Evaluation of MF/UF Technology on the Nooksack River for Drinking Water Production

PNWS SECTION AWWA 2008

Dan Hugaboom

Engineers...Working Wonders With Water™

Acknowledgements

1. City of Lynden
    a. Tami Adams
    b. Rick Stroebel
    c. Duane Huskey
    d. Mark Sandal

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2. Washington Department of Health
    a. John Thielemann

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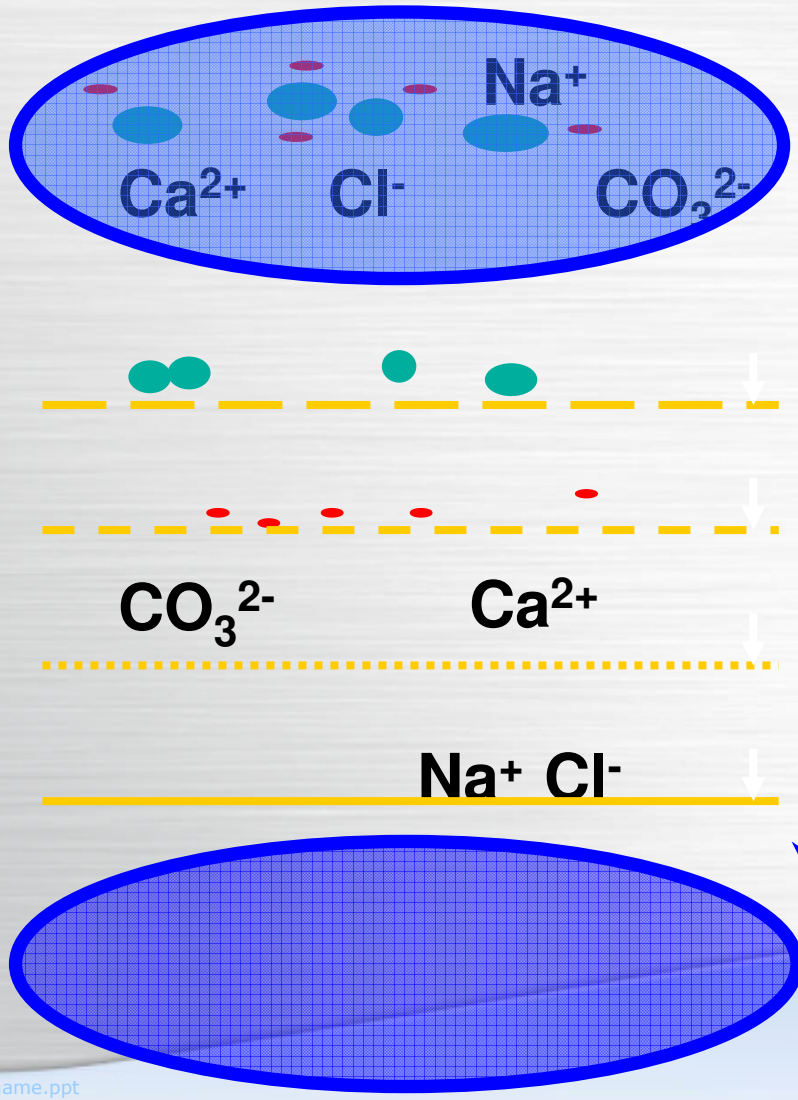
3. Carollo Engineers
   a. Trevor Dykstra
   b. Jim Mahady

Presentation Summary

1. MF/UF Membrane Operation
2. Tools for Sustaining Operation
3. Key Components of a Pilot Protocol
4. Results from the City of Lynden
5. Conclusions

Micro- & Ultrafiltration (MF/UF) Membranes Remove Particles



Microfiltration - 0.1 μm

>99.9999% Removal of *Cryptosporidium*

Ultrafiltration - 0.01 μm

Up to 99.9999% Removal of Virus

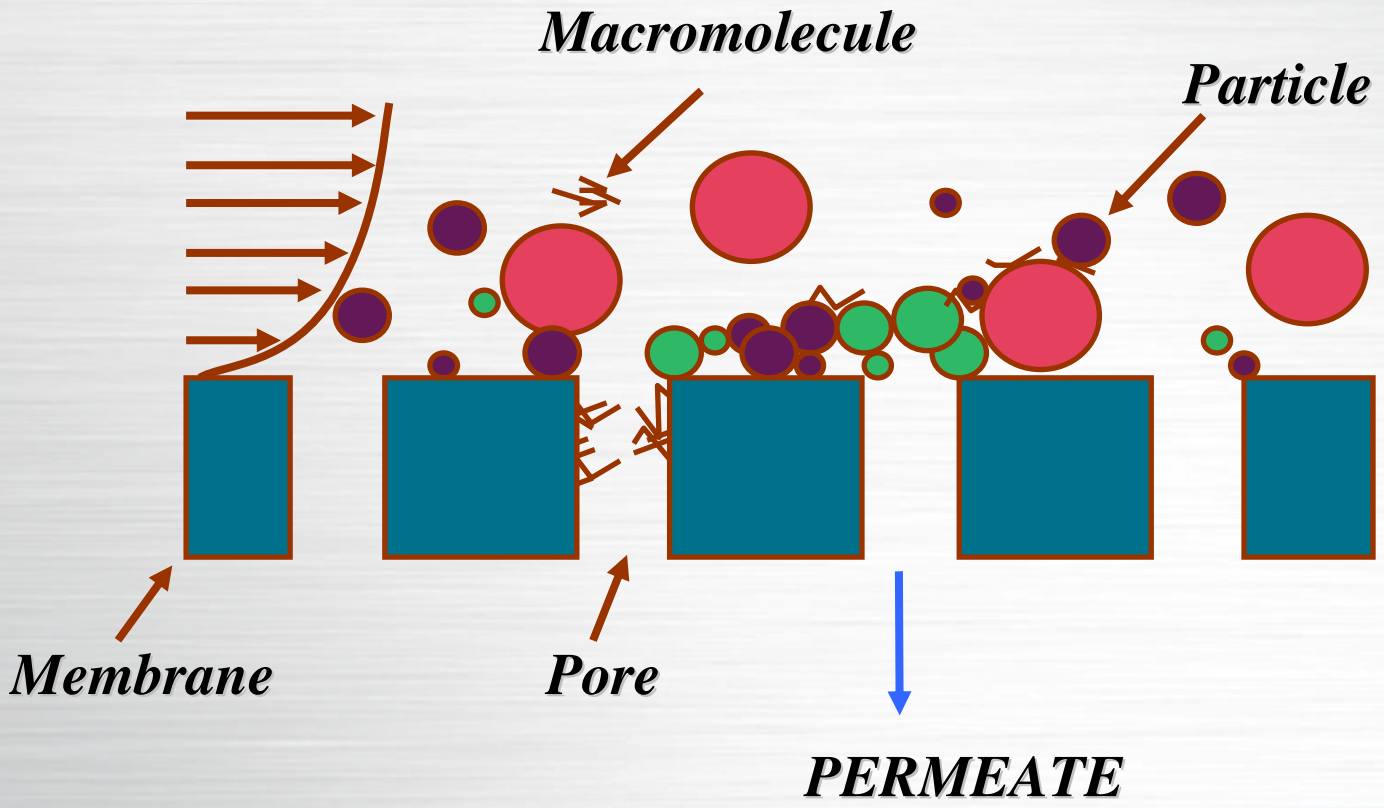
Nanofiltration

Up to 90% Calcium Rejection

Reverse osmosis

Up to 90% Sodium Rejection

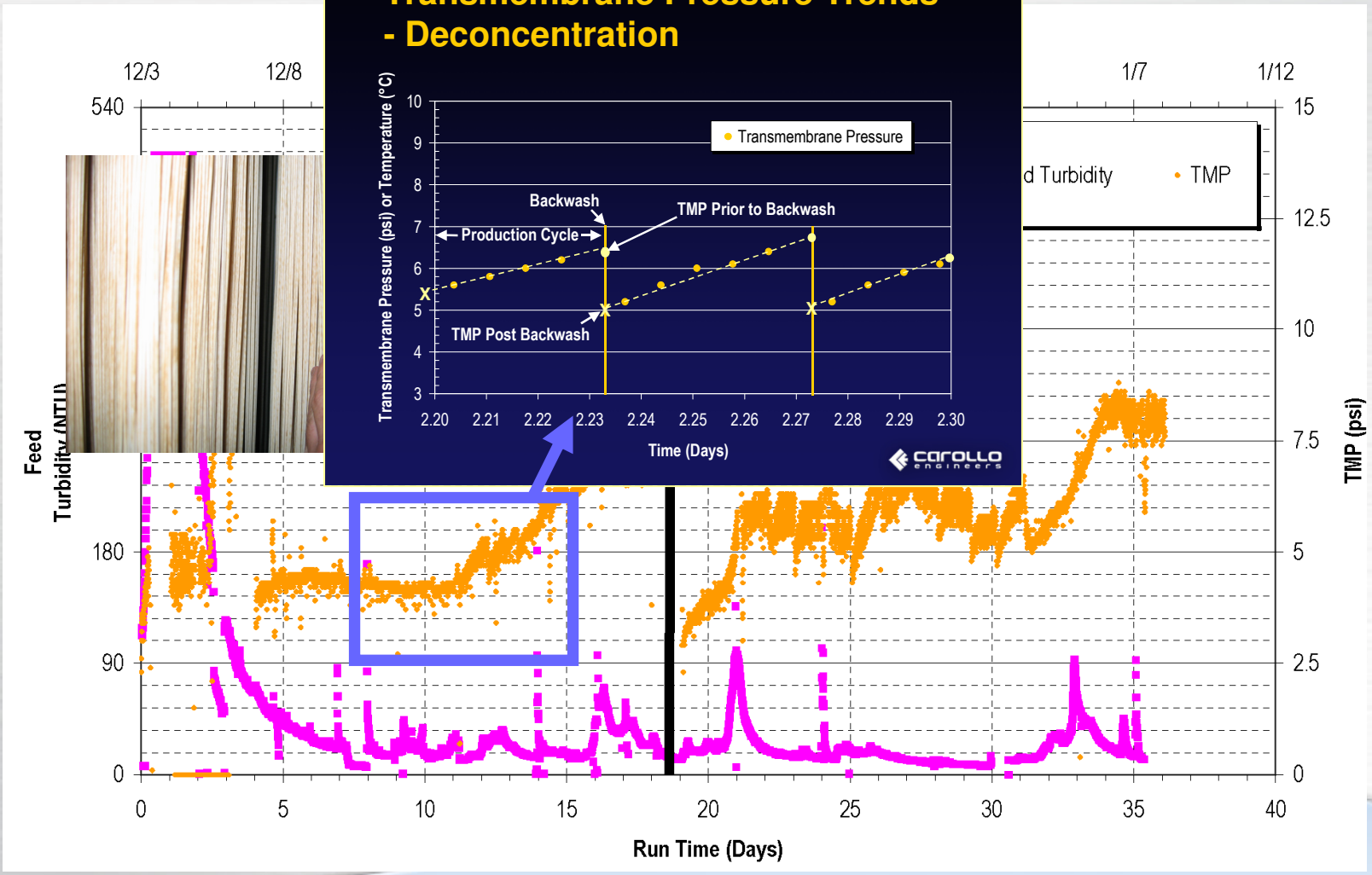
Driving force is Pressure – Positive or Negative (Vacuum)



