarbonate - HCO3 (mg/L)	73.2	73.2	61	3.66	292.8	0.0	16.7	16.7	-1.7	-	80.2%	94.0	96.9
Bromide Br (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Calcium Ca (mg/L)	66	66	65	< 4.0	330	0.0	1.5	1.5	> -7.4	< -2.5	-	> 93.8	> 96.9
Copper Cu (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	0.022	-	-	-	-	-	-	-	-
Chloride Cl (mg/L)	64	64	65	5.4	360	0.0	-1.6	-1.6	-18.4	-	83.2%	91.7	95.7
Fluoride Fl (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	1.3	-	-	-	-	-	-	-	-
Hardness Total (Ca/Mg) (CaCO3, mg/L)	280	280	280	< 22	1400	0.0	0.0	0.0	> -7.2	< -0.9	-	> 92.1	> 96.0
Hardness, Calcium Calc.(CaCO3, mg/L)	160	160	160	< 10	820	0.0	0.0	0.0	> -8.4	< -3.4	-	> 93.8	> 96.8
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	< 0.30	< 0.30	< 0.30	-	-	-	-	-	-	-	-
Magnesium Mg (mg/L)	29	29	29	< 3.0	140	0.0	0.0	0.0	> -5.7	< 2.6	-	> 89.7	> 94.6
Manganese Mn (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	-	-	-	-	-	-	-	-
Potassium K (mg/L)	6.9	7	7.2	< 5.0	31	-1.4	-2.9	-4.3	> -42.3	< 13.1	-	> 30.6	> 49.5
Silica Si03 (mg/L)	9.9	9.9	9.4	0.40	50	0.0	5.1	5.1	> -10.8	< -7.4	-	> 95.7	> 97.8
Sodium Na (mg/L)	90	90	91	5.7	420	0.0	-1.1	-1.1	1.8	-	79.4%	93.7	96.8
Strontium Sr (mg/L)	1.8	1.8	1.8	1.80	12	0.0	0.0	0.0	> -114.4	< -34.6	-	> 0.0	> 0.0
Sulfate SO4 (mg/L)	230	230	260	< 5.0	1300	0.0	-13.0	-13.0	> -2.5	< -0.9	-	> 98.1	> 99.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	4	3.3	3.4	< 0.50	13	17.5	-3.0	15.0	> 11.1	< 22.8	-	> 85.3	> 92.2
Total Dissolved Solids TDS (mg/L)	569	569	588	< 33	< 2920	0.0	-3.3	-3.3	-	-	-	> 94.4	> 97.1
TDS (Residue @180 C) (mg/L)	650	710	690	88	3100	-9.2	2.8	-6.2	-0.9	-	80.0%	87.2	93.3
THM (µg/L)	< 1	< 1	< 1	< 1	< 1	-	-	-	-	-	-	-	-
Trihalomethane Formation Potential (THMFP µg/L)													
Chloroform	92.7	82.4	98.6	3	95.8	11.1	-19.7	-6.4	78.0	-	-3.0%	97.0	98.5
Bromoform	< 0.5	0.5	< 0.5	< 0.5	7.3	-	-	-	-	-	-	-	-
Bromodichloromethane	30.7	31.1	30.2	< 0.5	66.6	-1.3	2.9	1.6	> 54.2	< 55.5	-	> 98.3	> 99.2
Dibromochloromethane	9.6	11	9.4	< 0.5	38.4	-14.6	14.5	2.1	> 13.3	< 17.5	-	> 94.7	> 97.3
Total THMFP (µg/L)	133	125	138	3	208	6.0	-10.4	-3.8	67.8	-	34.1%	97.8	98.9
Lab pH (S.U.)	8	7.7	6.7	5.1	7.1								
Lab Conductivity EC (µmho/cm at 25 C)	880	880	920	3.5	3600								
UV 254 nm absorbance	0.032	0.028	0.027	0.001	0.179								

Table C- 6 --Chemical Balances and Removals on 12-17-01

RO: Dow FilmTec NF90						Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water recovery	79.3%												
RO water flux (gal/ft^2/day)	10.7								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO element area measured 4/3/02 (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
Temperature - ^{o}C			11.7										
12/17/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.3	12.92	3.38						79.3%		
Dissolved Oxygen (mg/L)	9	8.5	9	8.9	9								
HPC CFU/mL	76	26	8	1	53	65.8							
Alkalinity													
Bicarbonate (As CaCO3, mg/L)	120	120	80	4	390	0.0	33.3	33.3	-5.1	-	80.3%	95.0	97.4
Carbonate (As CaCO3, mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Total (As CaCO3, mg/L)	120	120	80	4	390	0.0	33.3	33.3	-5.1	-	80.3%	95.0	97.4
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	-	-	-	-	-	-	-	-
Barium Ba (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	-	-	-	-	-	-	-	-
Bicarbonate - HCO3 (mg/L)	73.2	73.2	48.8	2.44	237.9	0.0	33.3	33.3	-5.1	-	80.3%	95.0	97.4
Bromide Br (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Calcium Ca (mg/L)	55	55	56	< 4.0	270	0.0	-1.8	-1.8	> -5.6	< 0.0	-	> 92.9	> 96.3
Copper Cu (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.02	-	-	-	-	-	-	-	-
Chloride Cl (mg/L)	64	64	64	3.5	320	0.0	0.0	0.0	-8.0	-	80.9%	94.5	97.2
Fluoride Fl (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	1.3	-	-	-	-	-	-	-	-
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	240	240	250	< 22	1200	0.0	-4.2	-4.2	> -6.5	< 0.5	-	> 91.2	> 95.4
Hardness, Calcium Calc.(as CaCO3, mg/L)	140	140	140	< 10	670	0.0	0.0	0.0	> -4.9	< 0.8	-	> 92.9	> 96.3
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	< 0.30	< 0.30	< 0.30	-	-	-	-	-	-	-	-
Magnesium Mg (mg/L)	26	26	26	< 3.0	130	0.0	0.0	0.0	> -12.8	< -3.7	-	> 88.5	> 93.9
Manganese Mn (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	-	-	-	-	-	-	-	-
Potassium K (mg/L)	7.1	6.9	7	< 5.0	30	2.8	-1.4	1.4	> -45.5	< 11.1	-	> 28.6	> 46.9
Silica Si03 (mg/L)	8.0	7.6	7.8	0.20	40	5.0	-2.6	2.5	> -8.4	< -6.3	-	> 97.4	> 98.7
Sodium Na (mg/L)	92	91	93	< 5	410	1.1	-2.2	-1.1	> 4.3	< 8.6	-	> 94.6	> 97.2
Strontium Sr (mg/L)	1.3	1.3	1.3	< 0.20	7.8	0.0	0.0	0.0	> -36.6	< -24.4	-	> 84.6	> 91.7
Sulfate SO4 (mg/L)	240	240	270	< 5.0	1300	0.0	-12.5	-12.5	> -1.3	< 0.2	-	> 98.1	> 99.1
Tot. Organic Carbon TOC, as C (NPOC, mg/	4.2	3.8	3.9	< 0.50	13	9.5	-2.6	7.1	> 20.7	< 30.9	-	> 87.2	> 93.2
Total Dissolved Solids TDS (mg/L)	565	564	573	< 29	2735	0.3	-1.7	-1.4	> -3.0	< 1.0	-	> 94.9	> 97.4
TDS (Residue @180 C) (mg/L)	570	600	660	170	3000	-5.3	-10.0	-15.8	-14.7	-	82.7%	74.2	85.5
THM (µg/L)	< 1	< 1	< 1	< 1	< 1	-	-	-	-	-	-	-	-
Trihalomethane Formation Potential (THMFP µg/L)													
Chloroform	75.5	64.0	73.2	0.9	66.0	15.2	-14.4	3.0	80.3	-	-11.1%	98.8	99.4
Bromoform	0.5	0.6	0.5	< 0.5	7.3	-20.0	16.7	0.0	> -282.0	< -202.7	-	> 0.0	> 0.0
Bromodichloromethane	29	28.4	26.2	< 0.5	52.9	2.1	7.7	9.7	> 56.6	< 58.1	-	> 98.1	> 99.0
Dibromochloromethane	9.6	9.7	10.1	< 0.5	31.1	-1.0	-4.1	-5.2	> 32.2	< 36.1	-	> 95.0	> 97.5
Total THMFP (µg/L)	114.6	102.7	110	0.9	157.3	10.4	-7.1	4.0	69.7	-	30.2%	99.2	99.6
Lab pH (S.U.)	7.9	7.7	6.4	4.8	7								
Lab Conductivity EC (µmho/cm at 25 C)	910	900	940	2.2	3600								
UV 254 nm absorbance	0.046	0.041	0.039	0.008	0.189								

Table C- 7 --Chemical Balances and Removals on 1-15-02

RO: Dow FilmTec NF90													
RO water recovery	79.5%					Removal	Reduction	Reduction	RO equipment				
RO water flux (gal/ft^2/day)	10.9					by	between	between				RO removal (%)	
RO element area measured 4/3/02 (ft^2)	25.4					SSF	SSF	SSF	RO mass				Based
Temperature - °C			20.9				Outlet &	Feed &	bal. dev. (MBD)		RO water	Based	on avg.
1/15/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject		RO feed	RO feed	as % of feed		recovery	on feed	feed
Parameter						(%)	(%)	(%)	1	2	(%)	conc.	reject
Flow (L/min)	60.6	60.6	16.45	13.07	3.38						79.5%		
Dissolved Oxygen (mg/L)	9	7.8	8.5	8.3	8.2								
HPC CFU/mL	80	7	3	< 1	11	91.3							
Alkalinity													
Bicarbonate (As CaCO3, mg/L)	120	130	100	2	430	-8.3	23.1	16.7	> 10.1	< 11.6	-	> 98.0	> 99.0
Carbonate (As CaCO3, mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Total (As CaCO3, mg/L)	120	130	100	< 22	430	-8.3	23.1	16.7	> -5.8	< 11.6	-	> 78.0	> 87.9
Aluminum AL (Dissolved) (mg/L)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	-	-	-	-	-	-	-	-
Barium Ba (mg/L)	0.10	0.09	0.10	< 0.02	0.35	3.2	-4.3	-1.1	> 8.5	< 25.1	-	> 79.2	> 88.6
Bicarbonate - HCO3 (mg/L)	73.2	79.3	61	1.22	262.3	-8.3	23.1	16.7	10.1	-	77.1%	98.0	99.0
Bromide Br (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	-	-	-	-	-	-	-	-
Calcium Ca (mg/L)	65	64	64	< 4.0	300	1.5	0.0	1.5	> -1.3	< 3.7	-	> 93.8	> 96.8
Copper Cu (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.02	-	-	-	-	-	-	-	-
Chloride Cl (mg/L)	59	59	59	3.8	270	0.0	0.0	0.0	0.9	-	79.3%	93.6	96.7
Fluoride Fl (mg/L)	< 1.0	< 1.0	< 1.0	< 1.0	1.2	-	-	-	-	-	-	-	-
Hardness Total (Ca/Mg) (as CaCO3, mg/L)	270	270	270	< 22	1200	0.0	0.0	0.0	> 2.2	< 8.7	-	> 91.9	> 95.8
Hardness, Calcium Calc.(as CaCO3, mg/L)	160	160	160	< 10	750	0.0	0.0	0.0	> -1.3	< 3.7	-	> 93.8	> 96.8
Iron Fe (Dissolved) (mg/L)	< 0.30	< 0.30	< 0.30	< 0.30	< 0.30	-	-	-	-	-	-	-	-
Magnesium Mg (mg/L)	27	27	27	< 3.0	120	0.0	0.0	0.0	> -0.1	< 8.7	-	> 88.9	> 94.2
Manganese Mn (mg/L)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	-	-	-	-	-	-	-	-
Potassium K (mg/L)	6.1	6.1	6.1	< 5.0	27	0.0	0.0	0.0	> -56.1	< 9.1	-	> 18.0	> 33.4
Silica Si03 (mg/L)	7.0	6.7	6.9	0.60	30	4.3	-3.0	1.4	> 3.8	< 10.7	-	> 91.3	> 95.5
Sodium Na (mg/L)	86	88	86	< 5	380	-2.3	2.3	0.0	> 4.6	< 9.2	-	> 94.2	> 97.0
Strontium Sr (mg/L)	1.7	1.7	1.7	< 0.20	9	0.0	0.0	0.0	> -18.1	< -8.8	-	> 88.2	> 93.8
Sulfate SO4 (mg/L)	220	220	250	< 5.0	1100	0.0	-13.6	-13.6	-	-	-	> 98.0	> 99.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L	3.4	2.8	2.8	< 0.50	9.3	17.6	0.0	17.6	> 17.6	< 31.8	-	> 82.1	> 90.3
Total Dissolved Solids TDS (mg/L)	543	550	560	29	2486	-1.2	-1.9	-3.1	4.7	-	78.4%	94.9	97.4
TDS (Residue @180 C) (mg/L)	380	500	520	< 20	2600	-31.6	-4.0	-36.8	> -5.8	< -2.7	-	> 96.2	> 98.0
THM (µg/L)	< 1	< 1	< 1	< 1	< 1	-	-	-	-	-	-	-	-
Trihalomethane Formation Potential (THMFP µg/L)													
Chloroform	53.4	46.2	58.9	1.6	28.9	13.5	-27.5	-10.3	87.8	-	-109.9%	97.3	98.6
Bromoform	0.6	0.7	0.5	< 0.5	6.5	-16.7	28.6	16.7	> -246.6	< -167.1	-	> 0.0	> 0.0
Bromodichloromethane	26.3	23.9	25	< 0.5	49.9	9.1	-4.6	4.9	> 57.4	< 59.0	-	> 98.0	> 99.0
Dibromochloromethane	9.7	10.3	9.2	< 0.5	33.2	-6.2	10.7	5.2	> 21.5	< 25.9	-	> 94.6	> 97.2
Total THMFP (µg/L)	90	81.1	93.6	1.6	148	9.9	-15.4	-4.0	66.2	-	37.2%	98.3	99.1
Lab pH (S.U.)	7.9	7.7	8.6	4.8	7.3								
Lab Conductivity EC (µmho/cm at 25 C)	880	890	910	28	3400								
UV 254 nm absorbance	0.0330	0.0260	0.0330	0.0100	0.141								