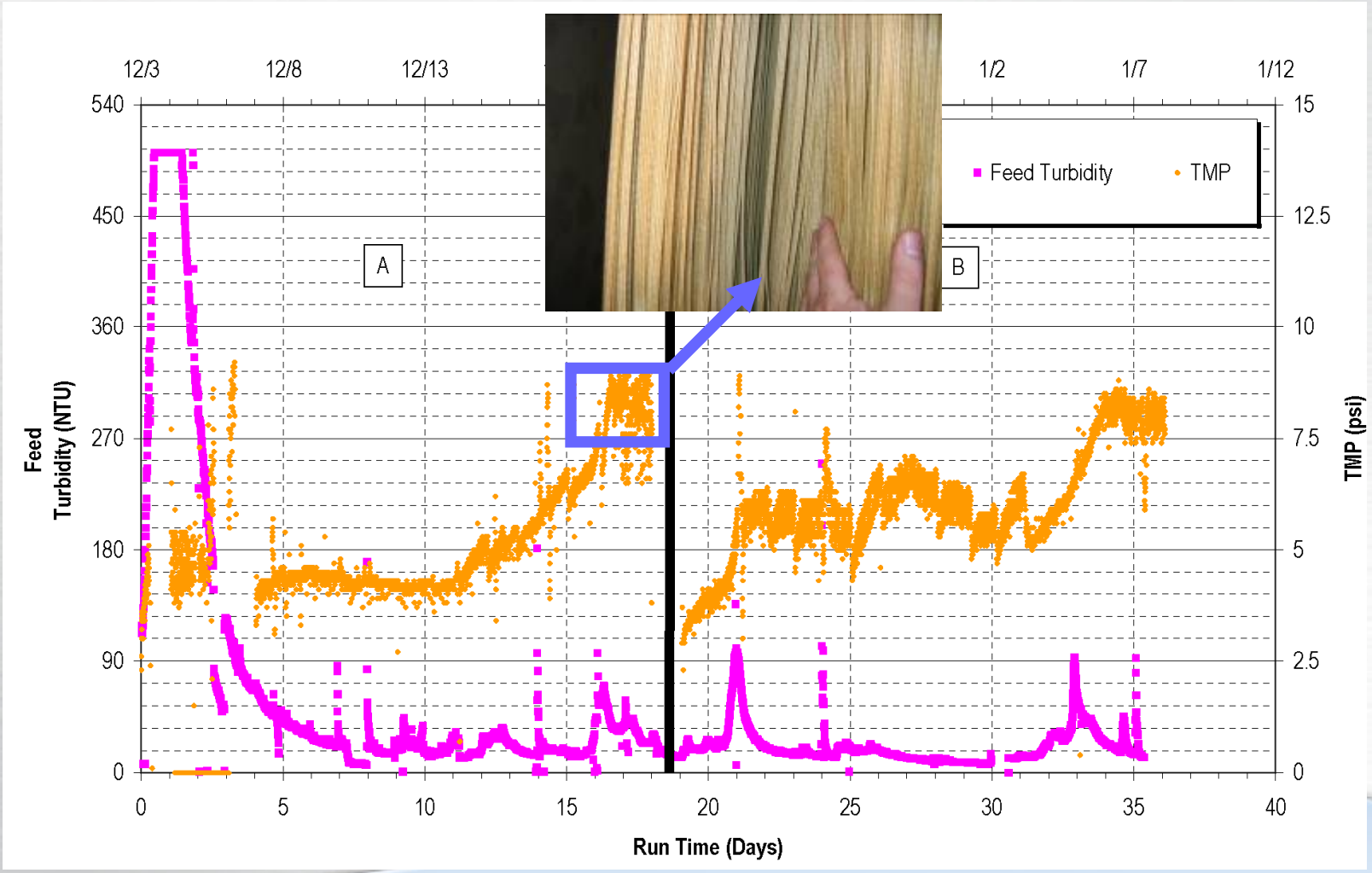
Tools for Sustaining Production

1. Reverse flow (backwash) and air scour for removing particles from the membrane surface
2. Chemical cleanings for Remove Sorbed or Precipitated Particles attached to the Membrane Surface
   a. Chemically Enhanced Backwashes (CEB)
   b. Clean-in-Place (CIP)