Table C- 8 --Chemical Balances and Removals on 9-4-01

RO: Dow FilmTec NF90 RO water recovery RO water flux (gal/ft^2/day) RO element area measured 4/3/02 (ft^2)	RO not in operation		Removal by SSF
9/4/2001	SSF feed	SSF outlet	
Parameter			(%)
Flow (L/min)	83.3	83.3	
HPC CFU/mL	238	38	84.0
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	4.6	3.72	19.1

Table C- 9 --Chemical Balances and Removals on 9-11-01

RO: Dow FilmTec NF90 RO water recovery RO water flux (gal/ft^2/day) RO element area measured 4/3/02 (ft^2)	RO not in operation		Removal by SSF
9/11/2001	SSF feed	SSF outlet	
Parameter			(%)
Flow (L/min)	83.3	83.3	
HPC CFU/mL	36	290	-705.6
Tot. Organic Carbon TOC, as C (NPOC, mg/L)	7.01	5.32	24.1

Table C- 10 --Chemical Balances and Removals on 9-18-01

RO: Dow FilmTec NF90 RO water recovery RO water flux (gal/ft^2/day) RO element area measured 4/3/02 (ft^2) 9/18/2001 Parameter	RO not in operation SSF feed	SSF outlet	RO feed	Removal by SSF (%)	educti etwee SSF Outlet & feed (%)	Reduction between SSF Feed & RO feed (%)
Flow (L/min)	83.3	83.3				
HPC CFU/mL	820	51		93.8		
TOC, as C (NPOC, mg/L)	3.00	2.48	2.92	17.3	-17.7	2.7

Membranes loaded 10/11/01 - so this analysis of feed/product/reject are in fact duplicate analysis of same water.

Table C- 11 --Chemical Balances and Removals on 10-2-01

RO: Dow FilmTec NF90	RO not in operation					Removal by SSF (%)	Reduction between SSF Outlet & RO feed (%)	Reduction between SSF Feed & RO feed (%)
RO water recovery								
RO water flux (gal/ft^2/day)								
RO element area (ft^2)	25.4		RO locations with no elements installed					
10/2/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject			
Parameter								
Flow (L/min)	83.3	83.3						
HPC CFU/mL	14	62	14	56	2	-342.9	77.4	0.0
TOC, as C (NPOC, mg/L)	3.98	2.72	3.00			31.7	-10.3	24.6

RO membranes were not loaded until 10/11/01.
Therefore, the HPC measurements at locations labeled RO feed, product, and reject may be considered repeat measurements of RO feedwater.

Table C- 12 --Chemical Balances and Removals on 10-9-01

RO: Dow FilmTec NF90 RO water recovery RO water flux (gal/ft^2/day) RO element area (ft^2)	RO not in operation 25.4		RO locations with no elements installed			Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed
10/9/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject			
Parameter						(%)	(%)	(%)
Flow (L/min)	83.3	83.3						
HPC CFU/mL	108	17	18	< 1	1	84.3		
TOC, as C (NPOC, mg/L)	4.55	3.89	4.16	4.40	3.99	14.5	-6.9	8.6

RO membranes were not loaded until 10/11/01.
Therefore, measurements at locations labeled RO feed, product, and reject may be considered repeat measurements of RO feedwater.

Table C- 13 --Chemical Balances and Removals on 10-16-01

RO: Dow FilmTec NF90													
RO water recovery	79.6%					Removal	Reduction	Reduction	RO equipment				
RO water flux (gal/ft^2/day)	10.5					by	between	between				RO removal (%)	
RO element area (ft^2)	25.4					SSF	SSF Outlet &	SSF Feed &	RO mass bal. dev. (MBD)		RO water	Based	Based on avg.
10/16/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject		RO feed	RO feed	as % of feed		recovery	on feed	feed
Parameter						(%)	(%)	(%)	1	2	(%)	conc.	reject
Flow (L/min)	83.3	83.3	15.9	12.7	3.3						79.6%		
HPC CFU/mL	17	9	4	3	53	47.1							
TOC, as C (NPOC, mg/L)	5.37	3.33	3.67	< 1.00	15	38.0	-10.2	31.7	> -5.1	< 16.6	-	> 72.8	> 84.6

Table C- 14 --Chemical Balances and Removals on 11-06-01

RO: Dow FilmTec NF90													
RO water recovery	79.7%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water flux (gal/ft^2/day)	10.9											RO removal (%)	
RO element area (ft^2)	25.4								RO mass bal. dev. (MBD) as % of feed		RO water recovery	Based on feed conc.	Based on avg. feed reject
11/6/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.4	13.1	3.3						79.7%		
HPC CFU/mL	18	48	16	< 1	28	-166.7							
TOC, as C (NPOC, mg/L)	3.06	2.99	2.88	< 1.00	14.5	2.3	3.7	5.9	> -29.9	< -2.2	-	> 65.3	> 79.7

Table C- 15 --Chemical Balances and Removals on 11-13-01

RO: Dow FilmTec NF90													
RO water recovery	79.7%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water flux (gal/ft^2/day)	10.9								RO mass bal. dev. (MBD) as % of feed		RO water recovery (%)	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
11/13/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2			
Flow (L/min)	83.3	83.3	16.4	13.1	3.3						79.7%		
HPC CFU/mL	62	139	8	< 1	106	-124.2							
TOC, as C (NPOC, mg/L)	3.62	2.54	2.51	< 1.00	14.5	29.8	1.2	30.7	> -49.1	< -17.3	-	> 60.2	> 76.0

Table C- 16 --Chemical Balances and Removals on 11-27-01

RO: Dow FilmTec NF90						Removal by SSF (%)	Reduction between SSF Outlet & RO feed (%)	Reduction between SSF Feed & RO feed (%)	RO equipment				
RO water recovery	79.3%												
RO water flux (gal/ft^2/day)	10.7								RO mass bal. dev. (MBD) as % of feed		RO water recovery (%)	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
11/27/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter									1	2			
Flow (L/min)	83.3	83.3	16.3	12.9	3.4						79.3%		
HPC CFU/mL	18	73	< 1	< 1	< 10	-305.6							
TOC, as C (NPOC, mg/L)	3.89	4.20	3.72	< 1.00	16.5	-8.0	11.4	4.4	> -13.3	< 8.0	-	> 73.1	> 84.8

Table C- 17 --Chemical Balances and Removals on 12-04-01

RO: Dow FilmTec NF90													
RO water recovery	79.9%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water flux (gal/ft^2/day)	10.9								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
12/4/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.4	13.1	3.3						79.9%		
HPC CFU/mL	61	30	12	< 1	11	50.8							
TOC, as C (NPOC, mg/L)	4.67	5.70	4.63	< 1.00	16.1	-22.1	18.8	0.9	> 12.7	< 29.9	-	> 78.4	> 88.2

Table C- 18 --Chemical Balances and Removals on 12-11-01

RO: Dow FilmTec NF90													
RO water recovery	79.3%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water flux (gal/ft^2/day)	10.7								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
12/11/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.3	12.9	3.4						79.3%		
HPC CFU/mL	18	36	< 1	1	4	-100.0							
TOC, as C (NPOC, mg/L)	3.37	3.48	3.20	< 1.00	14.4	-3.3	8.0	5.0	> -18.1	< 6.7	-	> 68.8	> 81.9

Table C- 19 --Chemical Balances and Removals on 12-18-01

RO: Dow FilmTec NF90						Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water recovery	79.3%								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%) Based on feed conc.	RO removal (%) Based on avg. feed reject
RO water flux (gal/ft^2/day)	10.7												
RO element area (ft^2)	25.4												
12/18/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.3	12.9	3.4						79.3%		
HPC CFU/mL	42	40	2	< 1	26	4.8							
TOC, as C (NPOC, mg/L)	1.67	1.07	1.04	< 1.00	14.6	35.9	2.8	37.7	> -267.3	< -191.1	-	> 3.8	> 8.7

Table C- 20 --Chemical Balances and Removals on 12-26-01

RO: Dow FilmTec NF90						Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water recovery	79.1%								RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO water flux (gal/ft^2/day)	10.6											Based on feed conc.	Based on avg. feed reject
RO element area (ft^2)	25.4												
12/26/2001	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	83.3	83.3	16.1	12.8	3.4						79.1%		
HPC CFU/mL	51	340	< 1	< 1	3	-566.7							
TOC, as C (NPOC, mg/L)	4.16	3.30	3.83	1.10	14.7	20.7	-16.1	7.9	> -3.1	< 19.6	-	> 71.3	> 83.5

Table C- 21 --Chemical Balances and Removals on 1-02-02

RO: Dow FilmTec NF90													
RO water recovery	79.5%					Removal	Reduction	Reduction	RO equipment				
RO water flux ($gal/ft^2/day$)	10.9					by	between	between				RO removal (%)	
RO element area (ft^2)	25.4					SSF	SSF Outlet &	SSF Feed &	RO mass bal. dev. (MBD)		RO water	Based	Based on avg.
1/2/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject		RO feed	RO feed	as % of feed		recovery	on feed	feed
Parameter						(%)	(%)	(%)	1	2	(%)	conc.	reject
Flow (L/min)	83.3	83.3	16.5	13.1	3.4						79.5%		
HPC CFU/mL	16	22	2	< 1	1	-37.5							
TOC, as C (NPOC, mg/L)	2.56	2.00	2.67	< 1.00	10.9	21.9	-33.5	-4.3	> -13.6	< 16.1	-	> 62.5	> 77.7

Table C- 22 --Chemical Balances and Removals on 1-08-02

RO: Dow FilmTec NF90													
RO water recovery	79.5%					Removal by SSF (%)	Reduction between SSF Outlet & RO feed (%)	Reduction between SSF Feed & RO feed (%)	RO equipment				
RO water flux (gal/ft^2/day)	10.9								RO mass bal. dev. (MBD) as % of feed		RO water recovery (%)	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
1/8/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter									1	2			
Flow (L/min)	60.6	60.6	16.5	13.1	3.4						79.5%		
HPC CFU/mL	8	8	1	1	2	0.0							
TOC, as C (NPOC, mg/L)	2.65	2.43	1.57	< 1.00	12.1	8.3	35.4	40.8	> -109.0	< -58.4	-	> 36.3	> 55.4

Table C- 23 --Chemical Balances and Removals on 1-24-02

RO: Dow FilmTec NF90													
									RO equipment				
RO water recovery	79.5%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO water flux (gal/ft^2/day)	10.9											Based on feed conc.	Based on avg. feed reject
RO element area (ft^2)	25.4												
1/24/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	60.6	60.6	16.5	13.1	3.4						79.5%		
HPC CFU/mL	94	26	6	< 1	2	72.3							
TOC, as C (NPOC, mg/L)	1.51	1.04	2.03	< 1.00	10.1	31.1	-95.2	-34.4	> -41.4	< -2.2	-	> 50.7	> 68.6