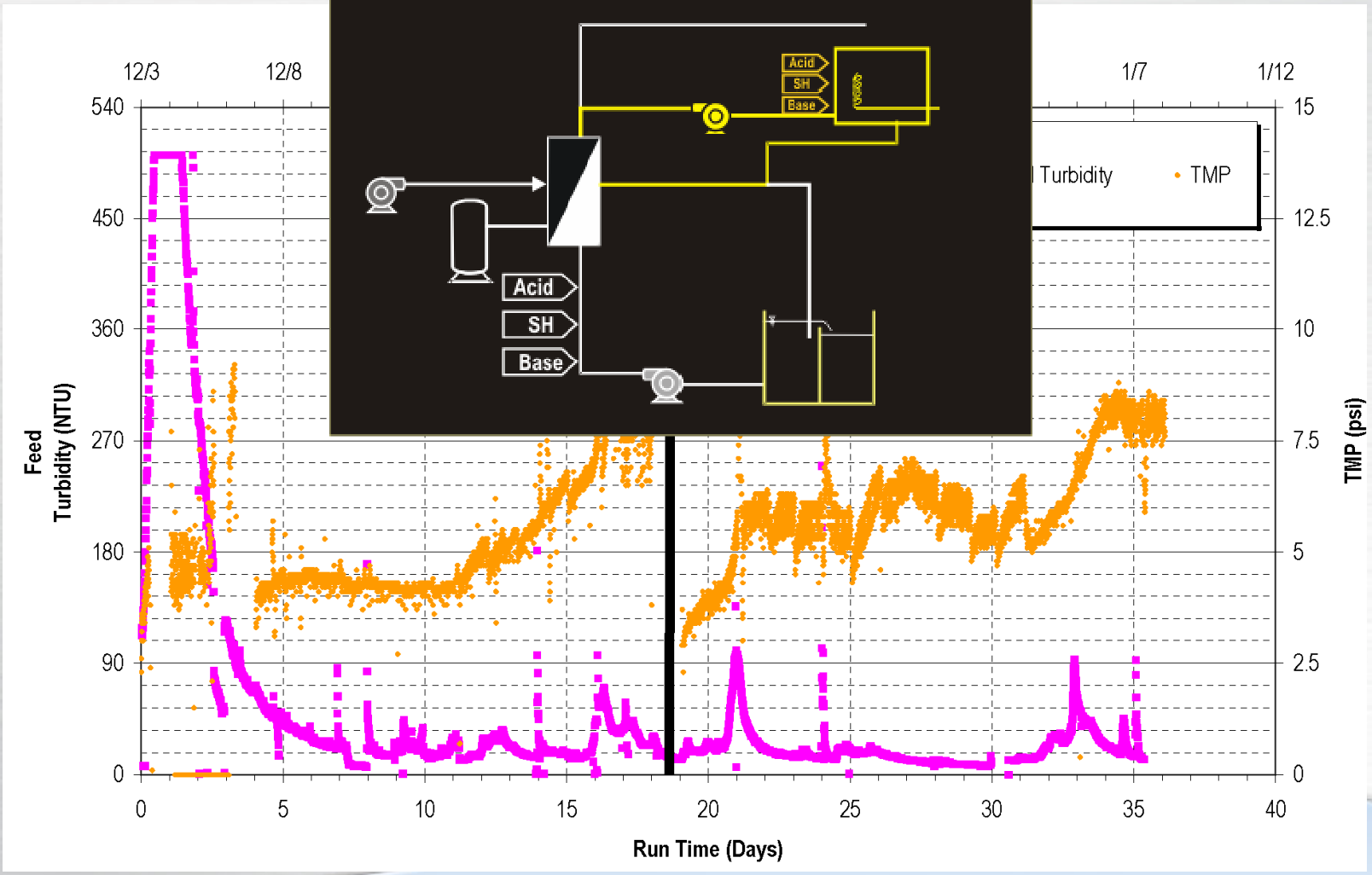
Typical Membrane Filtration Cycle



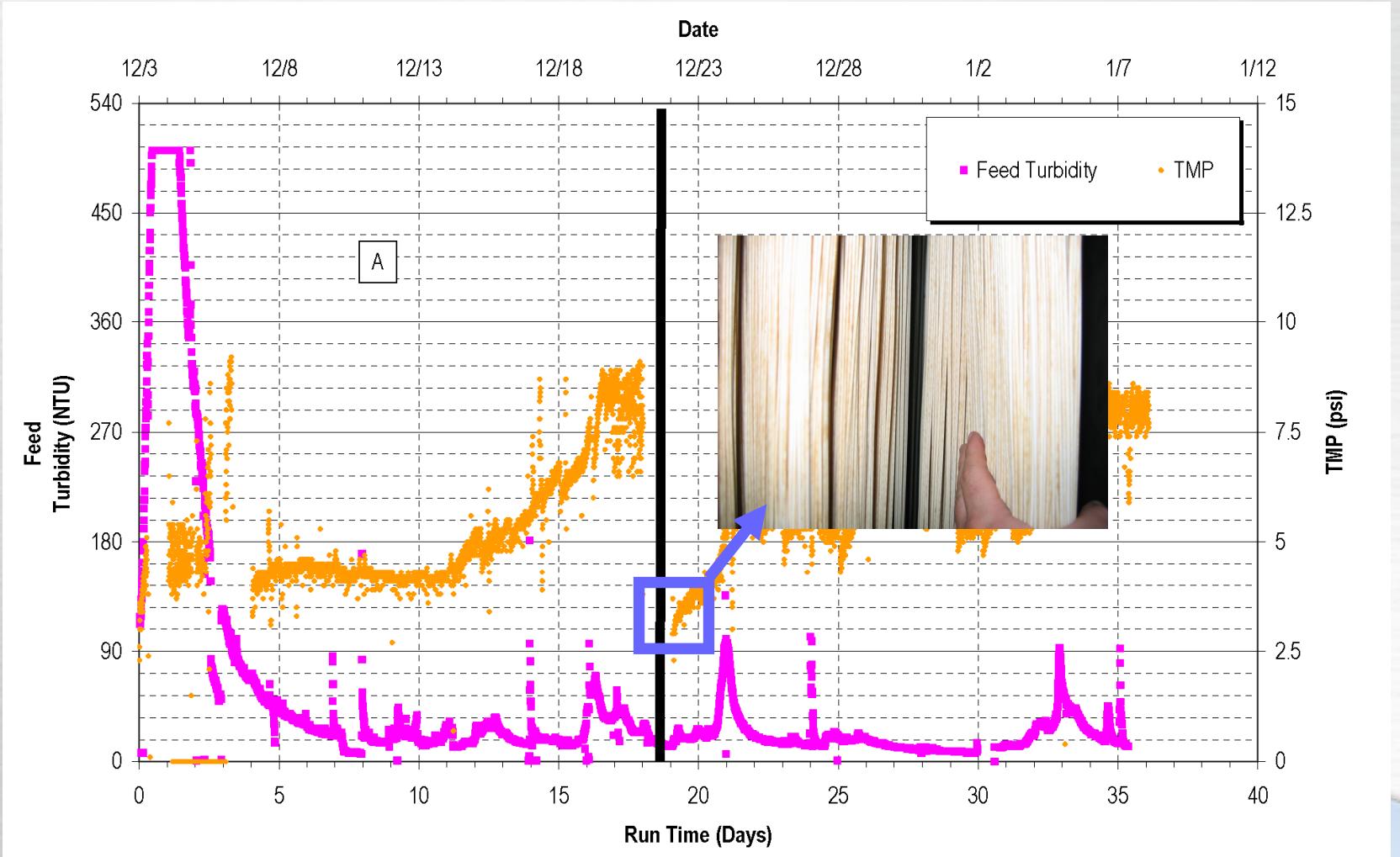
Typical Membrane Filtration Cycle



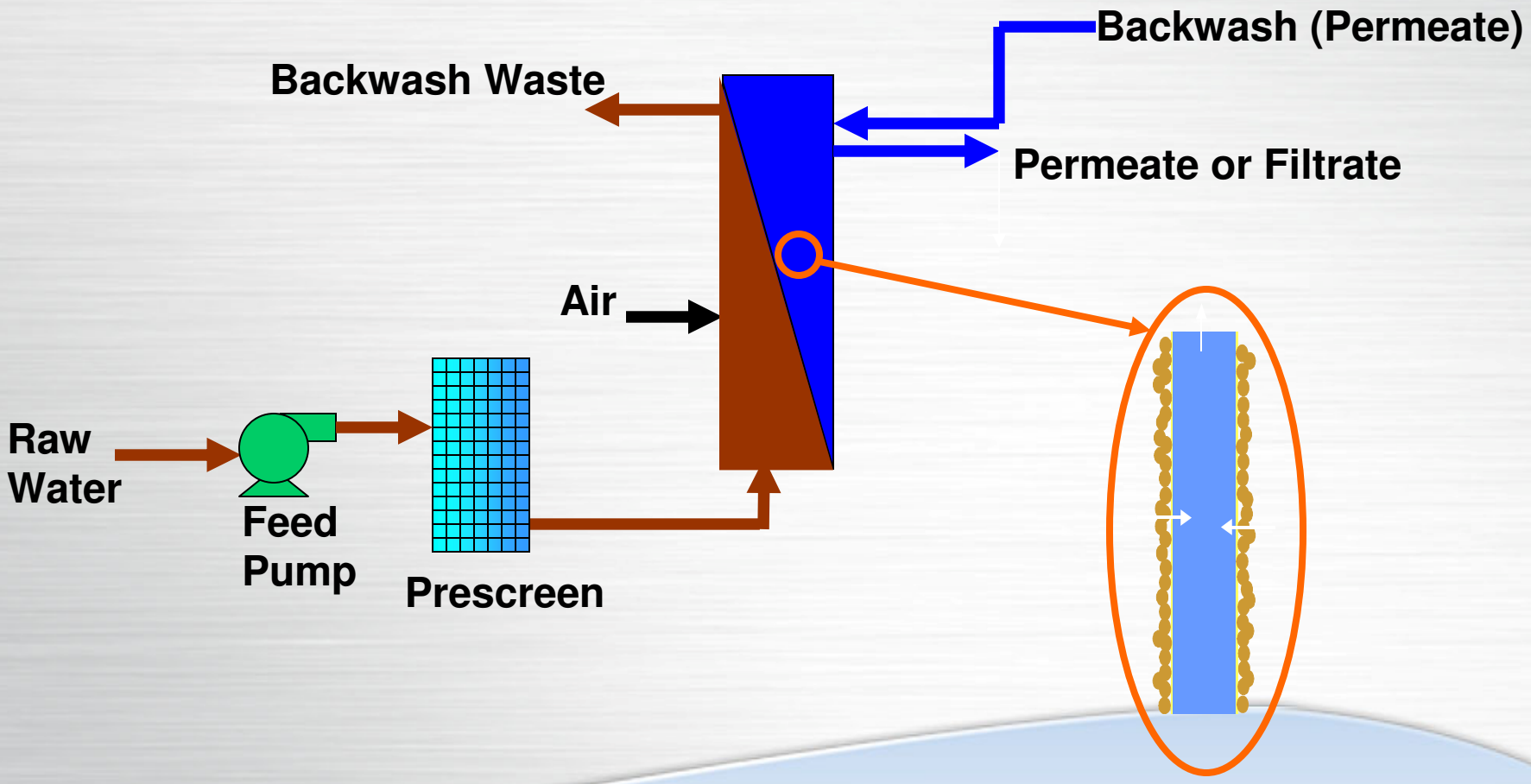
Typical Membrane Filtration Cycle



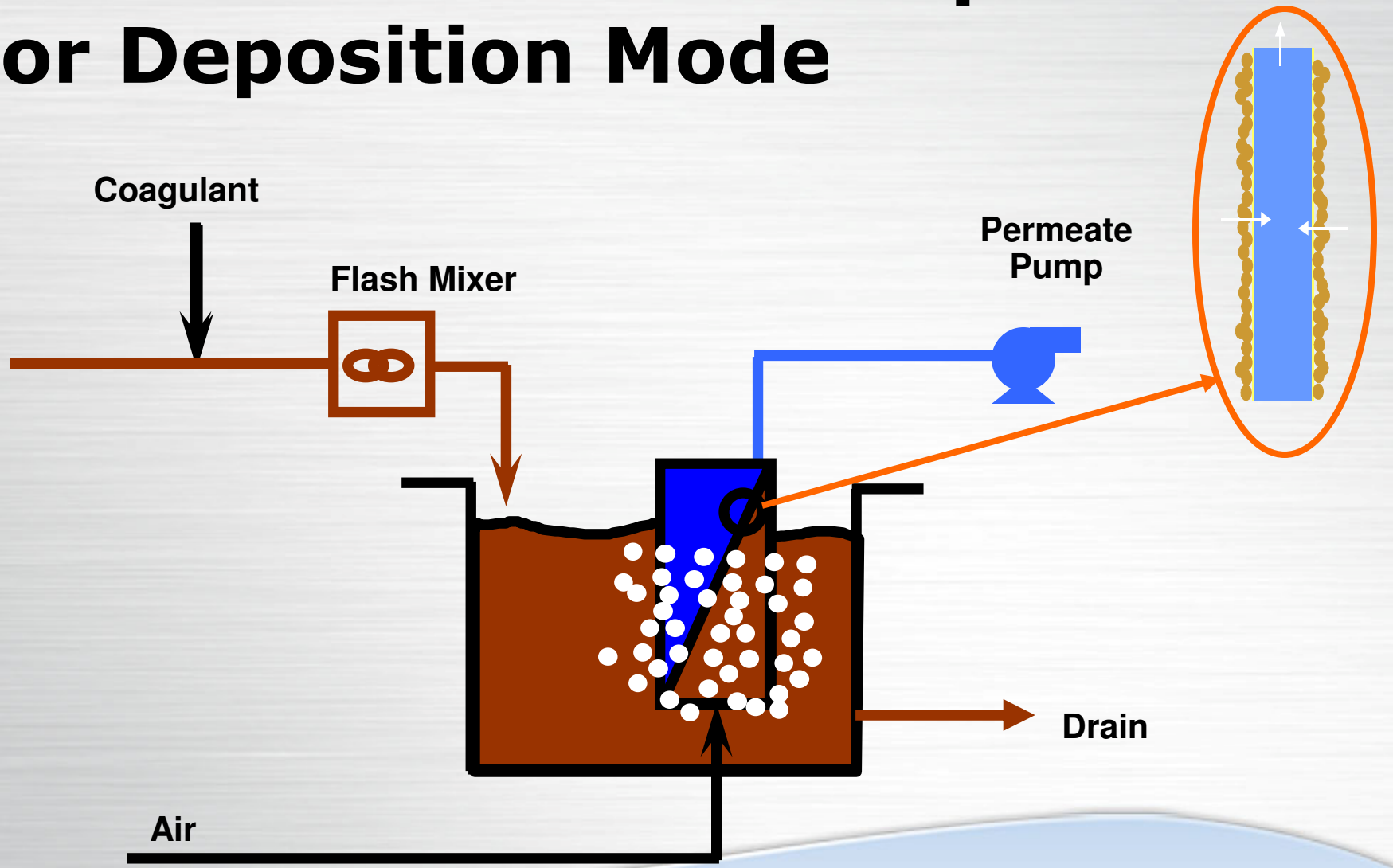
Typical Membrane Filtration Cycle



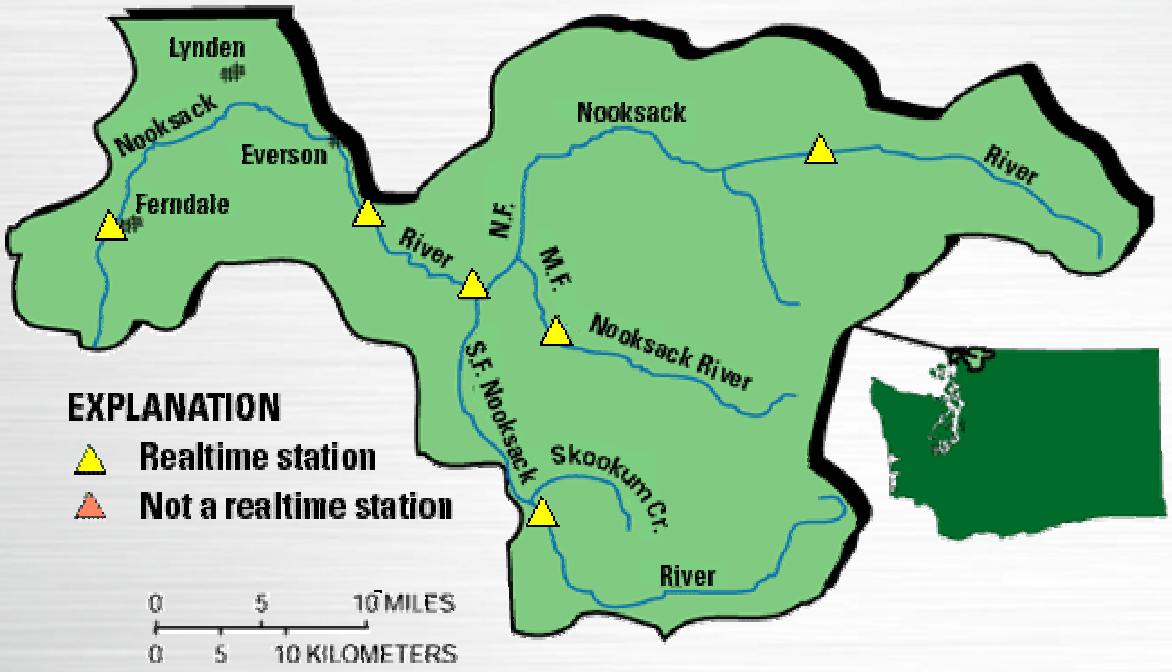
Pressure-Driven System in Deposition Mode



Vacuum-Driven in Suspension or Deposition Mode



City of Lynden and the Nooksack River in Northwest Washington



wa.water.usgs.gov/realtime/htmls/nooksack.html

Impetus for the Project

1. Original plant constructed in 1924 with various phases of upgrades since
   a. Conventional WTP with tube settlers
2. New round of upgrades and capacity expansion required
3. WDOH required Water System Update
4. The City wanted to evaluate membrane filtration as one the alternatives

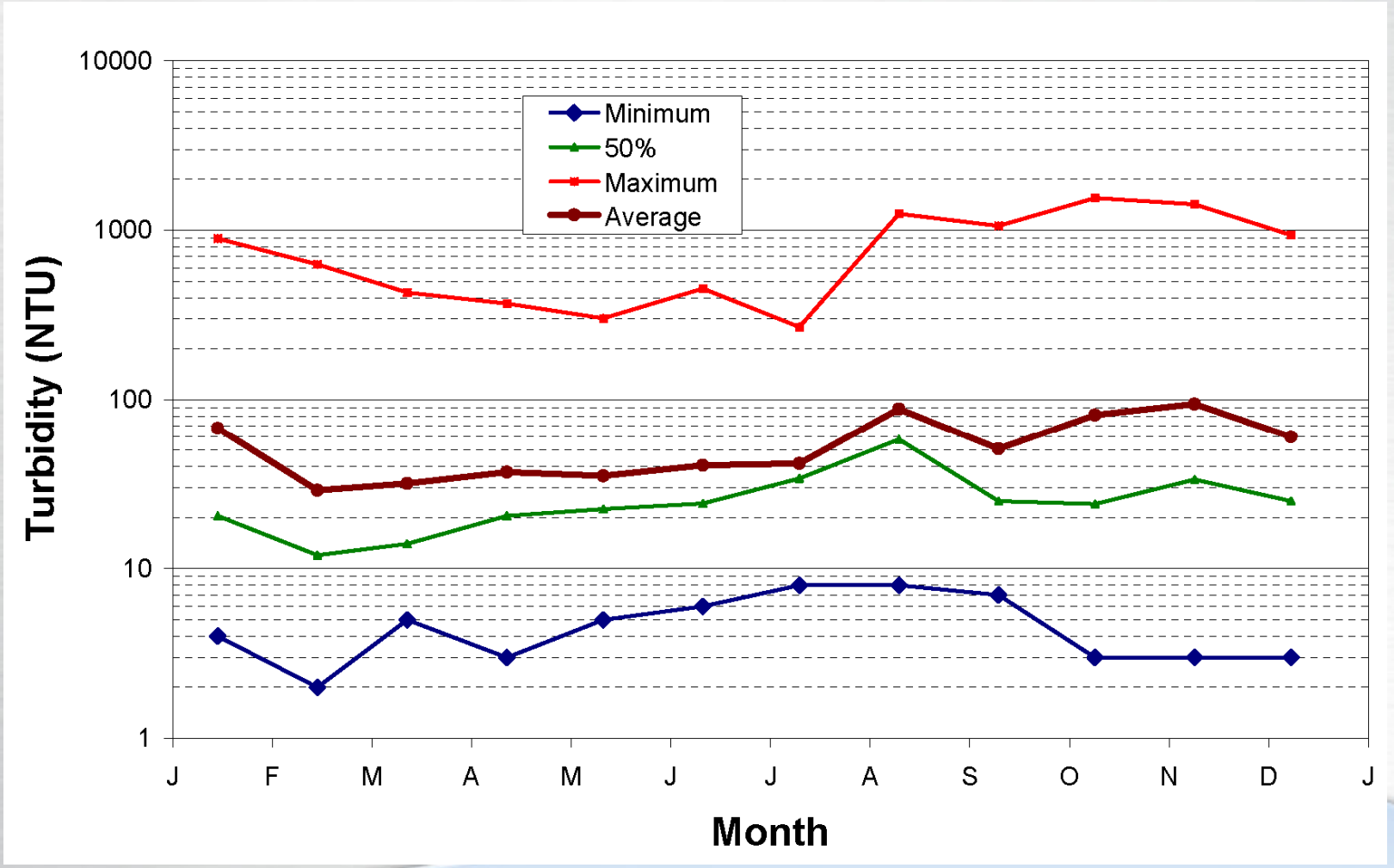
Drivers for Membranes

1. If proven feasible, membrane filtration of raw water (no clarification) would provide significant footprint and cost reduction
2. Modular expandability and flexibility to phase construction