Table C- 24 --Chemical Balances and Removals on 1-29-02

RO: Dow FilmTec NF90													
RO water recovery	79.5%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO equipment				
RO water flux (gal/ft^2/day)	10.9								RO mass bal. dev. (MBD) as % of feed		RO water recovery (%)	RO removal (%)	
RO element area (ft^2)	25.4											Based on feed conc.	Based on avg. feed reject
1/29/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2			
Flow (L/min)	60.6	60.6	16.5	13.1	3.4						79.5%		
HPC CFU/mL	26	7	2	1	22	73.1							
TOC, as C (NPOC, mg/L)	1.71	2.88	1.64	< 1.00	10.5	-68.4	43.1	4.1	> -80.0	< -31.6	-	> 39.0	> 58.1

Table C- 25 --Chemical Balances and Removals on 2-07-02

RO: Dow FilmTec NF90									RO equipment				
RO water recovery	79.5%												
RO water flux (gal/ft^2/day)	10.9												
RO element area (ft^2)	25.4												
Parameter	SSF feed	SSF outlet	RO feed	RO prod.	RO reject	Removal by SSF (%)	Reduction between SSF Outlet & RO feed (%)	Reduction between SSF Feed & RO feed (%)	RO mass bal. dev. (MBD) as % of feed 1	RO mass bal. dev. (MBD) as % of feed 2	RO water recovery (%)	RO removal (%) Based on feed conc.	RO removal (%) Based on avg. feed reject
Flow (L/min)	60.6	60.6	16.5	13.1	3.4						79.5%		
HPC CFU/mL	22	5	20	1	48	77.3							
TOC, as C (NPOC, mg/L)	2.20	1.54	1.60	< 1.00	11.6	30.0	-3.9	27.3	> -98.6	< -49.0	-	> 37.5	> 56.6

Table C- 26 --Chemical Balances and Removals on 2-12-02

RO: Dow FilmTec NF90						
RO water recovery	79.3%					Removal by SSF
RO water flux (gal/ft^2/day)	10.8					
RO element area measured 4/3/02 (ft^2)	25.4					
2/12/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject	
Parameter						(%)
Flow (L/min)	60.6	60.6	16.4	13.0	3.4	
HPC CFU/mL	38	33				13.2
TOC, as C (NPOC, mg/L)	3.13	2.69				14.1

Table C- 27 --Chemical Balances and Removals on 2-19-02

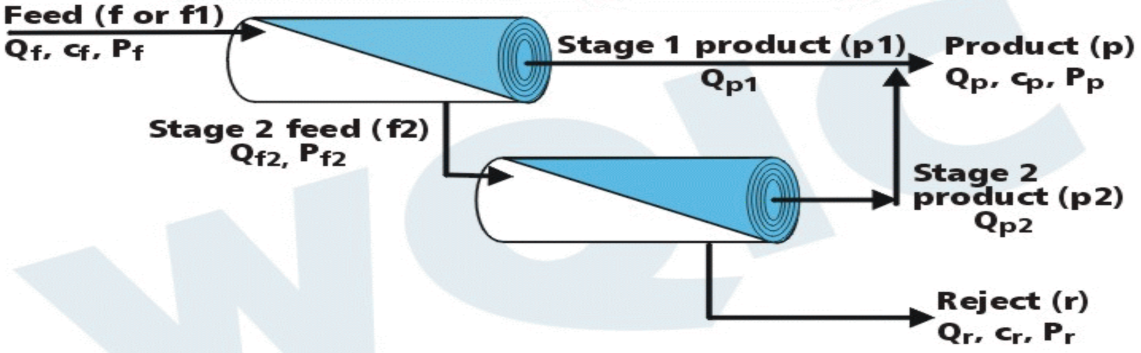
RO: Dow FilmTec NF90									RO equipment				
RO water recovery	79.3%					Removal by SSF	Reduction between SSF Outlet & RO feed	Reduction between SSF Feed & RO feed	RO mass bal. dev. (MBD) as % of feed		RO water recovery	RO removal (%)	
RO water flux (gal/ft^2/day)	10.8											Based on feed conc.	Based on avg. feed reject
RO element area measured 4/3/02 (ft^2)	25.4												
2/19/2002	SSF feed	SSF outlet	RO feed	RO prod.	RO reject								
Parameter						(%)	(%)	(%)	1	2	(%)		
Flow (L/min)	60.6	60.6	16.4	13.0	3.4						79.3%		
HPC CFU/mL	21	< 1	< 1	< 1	68	> 95.2	-	-	-	-	-	-	-
TOC, as C (NPOC, mg/L)	3.24	2.35	3.03	< 1.00	10.1	27.5	-28.9	6.5	> 4.8	< 30.9	-	> 67.0	> 80.7

Appendix D

WQIC Reverse Osmosis Equations

WQIC Reverse Osmosis Equations

Flow Schematic for 2-Stage RO Desalting Plant



Water Quality Improvement Center * U.S. Bureau of Reclamation

Pilot-scale membrane water treatment research * *520-343-8214* *www.yao.lc.usbr.gov*

Membrane Equations

(1) MBD = (Mass Flow In - Mass Flow Out)/(Mass Flow In) * 100%

(2) $MBD_w = (Q_f - Q_r - Q_p)/Q_f * 100\%$

(3) If Q_f is not accurately measured, then assume $MBD_w = 0$ and $Q_f = Q_r + Q_p$

(4) $MBD_s = (Q_f * c_f - Q_r * c_r - Q_p * c_p)/(Q_f * c_f) * 100\%$

(5) $q = Q_p / S$

(6) $r = (Q_p / Q_f) * 100\%$

(7) If $MBD_s = 0$ then $r(alt) = (c_r - c_f)/(c_r - c_p)$

(8) $Q_{cj} = -r_j / \ln(1 - r_j) * Q_{fj}$

(9) $SP = (c_p / c_c) * 100\%$ where

(10) $c_c = c_p * \ln(1 - r)/\ln(1 - r * c_p/c_f)$

or using concentrations alone:

(11) $c_c(alt) = c_f * \ln(c_r / c_f)/(1 - c_f / c_r)$

(12) $SR = 100\% - SP$

(13) $\overline{MW} = \Sigma(c_i / MW_i) / \Sigma(c_i) = \Sigma(c_i / MW_i) / TDS$

(14) $\Pi = (\Phi * TDS/\overline{MW}) * R * (T + 273.15)$

(15) $A = q/(P_f - 0.5 * (P_f - P_r) - P_p - \Pi_c + \Pi_p)$

(16) $A^\circ = A * 1.026^{(20 - T)}$

(17) $B = q * c_p / (c_c - c_p)$

(18) $B^\circ = B * 1.026^{(20 - T)}$

(19) $C_j = Q_{cj} / n_{vj} / (dP_j / n_e)^{0.6}$

(20) $C_j^\circ = C * 1.0047^{(20 - T)}$

Symbol List & Sample Calculations

Chemical parameters & temperature

SYMBOL	WQIC UNITS	OTHER UNITS	DESCRIPTION
R	8314 J/gmole/°K	0.08314 L-bar/gmole/K	Gas constant
$\overline{MW}$	g/mole		Solute mole weight
$\overline{MW}_p$	32 g/mole		Average mole weight of solutes in product; use mg/mole in equations
$\overline{MW}_c$	46 g/mole		Average mole weight of solutes in feed and reject; use mg/mole in equations
i			Subscript for solute species (e.g., Na^+, Ca^{2+}, Cl^-, SO_4^{2-})
ϕ	0.9		Osmotic coefficient; generally $0.80 < \phi < 1.00$
T	30 °C	86 °F	Temperature

Reverse osmosis module sizes

The example desalting plant contains 180 8″ by 40″ RO elements

S_e	32.1 m^2	346 ft^2	RO element membrane area: 2.5″ x 40″ = 2.1 - 2.3m^2; 4.0″ x 40″ = 6.3 - 7.2m^2; 8.0″ x 40″ = 28 - 37m^2
n_e	6		Number of RO elements per vessel

n_{v1}	20		Number of RO vessels in parallel in stage 1
n_{v2}	10		Number of RO vessels in parallel in stage 2
S	5,778 m^2	62,194 ft^2	Membrane active surface area; S=number of RO elements * S_e
j			Subscript for RO stage number (e.g., 1, 2, 3)

Water Flows

Q_p	0.0463 m^3/s	1,057,000 gpd	Total product water flow; gpd=gallons per day
Q_{p1}	0.0324 m^3/s	740,000 gpd	Product water flow from stage 1
Q_{p2}	0.0139 m^3/s	317,000 gpd	Product water flow from stage 2
Q_f	0.0579 m^3/s	1,321,000 gpd	Feed water flow
Q_r	0.0116 m^3/s	264,000 gpd	Reject water flow
q	8.02E-06 m^3/s	17.0 gfd	Average membrane water flux; gfd=gal/ft^2/day
Q_{c1}	0.0395 m^3/s	625.7 gpm	Average feed-reject concentrate flow in stage 1 gpm=gallons per minute
Q_{c2}	0.0176 m^3/s	279.2 gpm	Average feed-reject concentrate in stage 2
MBD_w	0 %		Mass balance deviation for water; $\|MBD_w\| > 3\%$ indicates inaccurate flowmeters or equipment leaks
r	80 %		Water recovery; percentage of feedwater converted to product water

Concentrations

SYMBOL	WQIC UNITS	OTHER UNITS	DESCRIPTION
c_p, c_f, c_r, c_c	mg/L		Concentration (TDS or individual solutes); c = TDS in this example; subscripts p = product, f = feed, r = reject, c = concentrate (average feed-reject)
EC_p	120 µS/cm	0.12 d S/m	Electrical conductivity (EC) of product at 25°C
EC_f	1,400 µS/cm	1.40 d S/m	Feedwater EC
EC_r	5,500 µS/cm	5.5 d S/m	Reject water EC
TDS_p	63 mg/L		Total dissolved solids (TDS); including all solutes and 100% of bicarbonate; TDS = Σc_i for all solutes, i; for Colorado River, RO product, TDS ≈ 5.0 + 0.486 * EC
TDS_f for	698 mg/L		TDS of feed; TDS_f and $TDS_r \approx a*(1+b*EC^{0.5})*EC$; RO of Colorado River from 700 to 5,000 mg/L, a ≈ 0.43, b ≈ 0.0046; for NaCl from 3,000 to 70,000 mg/L, a ≈ 0.485, b ≈ 0.00132; for seawater from 5,000 to 60,000 mg/L; a ≈ 0.47, b ≈ 0.0021
TDS_r	3,138 mg/L		TDS of reject
TDS_c	1,353 mg/L		Average TDS of concentrate (feed-reject) stream
TDS_c(alt)	1,350 mg/L		Average feed-reject TDS using concentration alone
MBD_s	2.9 %		Mass balance deviation for solute (for TDS and individual solutes) MBD_s < -10% indicates error probably in feed or reject flow or concentration measurements; MBD_s > 10% indicates feed or reject measurement error, equipment leaks, or membrane scaling
r (alt)	79.3 %		Water recovery estimated from concentration

Pressures (use Pa in equations)

P_f	1,379 kPa	200 psi	Feed pressure
P_{f2}	1,172 kPa	170 psi	Stage 2 feed pressure
P_r	965 kPa	140 psi	Reject pressure
P_p	34 kPa	5 psi	Product pressure
dP_1	207 kPa	30 psi	Stage 1 (feed-interstage) pressure drop; $dP_1=P_f - P_{f2}$
dP_2	207 kPa	30 psi	Stage 2 (interstage-reject) pressure drop; $dP_2=P_{f2}-P_r$
Π_p	4 kPa	0.7 psi	Osmotic pressure of product water
Π_c	67 kPa	9.7 psi	Average feed-reject osmotic pressure

Performance Parameters

SP	4.7 %		Solute passage (for TDS and individual solutes)
SR	95.3 %		Solute rejection (for TDS and individual solutes)
A	7.45E-12 m/s/Pa	0.109 gfd/psi 7.45E-05 cm/s/bar	Water transport coefficient; A is less than for the membrane alone by ca. 10-20% because of product water channel pressure drop and concentration polarization
A°	5.77E-12 m/s/Pa	0.084 gfd/psi 5.77E-05 cm/s/bar	A at 20°C; temperature correction term ranges from 1.024 to 1.030; A° decreasing over time indicates fouling or scaling; A° increasing over time indicates degradation
B	3.93E-07 m/s		Solute transport coefficient (for TDS and individual solutes); B is less than for the membrane alone by ca. 10-20% because of concentration polarization
B°	3.04E-07 m/s		B at 20°c; temperature correction term ranges from 1.024 to 1.030; B° increasing over time indicates degradation
B/A	53 kPa	7.7 psi 0.53 bar	Proportional to SP for low SP at constant hydrostatic and osmotic pressures
B/q	4.9 %		≈ SP for low SP

C_1	3.76E-06 $m^3/s/Pa^{0.6}$	11.9 $gpm/psi^{0.6}$	Stage 1 element coefficient; exponent on dP may vary from 0.60 to 0.67; C and the exponent are less than for the element alone because of vessel manifold pressure drops
C_2	3.34E-06 $m^3/s/Pa^{0.6}$	10.6 $gpm/psi^{0.6}$	Stage 2 element flow coefficient
$C_1°$	3.57E-06 $m^3/s/Pa^{0.6}$	11.4 $gpm/psi^{0.6}$	C_1 at 20°C; temperature correction term is 1.0047 for $dP^{0.60}$ and 1.0079 for $dP^{0.67}$; $C_1°$ decreasing over time indicates fouling
$C_2°$	3.19E-06 $m^3/s/Pa^{0.6}$	10.1 $gpm/psi^{0.6}$	C_2 at 20°C; $C_2°$ decreasing over time indicates fouling or scaling

The equations on this card are presented as useful tools for monitoring reverse osmosis performance. Equations such as Nos.15-20 are sometimes referred to as "normalization" equations. Other equations may also be used. Reclamation assumes no liability associated with the use of these calculations. © 2001, U.S. Bureau of Reclamation; Rev. 1, 2001

Water Quality Improvement Center * U.S. Bureau of Reclamation

Pilot-scale membrane water treatment research * ***520-343-8214*** *www.yao.lc.usbr.gov*

Appendix E

Cleaning Procedures for FILMTEC FT30 Elements

FILMTEC Membranes

Cleaning Procedures For FILMTEC FT30 Elements

The following are general recommendations for cleaning FILMTEC® FT30 elements. More detailed procedures for cleaning an RO system are typically included in the operating manual provided by the system supplier.

It should be emphasized that frequent cleaning is not required for a properly designed and properly operated RO system, but because of the FT30 membrane's combination of pH stability and temperature resistance, cleaning can be accomplished very effectively.

Cleaning Requirements

In normal operation, the membrane in reverse osmosis elements can become fouled by mineral scale, biological matter, colloidal particles, and insoluble organic constituents. Deposits build up on the membrane surfaces during operation until they cause loss in water output, loss of salt rejection, or both.

Elements should be cleaned whenever the normalized permeate flow drops by ≥10%, or the normalized salt passage increases by ≥5%, or the normalized differential pressure (feed pressure minus concentrate pressure) increases by ≥15% from the reference condition established during the first 48 hours of operation.

ΔP should be measured and recorded across each stage of the array of pressure vessels. If the brine channels within the element become fouled, the ΔP will increase.

It should be noted that the water output rate will drop if feedwater temperature decreases. This is normal and does not indicate membrane fouling. A malfunction in the pretreatment, pressure control, or pump can cause a drop in product water output or an increase in salt passage. If a problem is observed, these causes should be considered. The element(s) may not require cleaning.

A computer program called FT NORM is now available from Dow (Form No. 609-00163) for normalizing performance data of FILMTEC RO membranes. This program can be used to determine when to clean.

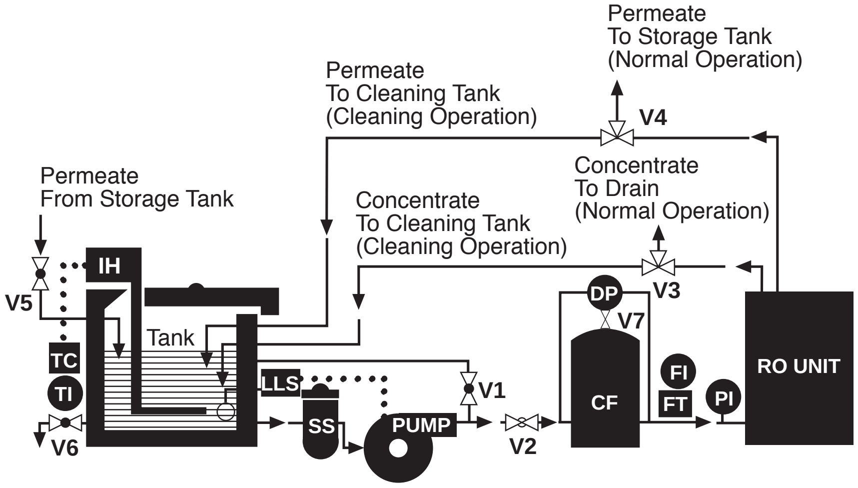
Safety Precautions

1. In using any chemical indicated in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions to the elements.
3. It is desirable to flush the elements with good-quality chlorine-free water (20°C minimum temperature) after cleaning. RO product water is recommended; but prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, the permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12 for BW/TW elements.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrustring is installed only on the reject end of the vessel. The same procedure is recommended also for smaller elements.

Equipment for cleaning is illustrated on the following page.

*Trademark of The Dow Chemical Company

Cleaning System Flow Diagram



TANK	Chemical Mixing Tank, polypropylene or FRP
IH	Immersion Heater (may be replaced by cooling coil for some site locations)
TI	Temperature Indicator
TC	Temperature Control
LLS	Lower Level Switch to shut off pump
SS	Security Screen–100 mesh
PUMP	Low-Pressure Pump, 316 SS or non-metallic composite
CF	Cartridge Filter, 5-10 micron polypropylene with PVC, FRP, or SS housing

DP	Differential Pressure Gauge
FI	Flow Indicator
FT	Flow Transmitter (optional)
PI	Pressure Indicator
V1	Pump Recirculation Valve, CPVC
V2	Flow Control Valve, CPVC
V3	Concentrate Valve, CPVC 3-way valve
V4	Permeate Valve, CPVC 3-way valve
V5	Permeate Inlet Valve, CPVC
V6	Tank Drain Valve, PVC, or CPVC
V7	Purge Valve, SS, PVC, or CPVC

Suggested Equipment

The equipment for cleaning is shown in the Cleaning System Flow Diagram. The pH of cleaning solutions used with FILMTEC elements can be in the range of 1 to 12 (see Table 2), and therefore non-corrosive materials should be used in the cleaning system.

1. The mixing tank should be constructed of polypropylene or fiberglass-reinforced plastic (FRP). The tank should be provided with a removable cover and a temperature gauge.

The cleaning procedure is more effective when performed at an elevated temperature, and it is recommended that the solution be maintained according to the pH and temperature guidelines listed in Table 2. It is not recommended to use a cleaning temperature below 15°C because of the very slow cleaning rate at low temperatures. In addition, chemicals such as sodium lauryl sulfate might precipitate at low temperatures. Cooling may also be required in certain parts of the world, so heating/cooling requirements must be considered during the design.

A rough rule of thumb in sizing a cleaning tank is to use approximately the empty pressure vessel volume and then add the volume of the feed and return hoses or pipes.

For example, to clean eight 8-inch diameter pressure vessels with six elements per vessel, the following calculations would apply:

A. Volume in Vessels

$$V1 = pr^2 \times L =$$

$$= 3.14 \frac{(\ 4\text{ in}\ )^2}{(144\text{ in}^2/\text{ft}^2)} (20\text{ ft})(7.48\text{ gal/ft}^3)$$

$V1 = 52$ gal/vessel (0.2 m^3)

$V1 = 52 \times 8 = 416$ gal (1.58 m^3)

B. Volume in Pipes, assume 50 ft length total 4” SCF 80 pipe

$$Vp = pr^2L$$

$$= 3.14 \frac{(\ 1.91\text{ in}\ )^2}{(144\text{ in}^2/\text{ft}^2)} (50\text{ ft})(7.48\text{ gal/ft}^3)$$

$= 30$ gals (0.11 m^3)

$Vct = V8 + Vp = 416 = 30 = 446$

Therefore, the cleaning tank should be about 450 gals (1.7 m^3).

2. The cleaning pump should be sized for the flows and pressures given in Table 1, making allowances for pressure drops in the piping and across the cartridge filter. The pump should be constructed of 316 SS or nonmetallic composite polyesters.
3. Appropriate valves, flow meters, and pressure gauge should be installed to adequately control the flow. Service lines may be either hard piped or portable hoses. In either case, the flow rate should be a moderate 10 ft/sec (3 m/sec) or less.

Cleaning Elements In-Situ

There are six steps in the cleaning of elements:

1. Mix cleaning solution.
2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 1) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.
3. Recycle. After the process water is displaced, cleaning solution will be present in the concentrate stream. Then recycle the concentrate to the cleaning solution tank and allow the temperature to stabilize.

Table 1. Recommended feed flow rate per pressure vessel during high flow rate recirculation.

Feed Pressure[1] (psig)	Feed Pressure[1] (bar)	Element Diameter (inches)	Feed Flow Rate per PV (gpm)	Feed Flow Rate per PV (m^3/hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.8-9.1
20-60	1.5-4.0	8[2]	35-45[2]	8.0-10.2[2]

1) Dependent on number of elements in pressure vessel
2) For 400 sq. ft. area elements

Table 2. pH range and temperature limits during cleaning.

	Max Temp 50°C pH Range	Max Temp 35°C pH Range	Max Temp 30°C pH Range	Continuous Operation
SW30, SW30HR	3-10	2-11	2-12	2-11
BW30, TW30	2-10	1-11	1-12	2-11
NF45	3-10	2-11	2-11	3-10
NF55, NF70, NF90	3-10	2-11	1-11	3-9

4. Soak. Turn the pump off and allow the elements to soak. Sometimes a soak period of about 1 hour is sufficient. For difficult fouling an extended soak period is beneficial; soak the elements overnight for 10-15 hours. To maintain a high temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 1).

5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 1 for 30-60 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, a flow rate which is 50 percent higher than shown in Table 1 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 20 psi per element or 60 psi per multi-element vessel, whichever value is more limiting.

6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). To prevent precipitation, the minimum flush out temperature is 20°C.

Additional notes: Check the pH during acid cleaning. The acid is consumed when it dissolves inorganic precipitates. So, if the pH increases more than 0.5 pH units, add more acid.

If the system has to be shut down for a period of 24 hours to one week, the elements should be stored in a 1.5 percent (by weight) solution of sodium metabisulfite (food grade). For longer periods, the best medium for storage is an aqueous solution with 18 percent (by weight) propylene glycol and 1.5 percent (by weight) sodium metabisulfite (food grade). This solution also provides protection from freeze damage.

Multistage Systems

For multistage (tapered) systems, the flushing and soaking operations can always be done simultaneously in all stages. High-flow recirculation, however, should be carried out separately for each stage, so the flow rate is not too low in the first stage or too high in the last. This can be accomplished either by using one cleaning pump and operating one stage at a time, or by using a separate cleaning pump for each stage.

Cleaning Chemicals

Table 3, next page, lists suitable cleaning chemicals. Acid cleaners and alkaline cleaners are the standard cleaning chemicals. The acid cleaners are used to remove inorganic precipitates including iron, while the alkaline cleaners are used to remove organic fouling including biological matter. Sulfuric acid should not be used for cleaning because of the risk of calcium sulfate precipitation.

Preferably reverse osmosis permeate should be used for the cleaning solutions, but prefiltered raw water will also work in most cases. The raw water can be highly buffered, so more acid or hydroxide may be needed with raw water to reach the desired pH level, which is about 2 for acid cleaning and about 12 for alkaline cleaning.

FILMTEC Membranes

For more information about FILMTEC membranes,
call Dow Liquid Separations:
North America 1-800-447-4369
Latin America . . . .(+55) 11-5188-9345
Europe . . . .(+31) 20-691-6268
Japan . . . .(+81) 3-5460-2100
Australia . . . .(+61) 2-9776-3226
http://www.dow.com/liquidseps

Table 3. Simple cleaning solutions for FT30 membrane.

Cleaner / Foulant	0.1% (W) NaOH and pH 12, 30°C max. or 1.0% (W) Na_4EDTA and pH12, 30°C max.	0.1% (W) NaOH and pH 12, 30°C max. or 0.025% (W) Na-DSS and pH12, 30°C max.	0.1% STP and 1.0% Na_4EDTA or 0.1% TSP and 1.0% Na_4EDTA	0.2% (W) HCl	0.5% (W) H_3PO_4	2.0% (W) Citric Acid	0.2% (W) NH_2SO_3H	1.0 % (W) $Na_2S_2O_4$
Inorganic Salts (for example, $CaCO_3$				best	OK	OK	OK	
$CaSO_4$, $BaSO_4$)				best				
Metal Oxides (for example, iron)					good		OK	good
Inorganic Colloids (silt)		good						
Silica	OK							
Biofilms	best	good	good					
Organic	OK	good	good					

1. (W) denotes weight percent of active ingredient.
2. Foulant chemical symbols in order used: $CaCO_3$ is calcium carbonate; $CaSO_4$ is calcium sulfate; $BaSO_4$ is barium sulfate.
3. Cleaning chemical symbols in order used: NaOH is sodium hydroxide; Na_4EDTA is the tetrasodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE* 100 and VERSENE* 220 crystals; Na_4DSS is sodium salt of dodecylsulfate; STP is sodium triphosphate ($Na_5P_3O_{10}$); TSP is trisodium phosphate ($Na_3PO_4 \cdot 12H_2O$); HCl is hydrochloric acid; H_3PO_4 is phosphoric acid; $C_3H_4(OH)(CO_2H)_3$ is citric acid; NH_2SO_3H is sulfamic acid; $Na_2S_2O_4$ is sodium hydrosulfite.
4. Contact a representative of FILMTEC products if a more effective cleaner is needed for silica.