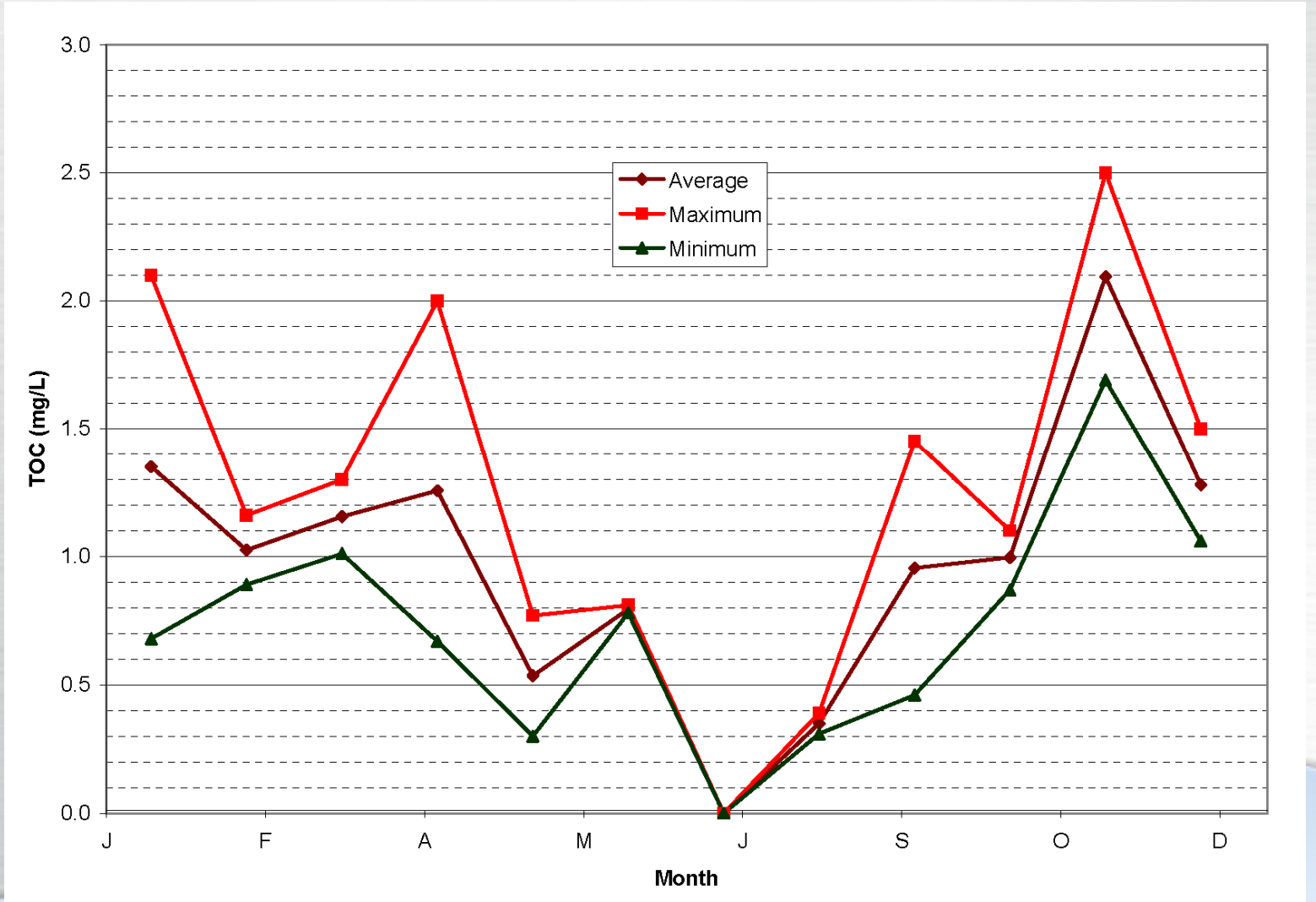
Membrane and Media Filtration Processes Considered

1. Coagulation/Flocculation/Plain Sedimentation/Media Filtration
2. Coagulation/Flocculation/High Rate Clarification/Media Filtration
3. Coagulation/Membrane Filtration
4. Coagulation/Flocculation/Sedimentation/ Membrane Filtration

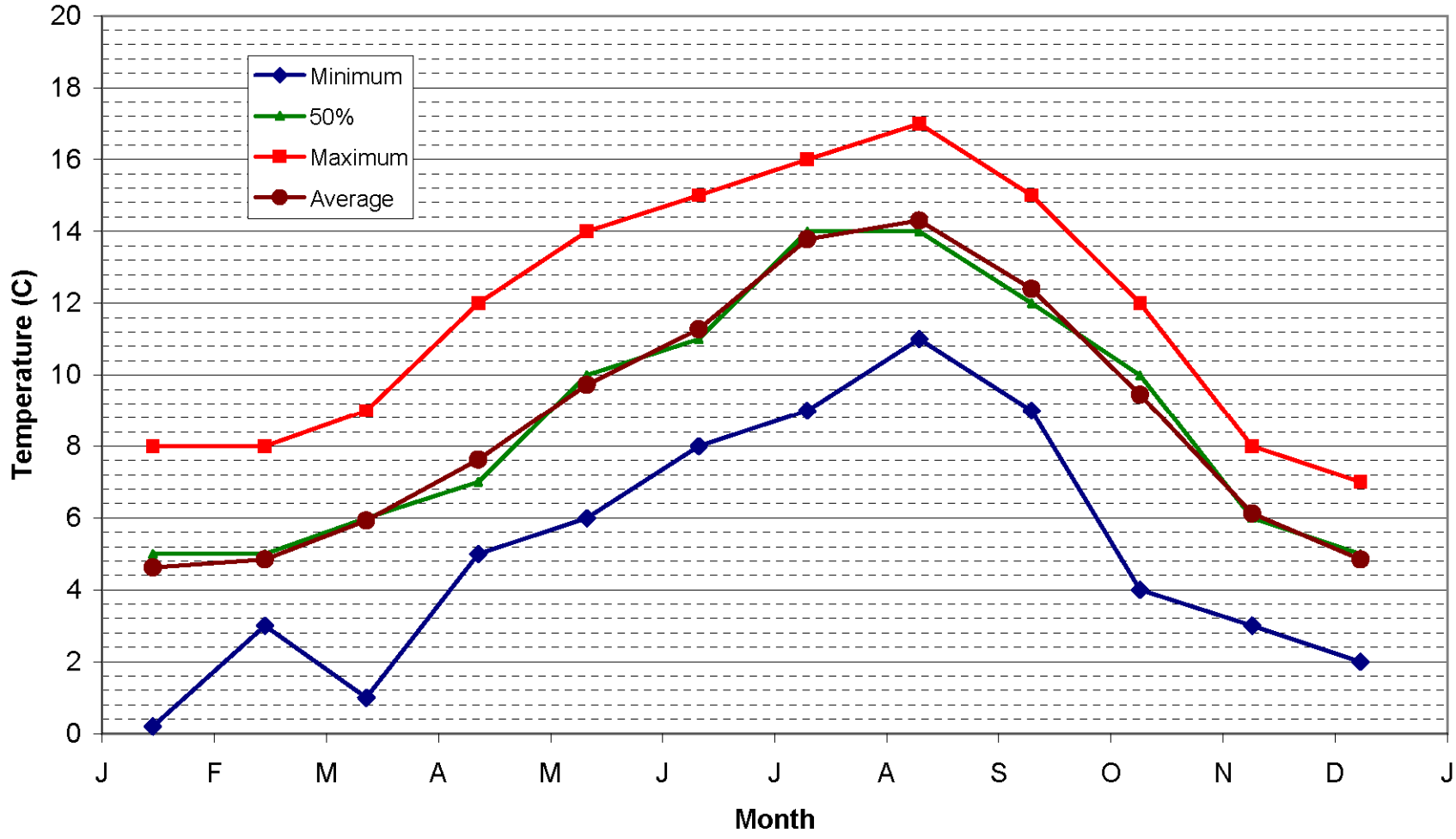
Raw Water Quality Data Review



Total Organic Carbon Varies Seasonally



Source Water Temperature is Seasonally Variable and Cold



Data Gaps for Assessing the Feasibility were Identified

Table 4.5 Water Quality Monitoring Program for Membrane Testing
Membrane Pilot Testing Protocol
City of Lynden

Parameter	Feed	Permeate	Backwash
pH	D	D	M
Temperature[1]	C	C	-
Total Organic Carbon (TOC)	2/W	2/W	M
UV-254 Absorption	2/W	2/W	M
Alkalinity (as $CaCO_3$)	1/W	1/W	M
True Color (C.U.)	1/W	1/W	-
Odor (TON)	1/W	1/W	-
Turbidity (NTU)	C	C	1/2W
Particle Counts	-	C	-
Total Suspended Solids (TSS)	1/2W	-	1/2W
Total Dissolved Solids (TDS)	1/2W	-	1/2W
Hardness (as $CaCO_3$)	-	1/W	-
Iron, Total	1/W	W	
Manganese, Total	1/W	W	
Disinfection By-Products			
SDS THM (µg/L)	-	1/2W	-
SDS HAA (µg/L)	-	1/2W	-

Pilot Test was Scheduled for Fall & Winter 2008

1. Pilot timing selected to coincided with maximum turbidity and TOC – the most challenging feed water condition

Table 5.1 Pilot Testing Schedule
Membrane Pilot Testing Protocol
City of Lynden

Event	Date	Duration
Deliver pilot units to site	October 8, 2007	1 day
Pilot Unit Setup and Startup	October 8-21, 2007	14 days
Initiate Phase 1 - Raw Water Testing	October 22, 2007	70 days
Complete Phase 1 - Raw Water Testing	December 31, 2007	
Phase 2a or 2b Tuning Period	January 2, 2008	7 days
Initiate Phase 2a or 2b	January 9, 2008	35 days
Complete Phase 2a or 2b Testing	February 12, 2008	
Demobilization Complete	February 16, 2008	

Testing Allows Data to be Evaluated in Distinct "Runs"

Table 4.3 Sequence of Events for Extended Runs
Membrane Pilot Testing Protocol
City of Lynden

	Related Tasks	Notes
Select Operating Conditions	Perform normalization calculations as required	• Based on tuning period and results of previous runs. • Consult membrane supplier prior to selecting conditions.
Initiate Run	Conduct routine sampling and instrument checks, document events in "Daily log Sheet" Coordinate Remote Monitoring connection with membrane suppliers Make normalization adjustments if water temperature changes cause normalized flux to deviate from target by more than 10% over a period of more than 48 hours. Manually initiate all CEBs	• Adjustments to be made by City staff or membrane supplier under supervision of City staff; membrane supplier to be consulted. • Adjustments not related to temperature normalization may only be made in the first five (5) days of operation • A maximum of one CEB is allowed per day.
End Run	Notify engineer and membrane supplier	• End run if relevant termination criteria are met.
Perform Integrity Test	Document in "IT Log Sheet"	• Conduct under guidance of membrane supplier.
Perform CIP	Document in "CIP Log Sheet"	• Conduct under guidance of membrane supplier.
Perform Integrity Test	Document in "IT Log Sheet"	• Conduct under guidance of membrane supplier.