Published April 1998.

Form No. 609-23010-498XQRP
CH 172-086-E-498R

Appendix F

RO Element Dissection

Appendix F

RO Element Dissection

Contents

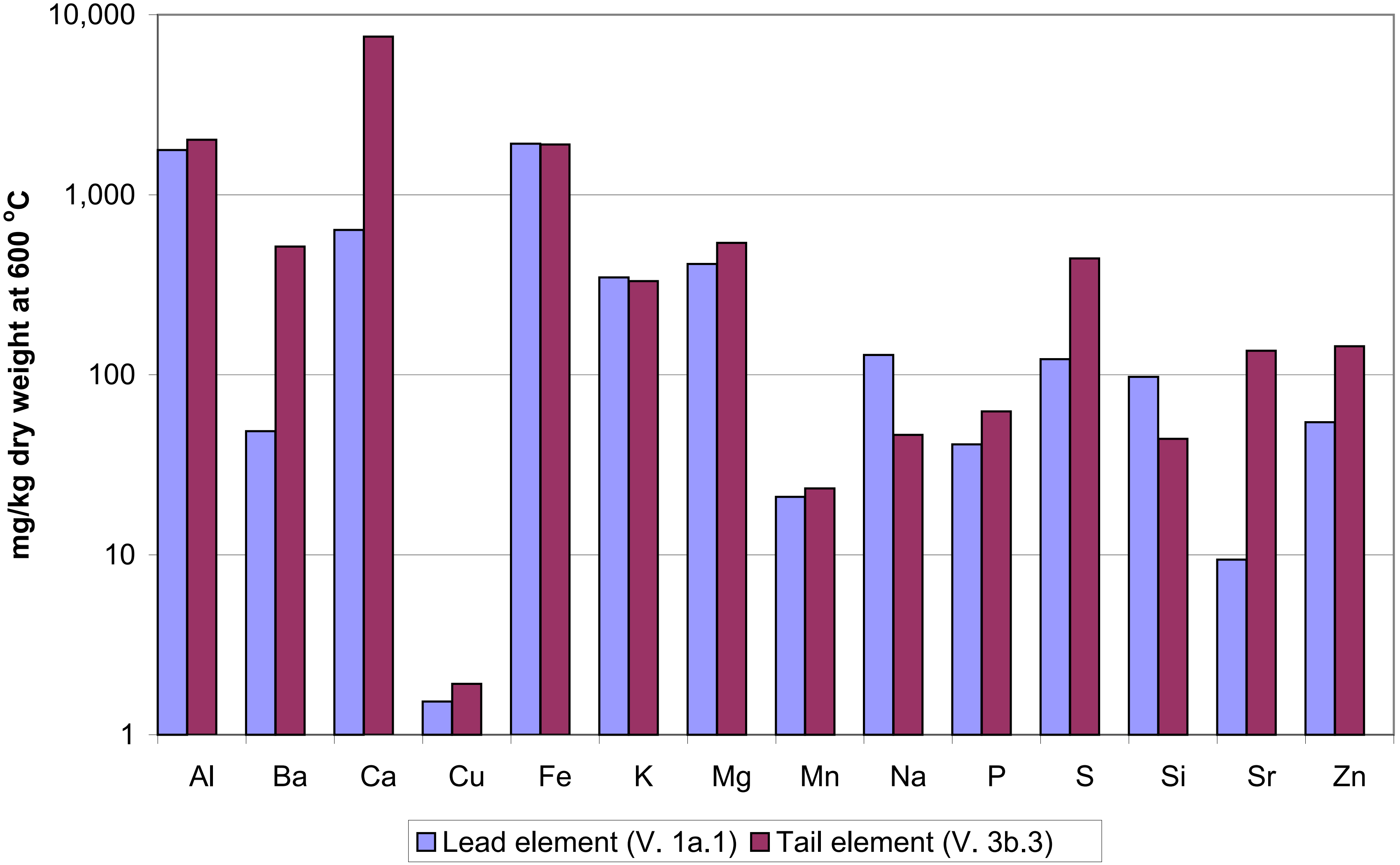


Figure F-1 --Composition of solids scraped from the lead and tail RO elements

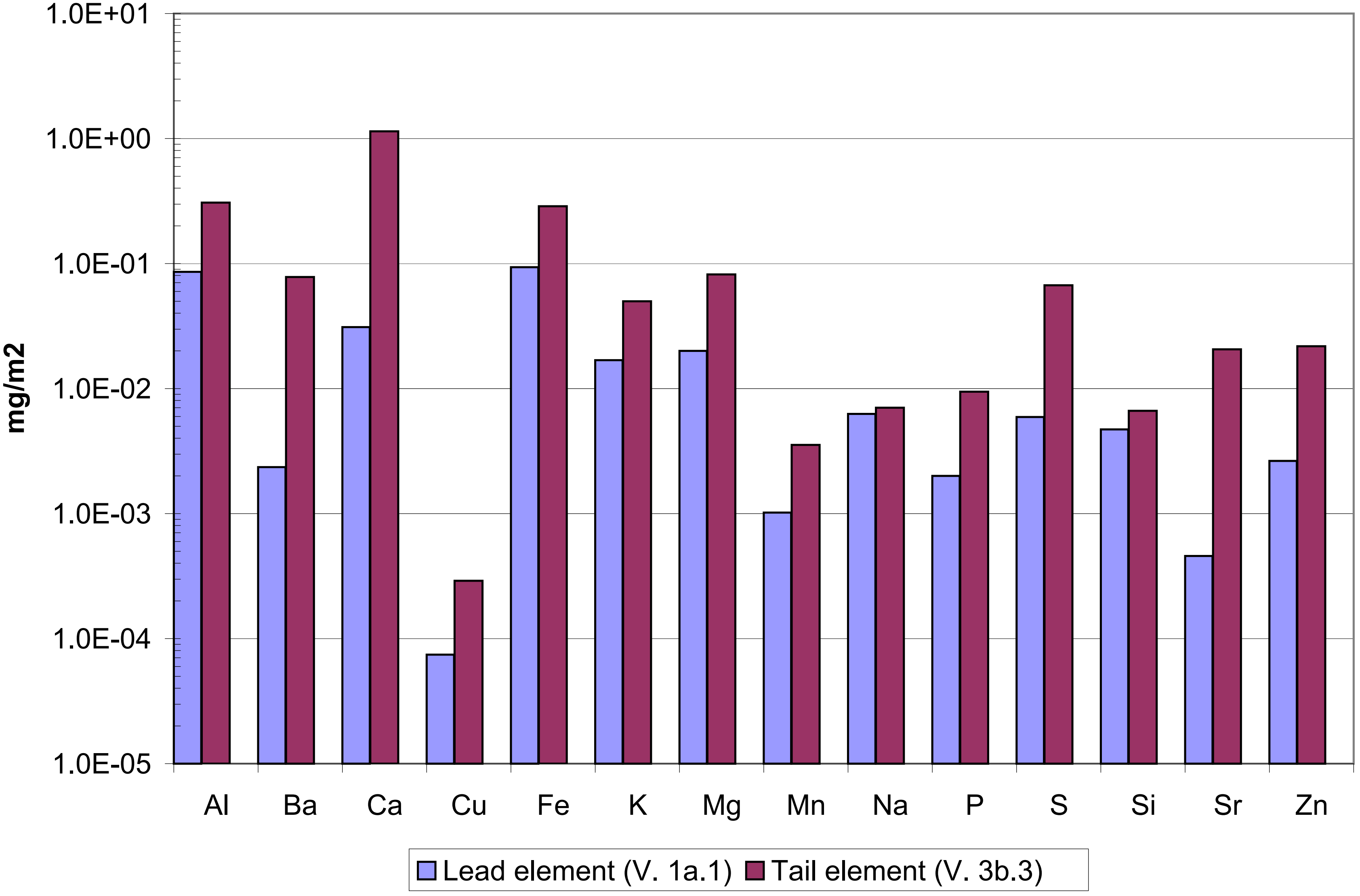


Figure F-2 --Surface density of solids scraped from the lead and tail RO elements

Separation Systems Technology
4901 Morena Blvd - Bldg 809
San Diego, CA. 92037

Tel 858 581 3765
Fax 858 581 1211

ELEMENT DISSECTION RESULTS: LEAD ELEMENT

FilmTec NF-90-2540 / Marana, AZ. pilot test, 10/01 TO 03/02
Lead Element V1A#1

Date: April 3, 2002

Autopsy by: Isa, Shui and Bob

Element:

Supplier: **FilmTec**
Designation: **NF-90 2540 A8425281**
Dimensions: **2.5" x 40"**
Weight: **1425 grams**
Dyed: **No**

Reason for Dissection:

Cause of failure: **Elements did not fail**
Element Quality Control: **Excellent**
Membrane sampling: **Yes**
Membrane area: **Yes**
Diagnostic: **Yes**

Element Materials of Construction:

Outerwrap: **2" yellow vinyl tape**
Product Water Tube: **Noryl**
Feed Spacer: Type: **Vexar** Thickness: **30 mils**
Product Water Channel: Type: **Tricot** Thickness **10 mils**
Adhesive: **Polyurethane**
Membrane: **Composite NF-90**

Membrane:

Type: **Composite NF-90** Color: **Straw** Substrate Materiall: **Polyester non-woven**
Total Thickness: **6.0 mils**, Substrate Thickness: **4.0 mils**; Peeled Membrane Thickness: **3.25 mils**
Peel Strength: **Good** Membrane Penetration into Substrate: **Slight**
Patches: **None** Wrinkles: **One** Osmotic Blisters: **None**
Vexar Damage: **Impression pattern could be seen**

Active (Net) Membrane Area:

Number of Membrane Leaves in Element: **2**
Leaf # 1 27.75" x 32.75" x 2 = **12.6** sq.ft Leaf # 2 27.5" x 33.0" x 2 = **12.6** sq.ft
Total Membrane Area in Element **25.2** sq.ft

Foulant:

Nature: **Tan colored paste** Amount: **1.8** gms / sq. ft
Biological: **Does not appear to be** Inorganic Scale: **Not likely**
Comments: **Appears to be pre-treatment material**

Adhesive:

Peel Strength: **Excellent** Penetration: **Good**

General Comments

- **Accompanying three photos were taken of the element through the autopsy.**
- **Lead element V1A#1, 5 months operation at Marana, AZ. pilot test - October 01 to March 02**
- **Foulant sample from one side of membrane leaf and component samples sent to Chuck Moody, Bureau of Reclamation**

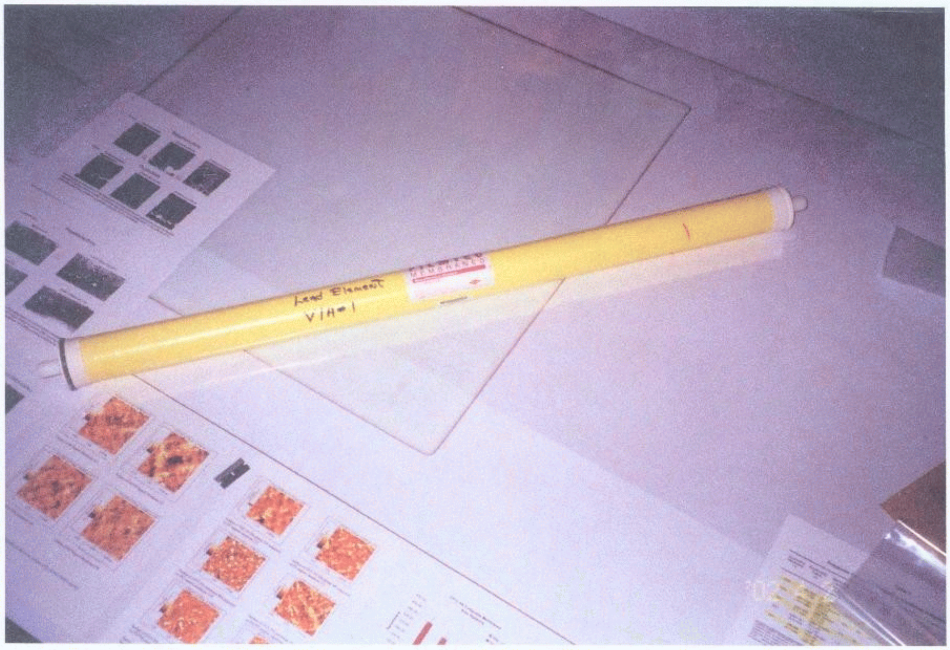


Figure 1 FilmTec NF-90-2540 A8425281. Lead element V1A#1 before autopsy
Morana, AZ. pilot test 10/01 – 03/02