Challenging Feed Water Required Adequate "Tuning Period"

Table 4.2 Summary of Pilot Testing Plan
Membrane Pilot Testing Protocol
City of Lynden

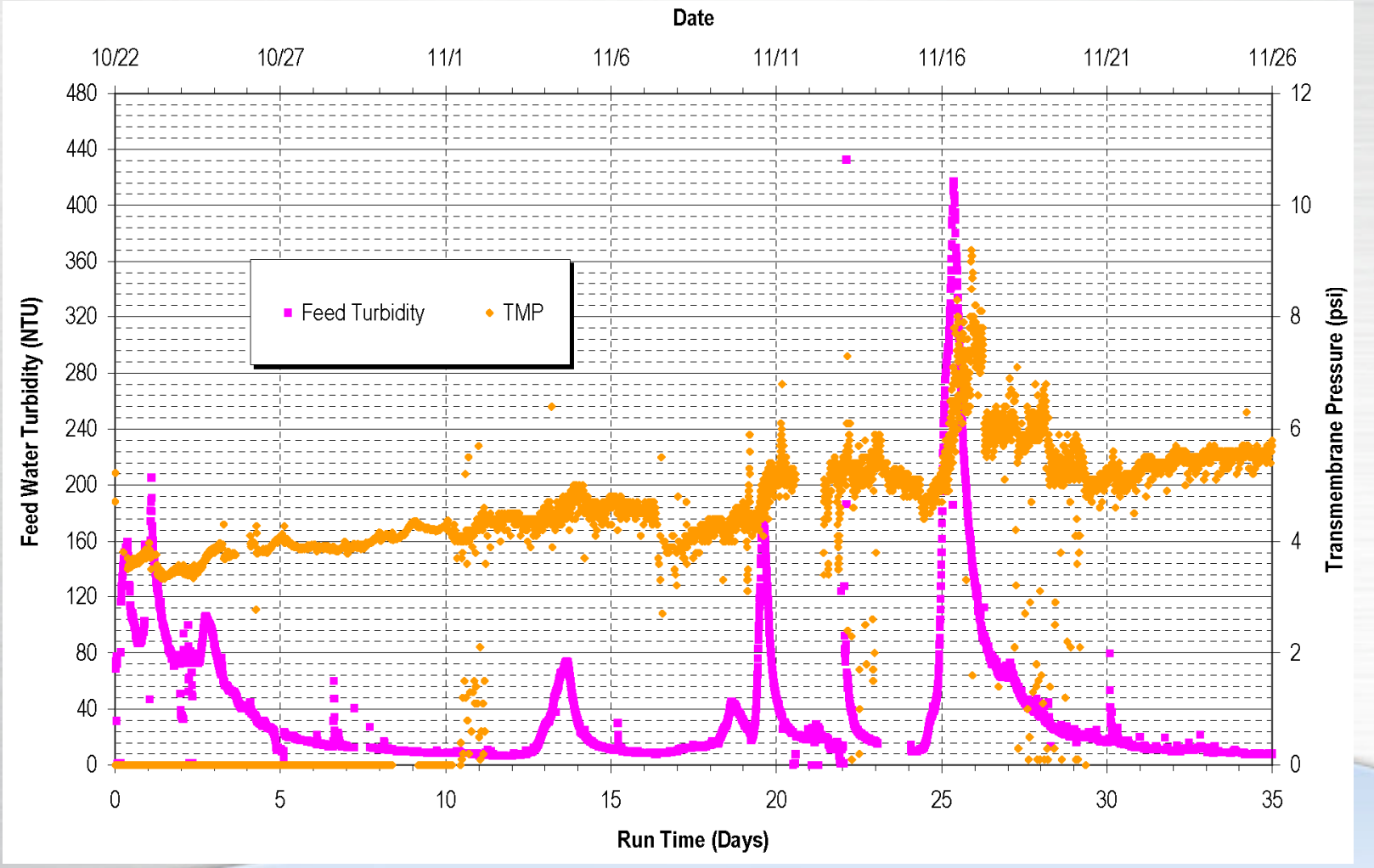
Task	Source Water	Duration	Comments
System Tuning Phase 1	Raw	1 week	CIP to be performed at conclusion of this phase
Phase 1	Raw	70 days	Includes two (2) continuous 30-day runs under consistent conditions
System Tuning Phase 2A or 2B	Settled or Raw	1 week	Adjust operating conditions as appropriate
Phase 2A or 2B	Settled or Raw	35 days	Includes one (1) continuous 30-day run under consistent conditions
Demobilization		1 week (approx.)	

Notes:
1. Phase 2 may be performed on raw water, depending on observed raw water quality, finished water quality (DBP testing), and membrane system performance.
2. In-line coagulation may be used if raw water is selected for Phase 2.

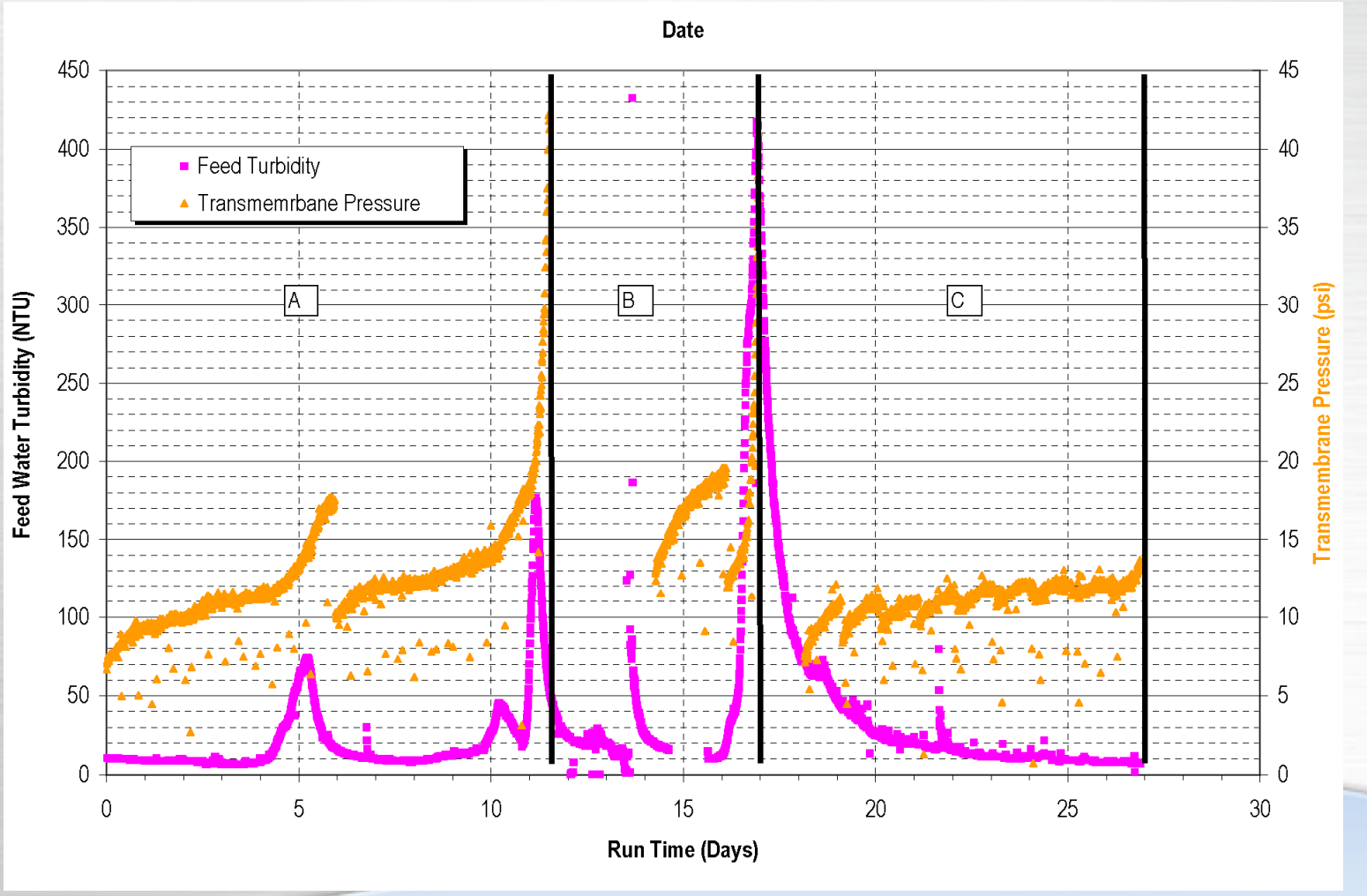
Three Membrane Suppliers Selected for Feasibility Evaluation and Pilot Study

1. Request for Qualifications
   a. National Experience
   b. Regional Experience
   c. Existing state-accepted third-party verification (NSF/ETV, State of California)
   d. Budgetary estimates and conceptual layouts
2. Three systems selected
   a. Two vacuum-driven (Siemens and Zenon)
   b. One pressure-driven (Pall)

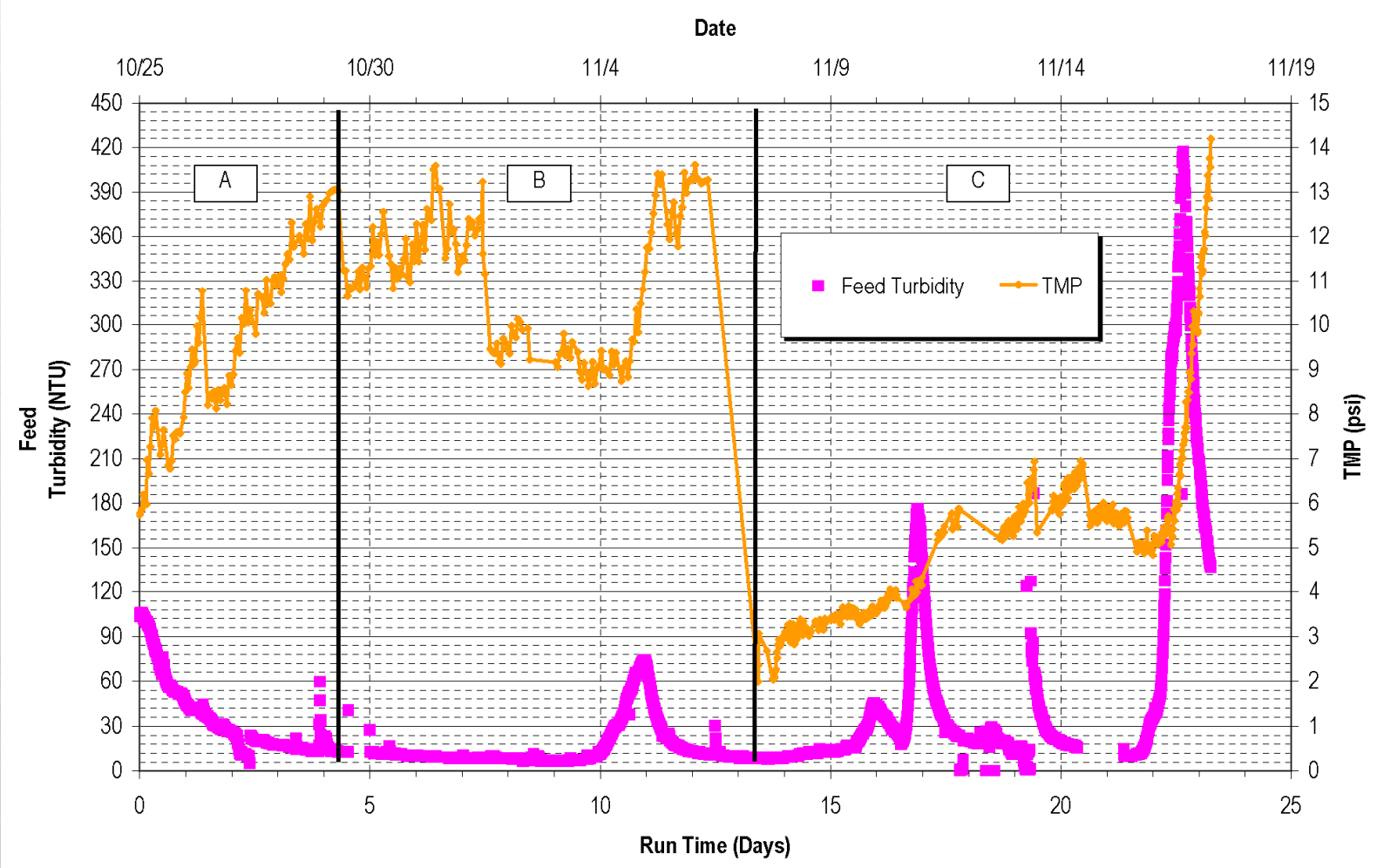
Siemens - Phase 1 at 33 gfd (Raw Water)



Pall - Phase 1 at 50 gfd (Raw Water)



Zenon - Phase 1 at 24 gfd and 27 gfd (Raw Water)