Figure 2 FilmTec NF-90-2540 A8425281. Lead element V1A#1 showing foulant.
Morana, AZ. pilot test 10/01 – 03/02

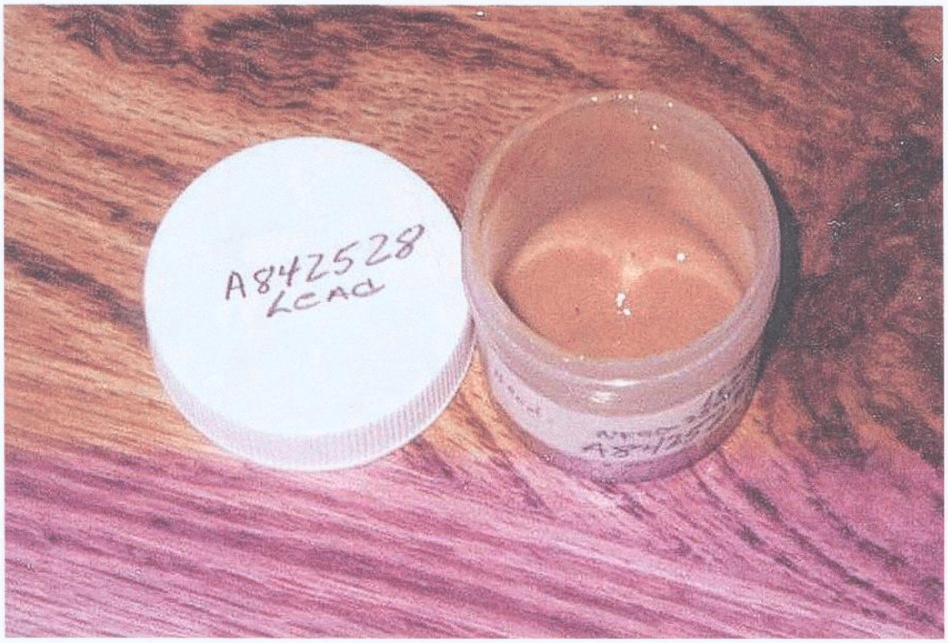


Figure 3 FilmTec NF-90-2540 A8425281. Lead element V1A#1 foulant collected from one-half element leaf. Morana, AZ pilot test. 10/01 – 03/02.

Separation Systems Technology
4901 Morena Blvd - Bldg 809
San Diego, CA. 92037

Tel 858 581 3765
Fax 858 581 1211

ELEMENT DISSECTION RESULTS: TAIL ELEMENT

FilmTec NF-90-2540 / Marana, AZ. pilot test, 10/01 TO 03/02
Tail Element V3B#3

Date: April 3, 2002

Autopsy by: Isa, Shui and Bob

Element:

Supplier: **FilmTec**
Designation: **NF-90 2540 A8425281**
Dimensions: **2.5” x 40”**
Weight: **1365 grams**
Dyed: **No**

Reason for Dissection:

Cause of failure: **Elements did not fail**
Element Quality Control: **Excellent**
Membrane sampling: **Yes**
Membrane area: **Yes**
Diagnostic: **Yes**

Element Materials of Construction:

Outerwrap: **2” yellow vinyl tape**
Adhesive: **Polyurethane**
Product Water Tube: **Noryl**
Membrane: **Composite NF-90**
Feed Spacer: Type: **Vexar** Thickness: **30 mils**
Product Water Channel: Type: **Tricot** Thickness **10 mils**

Membrane:

Type: **Composite NF-90** Color: **Straw** Substrate Materiall: **Polyester non-woven**
Total Thickness: **6.0 mils**, Substrate Thickness: **4.0 mils**; Peeled Membrane Thickness: **3.25 mils**
Peel Strength: **Good** Membrane Penetration into Substrate: **Slight**
Patches: **None** Wrinkles: **One** Osmotic Blisters: **None**˜˜
Vexar Damage: **Impression pattern could be seen**

Active (Net) Membrane Area:

Number of Membrane Leaves in Element: **2**
Leaf # 1 27.75” x 33.5” x 2 = **12.9** sq.ft Leaf # 2 27.5” x 33.25” x 2 = **12.7** sq.ft
Total Membrane Area in Element **25.6** sq.ft

Foulant:

Nature: **Tan colored paste**
Amount: **2.4** gms / sq. ft
Biological: **Does not appear to be**
Inorganic Scale: **Not likely**
Comments: **Appears to be pre-treatment material**

Adhesive:

Peel Strength: **Excellent** Penetration: **Good**

General Comments

- **Accompanying three photos were taken of the element through the autopsy.**
- **Tail element V3B#3, 5 months operation at Marana, AZ. pilot test - October 01 to March 02**
- **Foulant sample from one side of membrane leaf and component samples sent to Chuck Moody, Bureau of Reclamation**

Figure 1 FilmTec NF-90-2540 A8425280. Tail element V3B#3 before autoposy.
Morana, AZ. pilot test 10/10 – 03/02

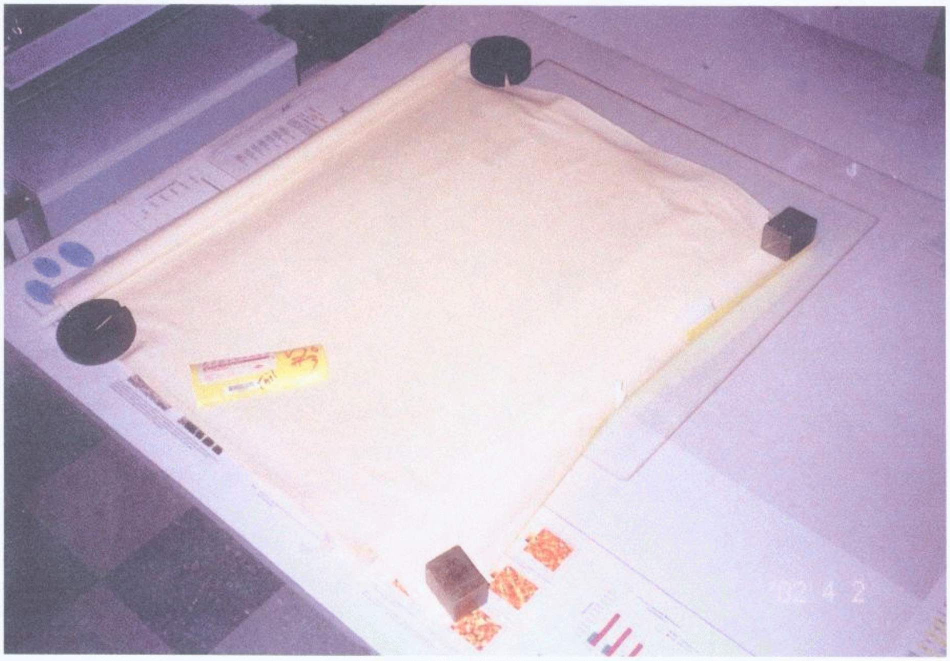


Figure 2 FilmTec NF-90-2540 A8425280. Tail element V3B#3 showing foulant.
Morana, AZ. pilot test 10/01 – 03/02

Figure 3 FilmTec NF-90-2540 A8425280. Tail element V3B#3 foulant collected.
Morana, AZ. pilot test 10/01 – 03/02

Membrane Foulant Analysis

for

Bureau of Reclamation
D-8230
Denver, CO 80225-0007

Attention: Mr. Chuck Moody

Service Request Number: 02-1093

June 21, 2002

ECOLAB®
Food & Beverage Division

Filtration Group Technical Service Department
820 Sibley Memorial Highway
Mendota Heights, MN   55118
Phone: 651-306-5842
Fax: 651-552-4854

Background

The Bureau of Reclamation has been running a pilot plant study using nano-filtration thin film composite membranes on a water feed source. The feed source is treated with an antiscalant agent known as Flocon 100.

At the end of the pilot study the FilmTec™ NF90 2540 reverse osmosis (RO) elements were dissected. They were found to have a gelatinous deposit on the membrane surface. Mr. Moody meticulously removed samples of this material from the active membrane surface and asked to have them analyzed by Ecolab to see if the Flocon 100 was part of the gel layer. The samples provided were taken from two separate elements from one leaf of each. Also provided was a 125 ml sample taken from the resident Flocon 100 source to aid in the Fourier Transform Infrared Spectrometer (FTIR) comparison.

Sample Inspection

Antiscalant

This sample was received in a 125 ml nalgene sample container. The container was in excellent condition with no signs of leakage. The amber colored liquid contained within and the aroma of the material is consistent with the Flocon 100 product.

"Lead" scrape sample (A)

Labeling on this container indicated the contents were from a "lead" element of the pilot plant with the serial number A8425281. The contents' color is light tan/brown. There is an earthen aroma to the contents. The texture of the substance is like a very moist liquid paste.

"Tail" scrape sample (B)

Labeling on this container indicated the contents were from "tail" or the last element contained within the RO element series. The elements' serial number is A8425280. The contents, color and aromatic quality of this sample is the same as the previously described sample.

Analytical :

FTIR
All three samples prepared and sent to the analytical labs. It was decided that FTIR would be used to identify and compare the spectroscopy of the three samples provided to aid in identifying the presence of Flocon 100 within the gel substance. The spectrum from sample C was consistent when compared to samples of Flocon 100 on file.

The three samples were processed with all three graph images placed on one page for ease of comparison. The graph images are referenced later in this text in Appendix 1.

ICP

Portions of all three samples were processed through Inductively Coupled Plasma (ICP) to discover the cationic constituency of the substance. An interest was also noted for the weight differentials during the ash process of the preparation of the samples.

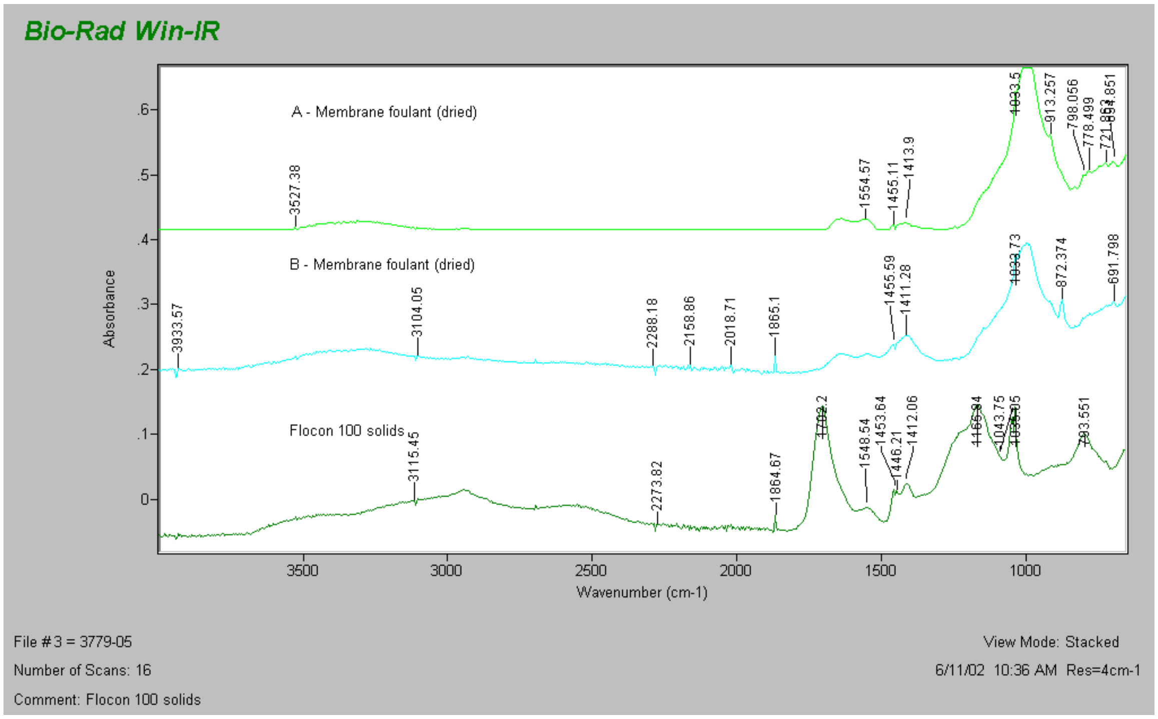
A summery of constituents along with the weights taken during the preparation of the samples is listed below in Appendix 2.