Post-Turbidity Event Membrane Examination

1. Fine Sand Buildup in Tank Bottoms

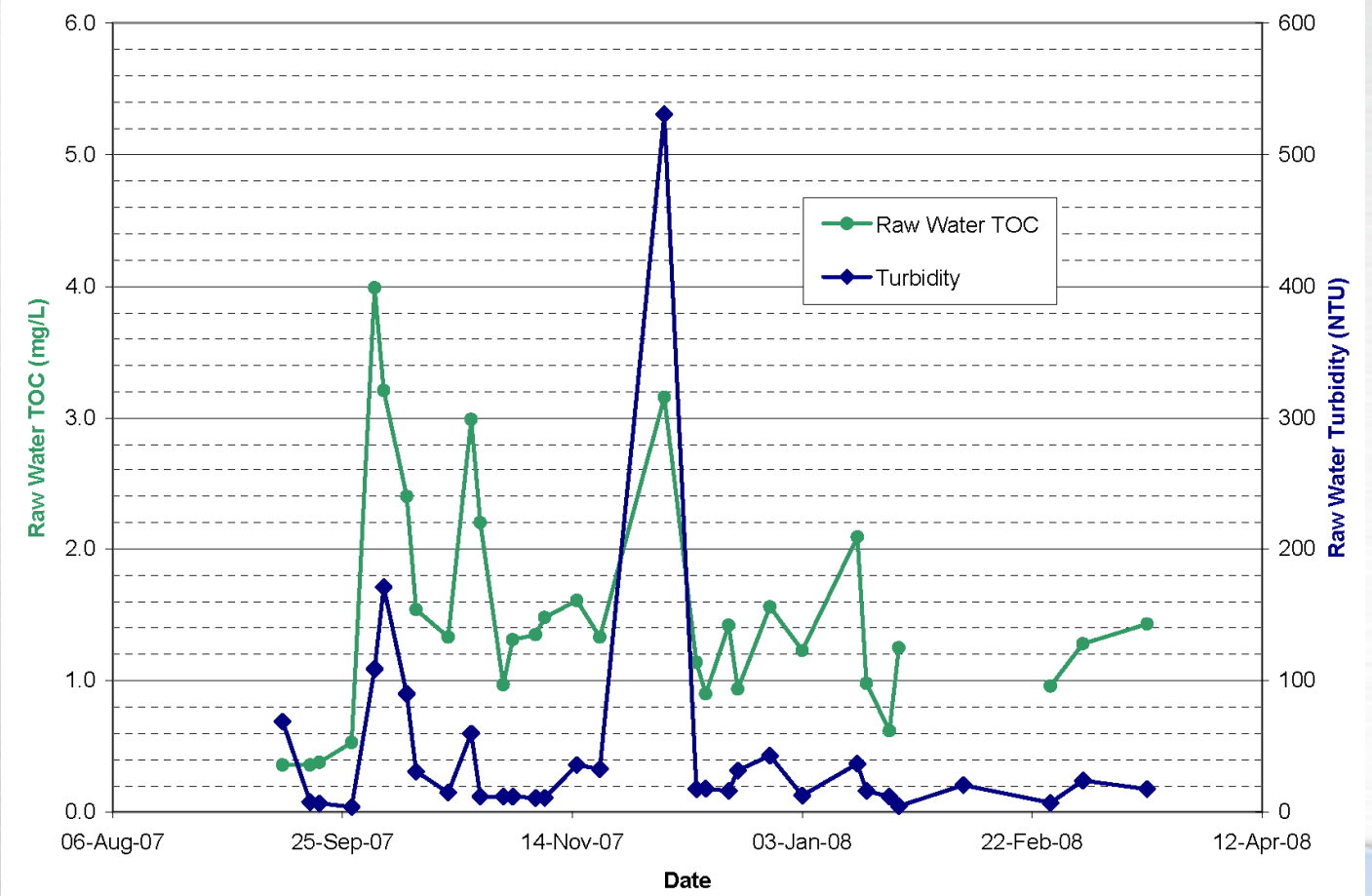
Water Quality – Raw Water Operation

Table 2 Summary of Key Water Quality Parameters in Raw Water Runs[1,2]
Membrane Pilot Testing Protocol
City of Lynden, Washington

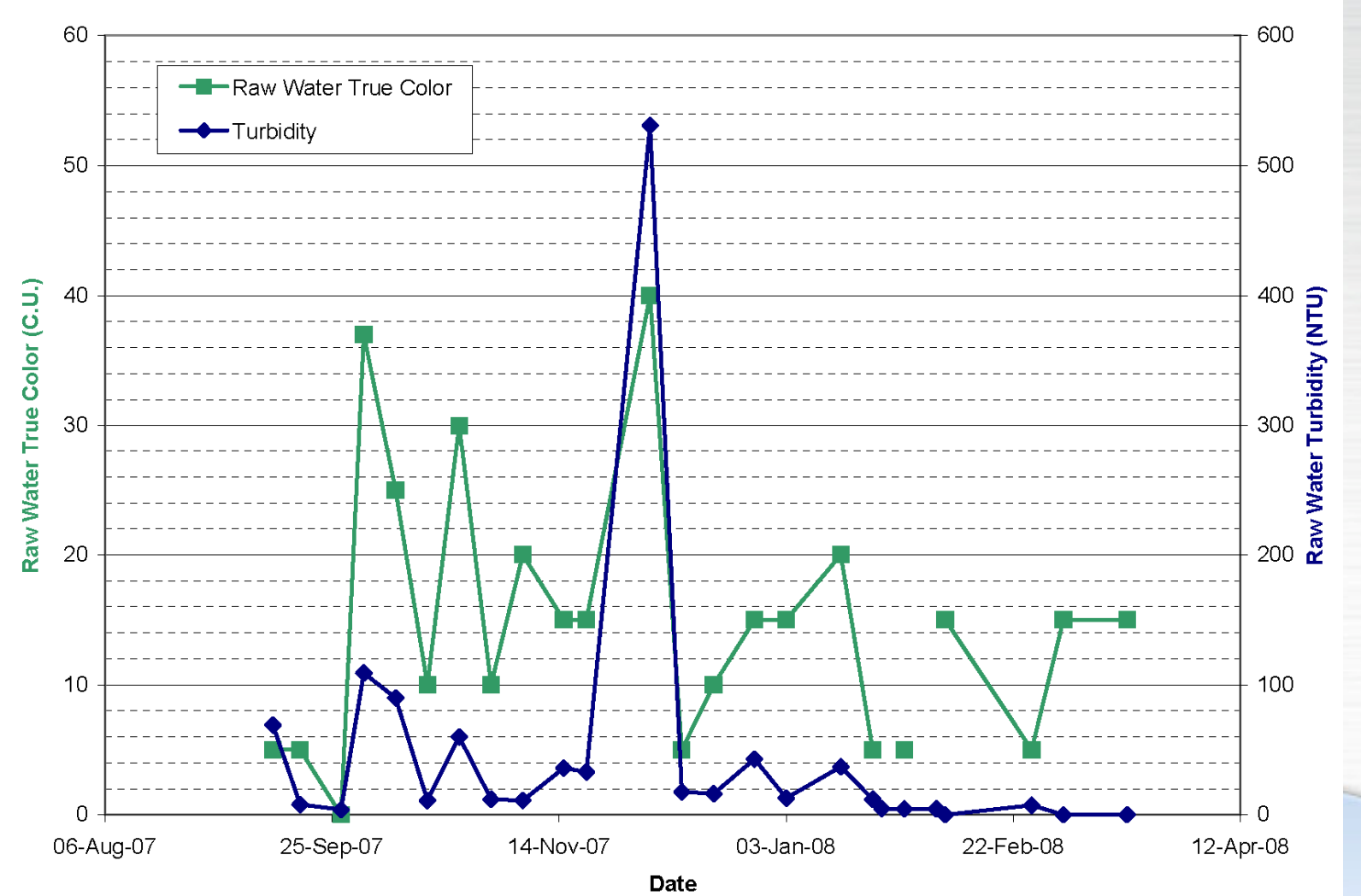
Parameter	Average	Range	Comment
TOC (mg/L)			
Raw Water	1.8	1.0 - 3.2	
Permeate Water	1.4	0.8 - 2.5	Average Removal = 13%
Color (True Color Units)			Goal <5 T.C.U.
Raw Water	22	10 - 40	
Permeate Water	15	5 - 25	70% of results >= 15 T.C.U.
Turbidity (NTU)			Goal <0.1 NTU
Raw Water	37	1.0 - 535	
[illegible]	[illegible]	[illegible]	[illegible]
SDS HAA (µg/L)[3]			Goal <40 µg/L
24 Hour	30	29 - 31	
48 Hour	45	29 - 66	One value exceed 60 ppb limit
72 Hour	48	37 - 56	
SDS TTHM (µg/L)[3]			Goal <60 µg/L
24 Hour	36	31 - 40	
48 Hour	46	36 - 57	
72 Hour	44	38 - 55	

Legend:
* = Feed water not tested
** = Test performed, but evaluation criteria not met.
Note:
1. All pilot operated on raw water October 2007 through November 2007.
2. Raw water membrane filtration was eliminated from consideration due to elevated color measured in treated water.
3. Simulated Distribution Test results are for permeate water. In the two sampling events, TOC was 1.0 mg/L and 1.5 mg/L.

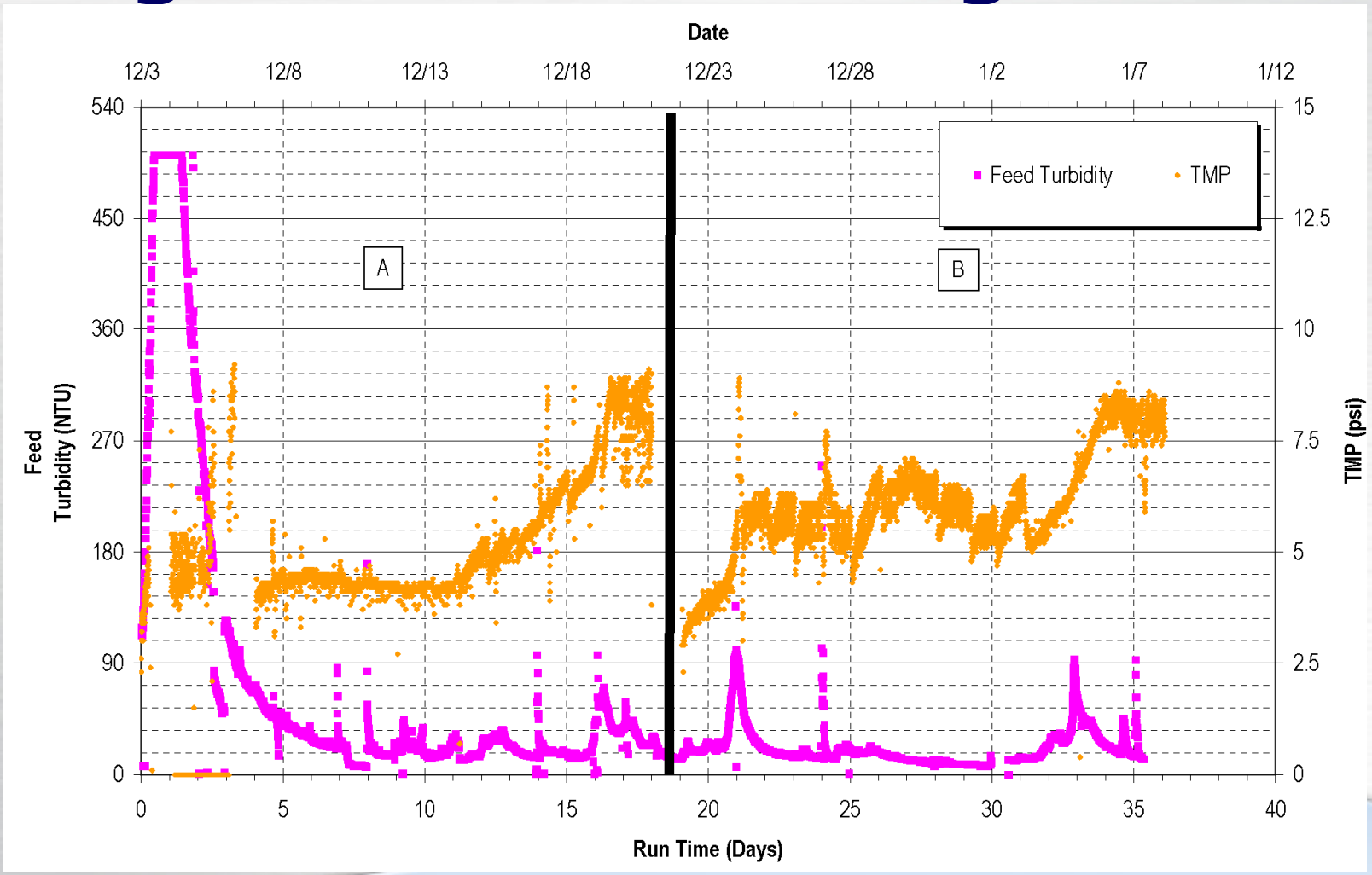
Raw Water TOC Peaks with Turbidity



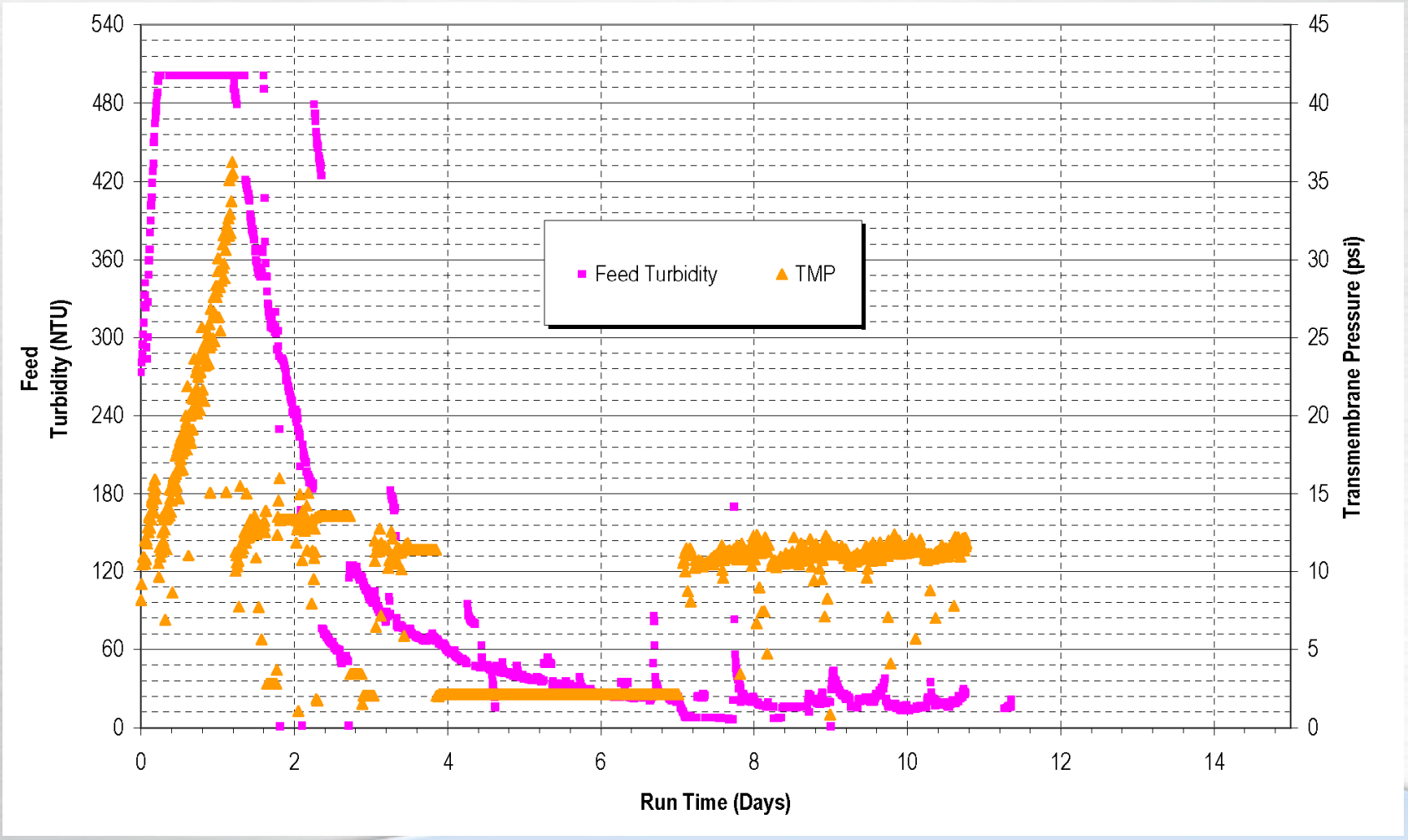
Raw Water True Color Peaks with Turbidity Too!



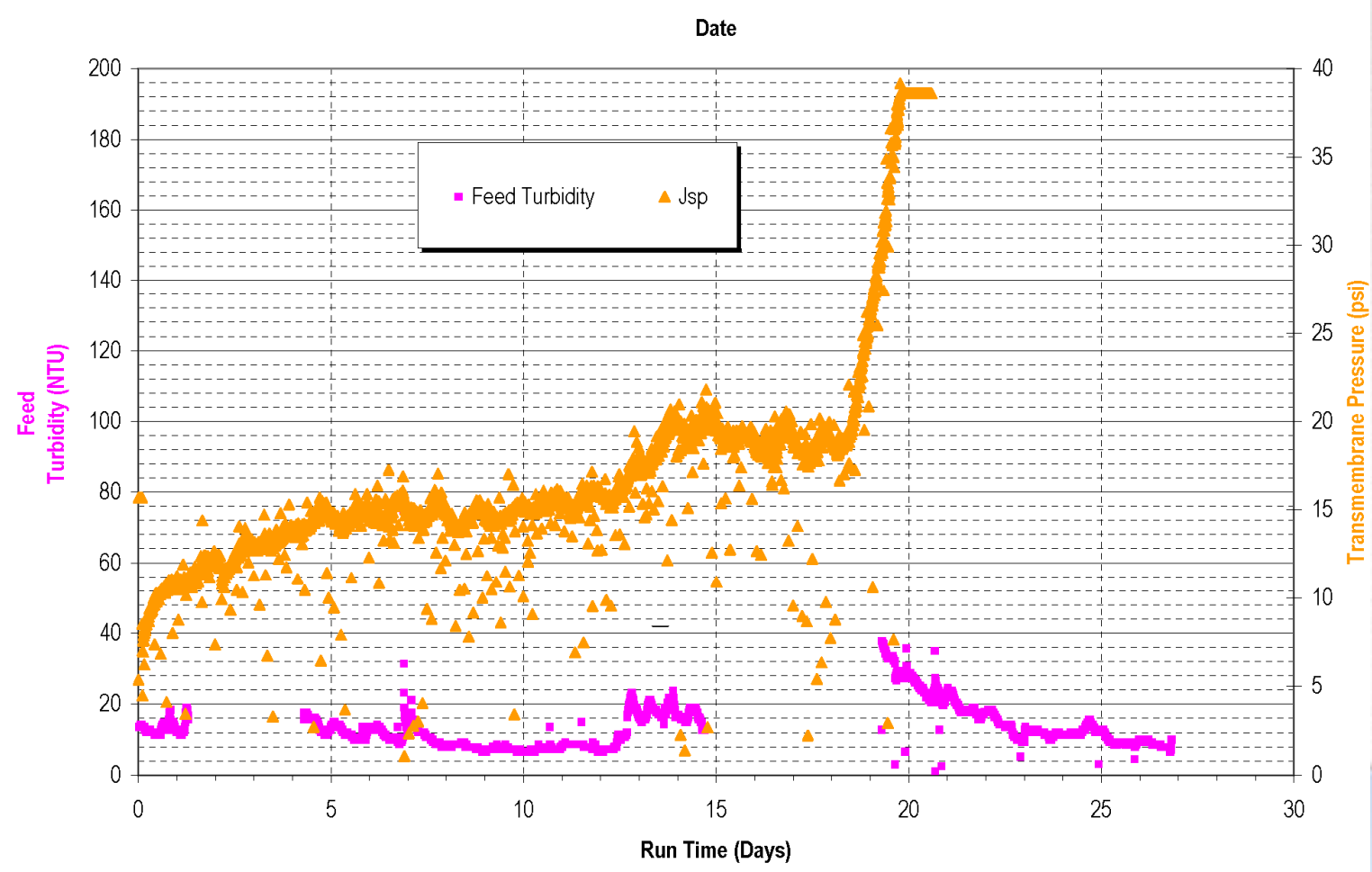
Siemens Results – Coagulated Water 39 gfd