Conclusions

The spectrum contained some peaks that were consistent with the Flocon 100. However, it is not possible to confirm the presence of Flocon 100 based on the data. Taking the finding from both the FTIR and ICP the mixture of material contained in samples A and B are more consistent with a mixture of silt, clay and bioorganic material.

Martin P. Grimes
Senior Service Technician
Ecolab, Filtration Group

APPENDIX 1



File # 3 = 3779-05

Number of Scans: 16

Comment: Flocon 100 solids

6/11/02 10:36 AM Res=4cm-1

APPENDIX 2

Weights taken prior and after to subjecting sample to 105˚F drying preparation process and then the final weight after the sample was subjected to the 600˚F preparation process.

Sample	A	B
Weight	Grams	Grams
RAW	1.608	3.3131
After 105	0.0827	0.4642
After 600	0.0574	0.1787

The constituency of the ash material from samples of the Flocon 100, Sample A and Sample B in mg/kg (or ppm) are as follows: (sample "C" is the Flocon 100)

Description	Sample A	Sample B	Sample C
Barium	48.5	516.0	<0.025
Calcium	638.0	7570.0	3.67
Copper	1.53	1.92	Not Cal.
Dilution Fac.	14.88	7.55	1.0
Potassium	347.0	331.00	128.0
Magnesium	413.0	541.00	0.87
Manganese	21.0	23.4	0.283
Sodium	129.0	46.4	21400.00
Phosphorus	41.0	62.6	Not Cal
Sulfur	122.0	443.0	4670.0
Silicon	97.3	44.0	0.68
Zinc	54.4	144.0	0.26
Aluminum	1770.0	2020.0	0.11
Iron	1920.0	1900.0	30.0
Strontium	9.4	136.0	0.0215

Appendix G

Revised Cost Estimates

Appendix G

Revised Cost Estimates

Reclamation included a detailed design and cost estimate for SSF and SSF-RO in SARWMS (Reclamation, 2000). Several of the supporting tables have been revised in accordance with pilot test results and are presented in this appendix.

The appraisal-level estimates of SSF O&M labor costs (Reclamation, 2000, tables E-5 and E-6) are based on using a single operator for a 42-MGD facility. However, many activities at a water treatment facility require at least two persons for safe and efficient operation. For this reason, and to accommodate the increased SSF cleaning frequency from 6 to 17 times per year (see below), the revised estimate includes increased labor costs for a staff of three operators. This change increases the labor cost from $41,600 per year to $124,800 per year.

Reclamation, 2000 (p. E-10 table E-3) estimated a sand filter cleaning frequency of six times a year. Based on pilot results with 22-day filter runs (refer to appendix B, figure B-1, runs 7 and 8), the estimated sand filter cleaning frequency has been revised to 17 times per year. The higher SSF cleaning frequency is estimated to increase costs of sand replacement by a factor of 17/6.

The pilot study indicated no changes to the RO design or cost estimates.

Tables G-1 and G-2 describe the changes in SSF O&M costs for the increased labor and sand replacement costs. For SSF treatment without desalting, the SSF O&M cost estimate increases from $157,000 to $325,000 per year. Table G-3 includes this revised SSF O&M cost in the revised total O&M cost estimate of $0.41 million per year.

For treatment with desalting by SSF and RO, the SSF O&M cost estimate increases from $131,000 to $275,000 per year (refer to table G-2). Table G-4 includes this revised SSF O&M cost in the revised total treatment O&M cost estimate of $2.51 million per year.

Table G-5 summarizes the costs of all treatment and concentrate disposal alternatives evaluated by Reclamation, 2000, revised to include the revised O&M cost estimates.

From the cost summary in table G-5, table G-6 calculates the costs to incorporate RO desalting for the two recommended desalting alternatives: SSF - RO and MF/UF - RO with concentrate disposal alternative d.

Table G-1 --SSF O&M cost revisions for 67% plant factor for treatment alternative CAP-SSF

	Appraisal study[1]		Revised	
Cost component	Source	Cost	Change	Cost
Reference plant capacity (x), MGD	Table E-7, p. E-17	42.0	None	42.0
Reference plant average production, MGD	0.667 * plant capacity	28.0	None	28.0
Annual SSF O&M, $/yr				
Elec	Table E-6, p. E-16	23,943	None	23,943
Labor	Table E-6, p. E-16	41,600	x 3.0	124,800
Repair & replacement	Table E-6, p. E-16	48,680	None	48,680
Sand replacement	Table E-6, p. E-16	50,250	x 17/6	142,375
Total SSF O&M (y), $/yr	Table E-6, p. E-16	164,473		339,798
Cost factor (a), $/yr per MGD capacity	Figure E-3, p. E-20	3,916	a = y/x	**8,090**
SARWMS SSF plant capacity (x), MGD	Table E-36, p. E-86	40.14	None	40.14
SARWMS SSF average production, MGD	0.667 * plant capacity	26.76	None	26.76
SARWMS total SSF O&M (y), $/yr, y = a * x	Table E-36, p. E-86	157,000		**325,000**

[1] Reclamation, 2000

Table G-2 --SSF O&M cost revisions for 95% plant factor for treatment alternative CAP-SSF-RC

	Appraisal study[1]		Revised	
Cost component	Source	Cost	Change	Cost
Reference plant capacity (x), MGD	Table E-7, p. E-17	42.0	None	42.0
Reference plant average production, MGD	0.95 * plant capacity	39.9	None	39.9
Annual SSF O&M, $/yr				
Elec	Table E-5, p. E-14	33,949	None	33,949
Labor	Table E-5, p. E-14	41,600	x 3.0	124,800
Repair & replacement	Table E-5, p. E-14	48,680	None	48,680
Sand replacement	Table E-5, p. E-14	71,250	x 17/6	201,875
Total SSF O&M (y), $/yr	Table E-5, p. E-14	195,479		409,304
Cost factor (a), $/yr per MGD capacity	Figure E-3, p. E-20	4,654.3	a = y/x	**9,745**
SARWMS SSF plant capacity (x), MGD	Table E-39, p. E-92	28.17	None	28.17
SARWMS SSF average production, MGD	0.95 * plant capacity	26.76	None	26.76
SARWMS total SSF O&M (y), $/yr, y = a * x	Table E-39, p. E-92	131,000		**275,000**

[1] Reclamation, 2000

Table G-3 -- CAP - SSF Summary

Variable-production plant to meet peak-day 40.14-MGD summer deliveries: summer peak flow production.(45,000 afy)

Product cap., MGD	Annual product		Annual RO plant factor	Temperature		Water recoveries
	MGD	af/yr		C	F	SSF
40.14	26.76	29,998	67%	22.4	72.3	99.9%

Stream property	Units	CAP intake	Product streams		Waste streams
			SSF	Post-treated product	SSF drying bed
Peak flow	MGD	40.18	40.14	40.14	0.04
TDS	mg/L	696.8	696.8	696.8	-
Hardness	mg/L	327.9	327.9	327.9	-
TOC	mg/L	3.5	2.5	2.5	-
HCO_3^-	mg/L	174.3	174.3	174.3	-
pH		8.5	8.5	8.5	-
LSI		1.0	1.0	1.0	-
Chemical dosage					
NH_3	mg/L			1.2	
Cl_2	mg/L			6	

Capital and O&M costs

Costs		Administration and chem. lab	Treatment (including post-treatment)	Finished water reservoir	
			SSF		Total
Capital	Million $	$ 1.06	$ 9.45	$ 1.84	$ 12.35
O&M	Million $/yr	$ 0.08	**$ 0.32**	$ 0.01	$ 0.41

Total annual cost and unit cost of post-treated product water

Amort. cap.	Million $/yr	$ 0.09	$ 0.79	$ 0.15	$ 1.03
Total ann.	Million $/yr	$ 0.16	$ 1.12	$ 0.16	$ 1.44
Prod. cost	$/1000 gallon	$ 0.02	$ 0.11	$ 0.02	$ 0.15

Capital recovery factors are: Treatment: 0.0837 for 5.5%, 20 years.

Table G-4 -- CAP - SSF - RO Summary

Constant-production plant: capacity and average annual production

Product	Annual production		Annual RO	Temperature		Water recoveries		
cap., MGD	MGD	af/yr	plant factor	C	F	SSF	RO	Total
23.9	22.75	25,503	95%	22.4	72.3	99.9%	85.0%	84.9%

			Product streams			Waste streams	
Stream property	Units	CAP intake	SSF	RO product	Post-treated product	SSF drying bed	RO concentrate
Cap. flow	MGD	28.20	28.17	23.95	23.95	0.03	4.23
Avg. flow	MGD	26.79	26.76	22.75	22.75	0.03	4.01
TDS	mg/L	696.8	696.8	56.3	95.5	-	4326
Hardness	mg/L	327.9	327.9	5.4	44.4	-	2155
TOC	mg/L	3.5	2.5	0.1	0.1	-	14
HCO_3^-	mg/L	174.3	174.3	24.3	72.1	-	907
pH		8.5	8.5	6.4	9.0	-	8.0
LSI		1.0	0.99	-3.88	0.73	-	1.9
Chemical dosage							
$FeCl_3$	mg/L						
Coag.Aid	mg/L						
Antiscalant	mg/L		2				
H_2SO_4	mg/L 93%			20			
$Ca(OH)_2$	mg/L				29		
CO2	mg/L				16		
Cl_2	mg/L				1.5		

Capital and O&M costs

			Treatment						Concentrate disposal					
Costs		Administration and chem. lab	SSF	RO	Post-treatment	ASR	Finished water reservoir	Total	a. Pipeline to Puerto Penasco w/o Partners	b. Evaporation Ponds	c. Pipeline to Puerto Penasco w/ Partners	d. CASI pipeline w/SROG	e. CASI canal w/SROG	f. CASI canal w/partners
Capital	Million $	$ 1.06	$ 7.51	$ 23.51	$ 0.37	$ 0.64	$ 1.84	$ 34.93	$ 75.02	$ 62.96	$ 15.50	$ 48.64	$ 28.47	$ 13.72
O&M	Million $/yr	$ 0.076	$ 0.27	$ 1.77	$ 0.14	$ 0.24	$ 0.01	$ 2.51	$ 0.20	$ 0.074	$ 0.041	$ 0.13	$ 0.23	$ 0.011

Total annual cost and unit cost of post-treated product water

Amort. cap.	Million $/yr	$ 0.088	$ 0.63	$ 1.97	$ 0.03	$ 0.05	$ 0.15	$ 2.92	$ 5.71	$ 4.79	$ 1.18	$ 3.70	$ 2.17	$ 1.04
Total ann.	Million $/yr	$ 0.16	$ 0.90	$ 3.74	$ 0.18	$ 0.29	$ 0.16	$ 5.44	$ 5.91	$ 4.87	$ 1.22	$ 3.83	$ 2.40	$ 1.05
Prod. cost	$/1000 gallon	$ 0.020	$ 0.11	$ 0.45	$ 0.02	$ 0.04	$ 0.02	$ 0.65	$ 0.71	$ 0.59	$ 0.15	$ 0.46	$ 0.29	$ 0.13

Capital recovery factors are: Treatment: 0.0837 for 5.5%, 20 years; Concentrate disposal: 0.0761 for 7.125%, 40 years.