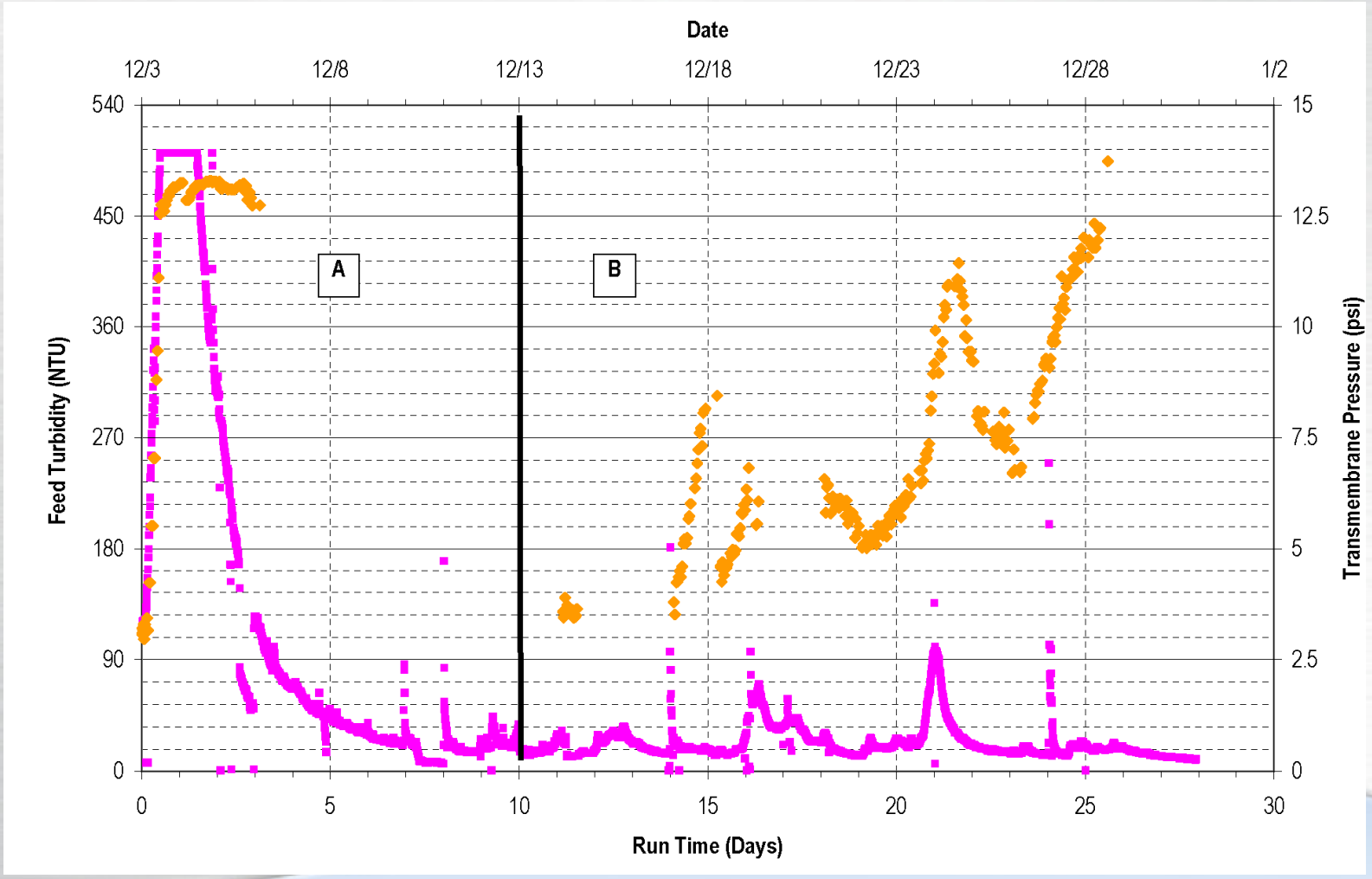
Pall Results – Coagulated Water 50 gfd



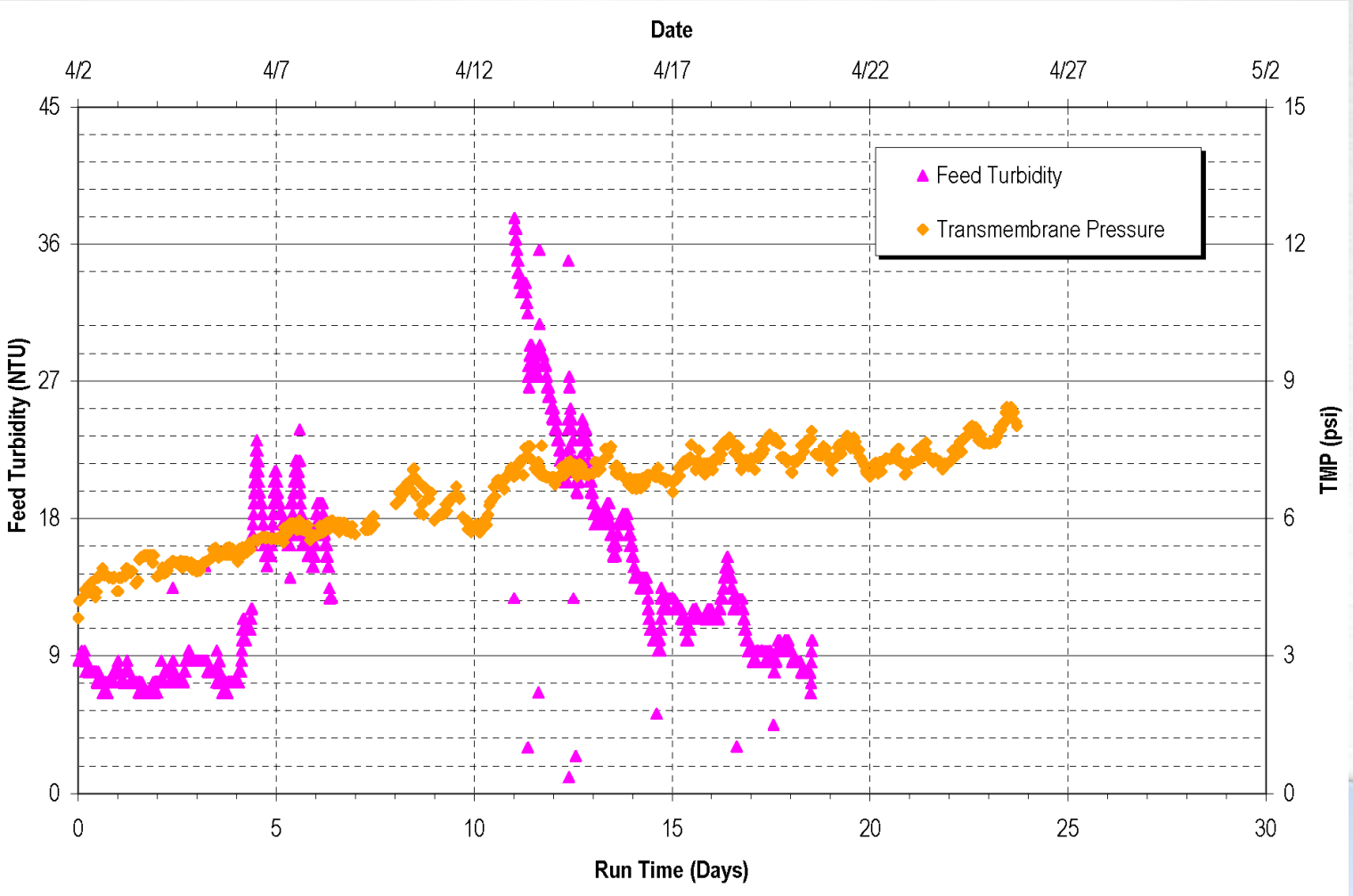
Pall Results – Coagulated Water 46 gfd



Zenon Results – Coagulated Water 30 gfd



Zenon Results – Coagulated Water 35 gfd

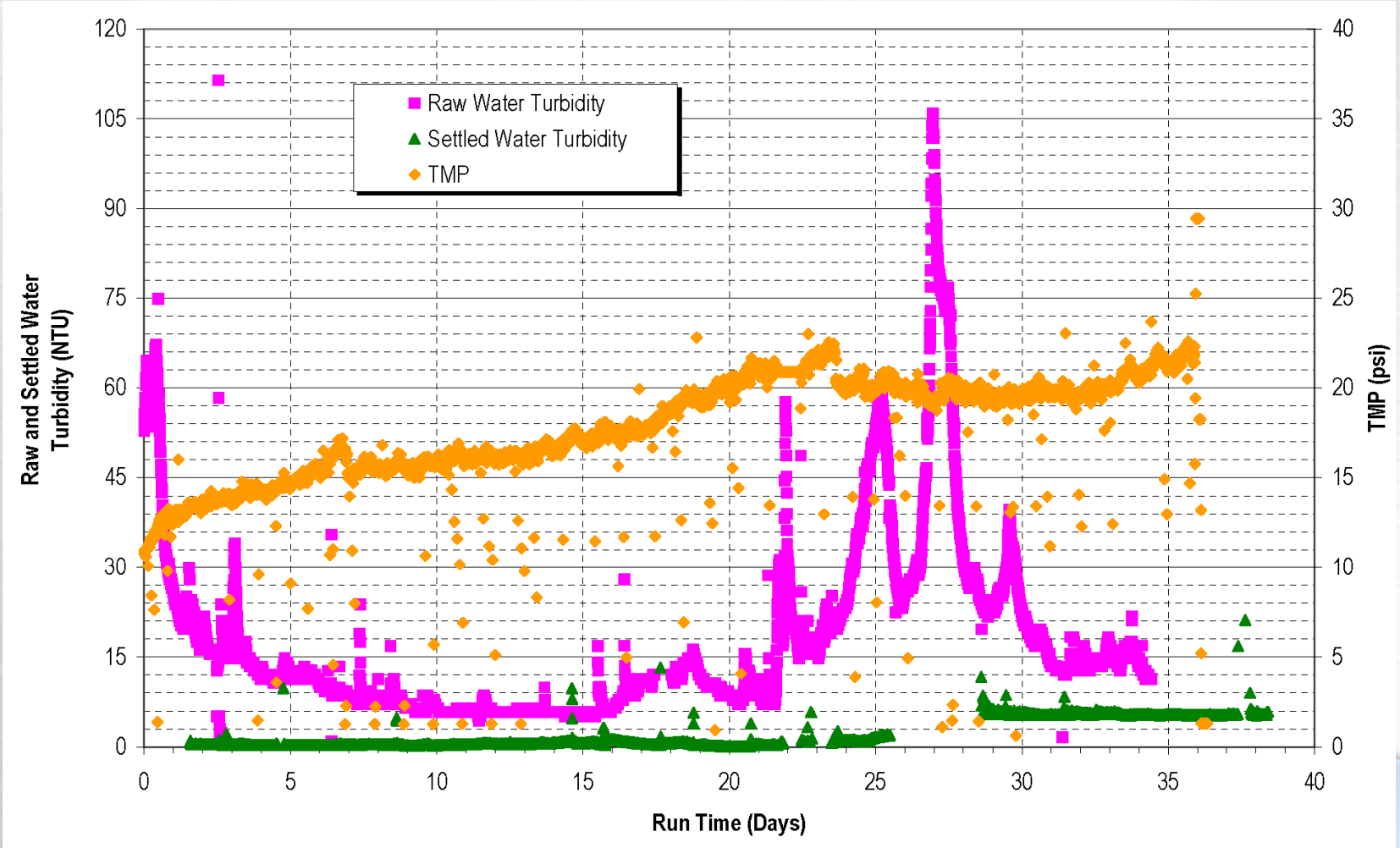


Water Quality - Coagulated Water Operation

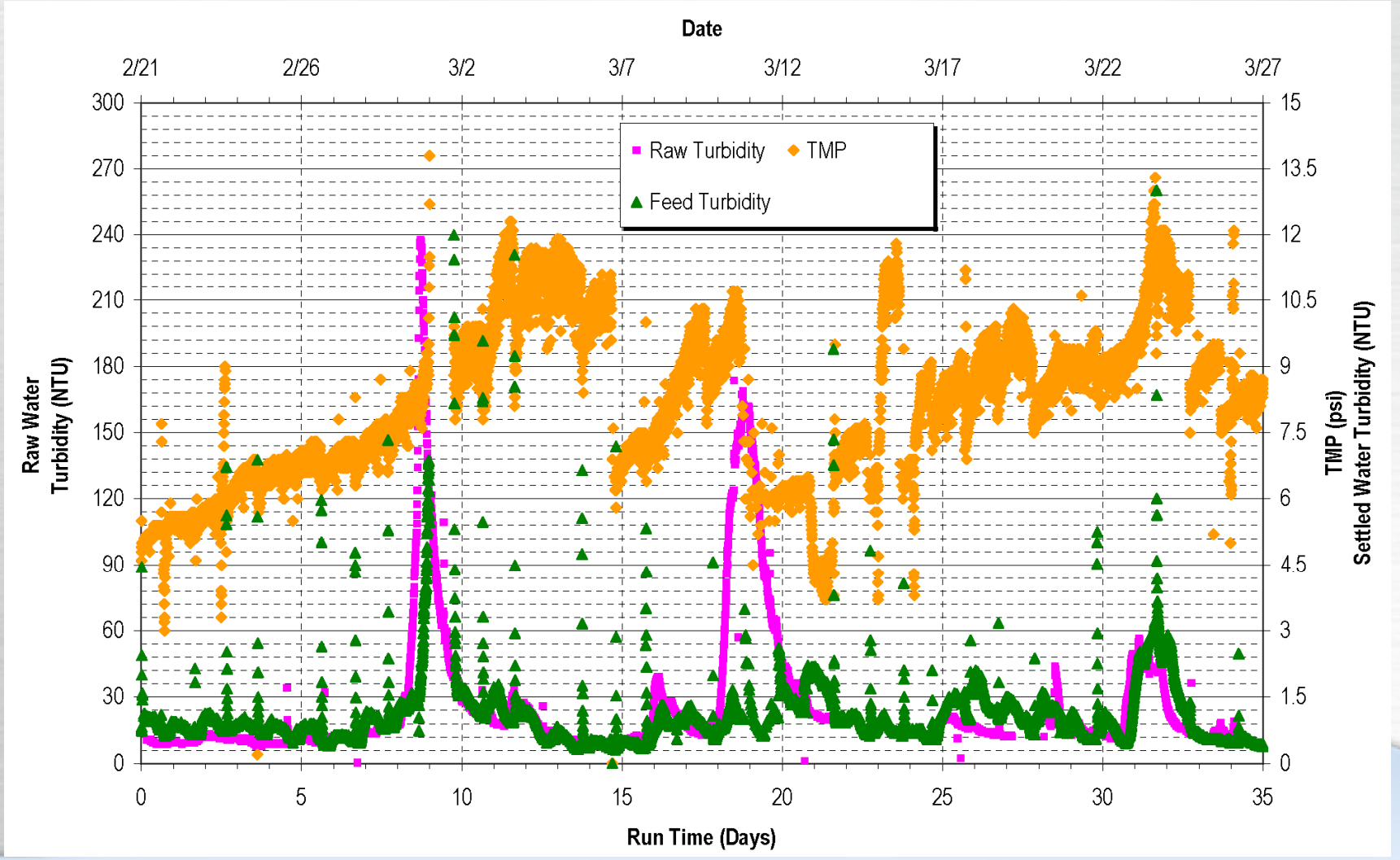
Table 3 **Summary of Key Water Quality Parameters in Coagulated Water Runs[1]**
Membrane Pilot Testing Protocol
City of Lynden, Washington

Parameter	Average	Range	Comment
TOC (mg/L)			
Raw Water	1.9	0.6 - 9.4	
Permeate Water	1.3	0.6 - 3.3	Average removal = 31%
Color (True Color Units)			Goal <5 T.C.U.
Raw Water	14	5 -40	
Permeate Water	7	ND - 25	33% of results >= 15 T.C.U.
Turbidity (NTU)			Goal <0.1 NTU
Raw Water	33	1.0 - 535	
Permeate Water	<0.1	<0.1	
SDS HAA (µg/L)[2]			Goal <40 µg/L
24 Hour	11.3	-	Raw water = 32 µg/L
48 Hour	13	-	Raw water = 37µg/L
72 Hour	10.3	-	Raw water = 73 µg/L
SDS THM (µg/L)			Goal <60 µg/L
24 Hour	12.5	-	Raw water = 31 µg/L
48 Hour	12.5	-	Raw water = 37µg/L
72 Hour	12.9	-	Raw water = 49 µg/L

Pall Results – Settled Water 65 gfd



Siemens Results – Settled Water 39 gfd



Water Quality – Settled Water Operation

Table 4 Summary of Key Water Quality Parameters in Settled Water Runs[1]
Membrane Pilot Testing Protocol
City of Lynden, Washington

Parameter	Average	Range	Comment
TOC (mg/L)			
Raw Water	1.2	ND - 2.1	
Settled Water	0.8	0.3 - 1.5	
Permeate Water	0.7	0.2 - 1.2	Average removal = 41%
Color (True Color Units)			Goal <5 T.C.U.
Raw Water	11	5 - 20	
Settled Water	ND	ND - 10	
Permeate Water	ND	ND - 5	
Turbidity (NTU)			Goal <0.1 NTU
Raw Water	22	<1 - 238	
Settled Water	0.8	0.3 - 5.5	
Permeate Water	<0.1	<0.1 - <0.1	
SDS HAA (µg/L)[2]			Goal <40 µg/L
24 Hour	12	10 - 13	Raw water = 32 µg/L
48 Hour	13	12 - 14	Raw water = 37 µg/L
72 Hour	20	16 - 24	Raw water = 73 µg/L
SDS TTHM (µg/L)[2]			Goal <60 µg/L
24 Hour	13	13 -13	Raw water = 31 µg/L
48 Hour	16	16 - 17	Raw water = 37 µg/L
72 Hour	19	19 - 20	Raw water = 49 µg/L

Conclusions

- A well defined data set beyond what is typically maintained at WTP is required to characterize membrane performance. If possible begin developing this data set well in advance of pilot testing.
- 30-day run times can be achieved on raw Nooksack River water with turbidities exceeding 400 NTU and 4 mg/L of TOC
- A minimum of in-line coagulation is needed to control color in the Nooksack R.; however, when combined with elevated turbidity rapid fouling can occur.

Conclusions

- Coagulation/flocculation/sedimentation was shown to reduce solids and TOC to levels where extended runs could be sustained

Current Work

- Development of cost comparisons of membrane and conventional process trains is in progress