Table G-5.—Treatment alternatives summary

Variable-production plant to meet peak-day 40.14-MGD capacity, 26.76-MGD average, and 67-percent plant factor (45,000 AFY)

	Treatment		Annual and unit costs	
	Configuration	Costs	$million/year	$/1,000 gallons
Capital costs ($ million)	CAP-CT	46.97	3.93	0.57
O&M costs ($million/year)		1.67	1.67	
Capital costs ($ million)	CAP-SSF	12.35	1.03	0.15
O&M costs ($million/year)		0.41	0.41	
Capital costs ($ million)	CAP-MF/UF	59.80	5.01	0.57
O&M costs ($million/year)		0.54	0.54	

Constant-production plant with ASR for 23.95-MGD average, 26.76-MGD peak capacity, and 95-percent plant factor (30,000 AFY)

	Treatment		Concentrate disposal			Annual and unit costs	
	Configuration	Costs	Alternative	Costs	Total costs	$million/year	$/1,000 gal
Capital costs ($ million)			a. Pipeline to Puerto Penasco	75.02	132.35	10.51	1.61
O&M costs ($million/year)			(with no partners)	0.20	3.53	3.53	
Capital costs ($ million)			b. Evaporation ponds	62.96	120.29	9.59	1.49
O&M costs ($million/year)				0.07	3.40	3.40	
Capital costs ($ million)			c. Pipeline to Puerto Penasco	15.50	72.82	5.98	1.07
O&M costs ($million/year)	CAP-CT-RO	57.32	with 17.6 MGD from Tucson	0.04	3.36	3.36	
Capital costs ($ million)		3.32	d. CASI pipeline to Yuma	48.64	105.96	8.50	1.37
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.13	3.45	3.45	
Capital costs ($ million)			e. CASI canal to Yuma	28.47	85.79	6.96	1.20
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.23	3.56	3.56	
Capital costs ($ million)			f. CASI canal to Yuma	13.72	71.04	5.84	1.05
O&M costs ($million/year)			with 272-MGD total flow	0.01	3.33	3.33	
Capital costs ($ million)			a. Pipeline to Puerto Penasco	75.02	109.95	8.63	1.30
O&M costs ($million/year)			(with no partners)	0.20	2.72	2.72	
Capital costs ($ million)			b. Evaporation ponds	62.96	97.89	7.71	1.18
O&M costs ($million/year)				0.07	2.59	2.59	
Capital costs ($ million)			c. Pipeline to Puerto Penasco	15.50	50.42	4.10	0.76
O&M costs ($million/year)	CAP-SSF-RO	34.93	with 17.6 MGD from Tucson	0.04	2.55	2.55	
Capital costs ($ million)		2.51	d. CASI pipeline to Yuma	48.64	83.56	6.62	1.06
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.13	2.64	2.64	
Capital costs ($ million)			e. CASI canal to Yuma	28.47	63.40	5.09	0.90
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.23	2.75	2.75	
Capital costs ($ million)			f. CASI canal to Yuma	13.72	48.65	3.97	0.74
O&M costs ($million/year)			with 272-MGD total flow	0.01	2.52	2.52	

Table G-5.—Treatment alternatives summary (continued)

Constant-production plant with ASR for 23.95 MGD average, 26.76 MGD peak capacity, and 95-percent plant factor (30,000 AFY) (continued)

	Treatment		Concentrate disposal			Annual and unit costs	
	Configuration	Costs	Alternative	Costs	Total costs	$million/year	$/1,000 gal
Capital costs ($ million)	CAP-MF/UF-RO	59.74	a. Pipeline to Puerto Penasco	75.02	134.76	10.71	1.55
O&M costs ($million/year)		2.68	(with no partners)	0.20	2.88	2.88	
Capital costs ($ million)			b. Evaporation ponds	62.96	122.70	9.79	1.43
O&M costs ($million/year)				0.07	2.75	2.75	
Capital costs ($ million)			c. Pipeline to Puerto Penasco	15.50	75.24	6.18	1.02
O&M costs ($million/year)			with 17.6 MGD from Tucson	0.04	2.72	2.72	
Capital costs ($ million)			d. CASI pipeline to Yuma	48.64	108.38	8.70	1.32
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.13	2.81	2.81	
Capital costs ($ million)			e. CASI canal to Yuma	28.47	88.21	7.17	1.15
O&M costs ($million/year)			with 37.6 MGD from Tucson and SROG	0.23	2.91	2.91	
Capital costs ($ million)			f. CASI canal to Yuma	13.72	73.46	6.04	1.00
O&M costs ($million/year)			with 272-MGD total flow	0.01	2.69	2.69	

Table G-6.—Costs to upgrade SSF and MF/UF to incorporate RO desalting

Treatment without desalting		Treatment with desalting			Cost to upgrade to desalting	
Treatment	Unit cost ($/1,000 gal)	Treatment	CDA[1]	Unit cost ($/1,000 gal)	Unit cost ($/1,000 gal)	Monthly cost ($/mo[2])
SSF	0.15	SSF - RO	a	1.30	1.15	11.50
			b	1.16	1.01	10.10
			c	0.78	0.53	5.30
			d	1.06	0.91	9.10
			e	0.90	0.75	7.50
			f	0.74	0.61	6.10
MF/UF	0.57	MF/UF-RO	a	1.56	0.99	9.90
			b	1.43	0.86	8.60
			c	1.02	0.45	4.50
			d	1.32	0.75	7.50
			e	1.15	0.58	5.80
			f	1.00	0.43	4.30

[1] Concentrate disposal alternative. Refer to table G-5 for brief descriptions.
[2] Based on a residential water delivery of 10,000 gallons per month.

Appendix H

Survey of Slowsand Filter Cleaning Techniques

Appendix H

Survey of Slowsand Filter Cleaning Techniques

The following is a summary of the literature and phone conversations pertaining to the methodology of cleaning/removing the schmutzedecke that accumulates on the top of filters during the slowsand filtration process.

Cleaning Techniques for Slowsand Filters

Hand Cleaning

Flat shovels are used in the dry by a team of laborers. The debris is carted off in wheelbarrows. Flat shovels and buckets were used during the 2001 - 2002 pilot tests.

Wet Harrowing and Backwashing

While the sand is submerged (water level is temporarily lowered), a rubber-tired or tracked tractor is used to drag a comb tooth harrow (or chain link fence section – bent at end) several times to loosen the debris. Raw water, flushed across the surface, carries the debris over a weir plate, through drain pipes, and to a detention/settling pond. Up-flow can also be used to limit clogging. Harrowing is repeated without flushing to evenly distribute the debris. Less than 1 day is required to reactivate the treatment layer.

Facility: Gorham, New Hampshire

Contact:	David Patry (603-466-3302) in Gorham, New Hampshire
Description:	1-million-gallon-per-day (MGD) facility 3 beds with an approximate 500,000-gallon-per-day maximum capacity each Each bed is approximately 70' x 70' in area
Technique:	Uses 4-wheel-drive Ford tractor with fence piece, bent at end – rakes 4 to 5 inches deep

Facility: West Hartford, Connecticut

Contact:	Sam Blais (860-313-0031) in West Hartford, Connecticut
Description:	50-MGD facility 22 filters – 16 are ½ acre (147' x 147'), and 6 are ¾ acre (180' x 180')
Technique:	Each filter bed is cleaned every 2 to 8 weeks. With all but 1 foot of water drained, a tractor pulls a rigid tooth harrow through the top 12 inches of sand. The depth can be adjusted by hydraulic control. The harrow loosens trapped particles, which are then washed into a nearby drain. The process uses about 2 million gallons of water to wash the loosened particles out. The water and particulates are piped to a retention/waste pond. Cleaning is completed the following day using a dry harrowing process, which uses a spring-tooth rake. In years past, a wheeled tractor was used, but presently, they use an Italian-made ("Rock") rubber-tracked tractor (the steel-tracked vehicles had durability problems because of the abrasiveness of the sand). Each bed must be reconditioned about every 12 years. All the sand is shoveled out and cleaned with specially designed hydraulic equipment.

Dry Skimming

Water is lowered to approximately 2 feet below the sand level at night (so that the next day it can be cleaned) and scraped with a specially designed vehicle that is equipped with an auger or blade. The debris is then conveyed to dump trucks, and the beds are leveled afterward.

Facility: Salem, Oregon

Contacts:	Tim Sherman (503-769-2095) – Operations Supervisor – Treatment Plant in Salem, Oregon; tsherman@open.org Mike Brown (800-887-3415, cell 503-910-4657, fax 503-843-2340) – owner, Dejong Welding – fabricator of filterbed cleaner at Salem
Description:	21-MGD facility Each cell is approximately 330' x 330' in area

Technique: Uses 3-wheeled vehicle with front scraper blade (cost about $85k). Debris is then conveyed into trucks, and ruts are leveled afterward with a box float behind the tractor.

Facility: Thames Water (London, UK)

Contacts: Mike Bauer (phone: 9 011 44 118 923 6246) in Reading, Berkshire, UK (near London); <mike.bauer@thameswater.co.uk>

Michael Chipps; <Michael.Chipps@thameswater.co.uk>

Description: Average cell is 208' x 208' (1 acre)
Largest cell is 280' x 280'

Technique: Uses specially designed vehicles (cost about $180k) with double screw augurs that feed onto a ramped conveyor – debris is collected in dump trucks, and ruts are leveled afterward with laser-controlled screed.

Barge Skimming/Suction Dredge

Contact: Mike Bauer (phone: 9 011 44 118 923 6246) in Reading, Berkshire, UK (near London); <mike.bauer@thameswater.co.uk>

Technique: This method has not been implemented, but is in development. It uses an unmanned, self-propelled skimmer that cleans the sand as it traverses the filter. Details on this technique are sketchy.

Conclusions and Observations

The full-scale filter design for the northwest Tucson area will have 330,450 square feet of filter area, divided into four cells, giving approximately 287' x 287' areas, producing 13.38 Mgd each. This cell size is roughly equal to the Thames, Salem, and West Hartford facility filters.

Factors that would influence the choice of one technique over another include initial cost, maintenance costs, cleaning effectiveness (or frequency of required cleaning), filter downtimes, and waste storage/disposal availability.

- Hand cleaning would be restricted to very small filters because of the labor-intensive and time-consuming nature of the process. Obviously, the equipment and maintenance costs would be inconsequential, but the filter downtimes would be longer.

- Wet-harrowing may be problematic to implement on a larger filter bed since the amount of water required to flush would be great and there would be associated disposal and handling difficulties. A large disposal pond would be required. The equipment required for smaller plants would mainly consist of a small tractor, but dump trucks are not required. It is used at West Hartford, where the beds are of comparable size to the full-scale model, but they have upgraded their equipment to a specialized rubber-tracked vehicle, which would significantly add to initial cost, but perhaps reduce the long-term maintenance costs. The tracks likely create less damage to the filter bed and would not bog down in the wet like a vehicle with normal tires would.

  It is unquestionably a good system for small beds since it allows quick cleaning and reactivation periods and does not necessarily require any specialized equipment.

- Dry skimming appears to be the one of choice for large filters; however, the initial cost and maintenance costs would be high since the skimming vehicles are expensive and because conveyors and dump trucks are necessary as well. Compared to the wet-harrowing method, the time to clean the filters would be greater. No waste pond or flushing water would be required. Thames Water is a world leader in this field, and this is the method they use.

- The suction dredge seems like it would be a good idea, but it would likely be a very expensive and largely untested method. Until it has been used more extensively, it would be risky to pursue this technique exclusively.

More extensive research would have to be performed before it could be conclusively determined which method would suit the application in Tucson. A more thorough analysis, factoring all the system requirements, expectations, and resource limitations, would have to be undertaken since this short investigation did not determine a clear-cut best method for the system at the northwest Tucson area.

Specifically, it would be logical to pursue the following:

- More research could be performed to determine if other variations of cleaning methods exist or if variations of existing methods could be adapted to the northwest Tucson project. Contacting other industry and academic sources could be undertaken.

- ☐ A rough cost analysis that factors the costs of design of the equipment, initial purchase of equipment, equipment maintenance and storage, labor, disposal/storage of waste, employee training, etc., along with the efficiency (required outage or reseeding periods, frequency of cleanings required) would have to performed. The specific requirements of the northwest Tucson project would have to be modeled. This analysis may eliminate one or more of the techniques as too costly or impractical.

- ☐ A pilot study could be performed to test the presumed "best" method(s) and bear out the cost analysis assumptions that were made. The pilot study could reveal system flaws or failures, which could be corrected before final implementation of a system for the northwest Tucson area.

References

Slow Sand Filtration, edited by Gary S. Logsdon (1991), published by the American Society of Civil Engineers, chapter 6, pp. 149-164.

Water Treatment Primer - Slowsand Filtration, by Mary Rust and Katie McArthur (1998), Virginia Tech website: <http://cee.vt.edu/program_areas/environmental/teach/wtprimer/slowsand/slowsand.html>.

Standard Operating Procedure for 1.0 MGD Slowsand Filtration Facility - Gorham New Hampshire, by Rist-Frost Associates, P.C., Laconia New Hampshire.

Slowsand Filtration – An International Compilation of Recent Scientific and Operational Developments, edited by M.R. Collins and M.J.D. Graham (1994), published by the American Water Works Association, chapter 7.1 ("Existing and New Cleaning Techniques for Larger-Scale Slow-sand Filters" – authored by P.J. Renton, R.G. Bayley, and M.J. Bauer), pp.273-286, and chapter 8 ("Research Needs: A Review," authored by N.J.D. Graham, A.J. Rachwal, J.S. Colburne, and M.R. Collins), pp. 293-303.

Website: <www.themdc.com/slowsandfiltration.htm> (Hartford, Connecticut, water treatment).

Website: <www.thames-water.com> (London, England, water treatment).