Water Management through Water Treatment Technologies

IETP Final Report

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Canadian Natural resources Limited

2014

Contents

1 Report abstract

Oil sands open pit mining process is facing enormous water management issues. Prior to mining and throughout the operational period, large volumes of saline and potentially sour groundwater, otherwise called Basal Water, need to be pumped out to depressurize the basal formation and to allow open pit mining of the overlying bitumen. Such water must be re-cycled/treated for process reuse or piped for deep well disposal, as applicable. Tailings produced during extraction trap a large fraction of the process water, necessitating the continual import of fresh water. This project addressed water management challenges directly through the application of innovative water treatment technologies. New technologies such as ceramic ultra-filtration, nano-flotation system along with commercial desalinations techniques were demonstrated to provide real operating data for basal and tailings water treatments. This report will discuss details of recently completed pilots with new technology flow sheets which were designed for a full-scale commercial oil sands mine water treatment plants.

2 Summary Project Status Report:

2.1 Members of the Project Team:

Name	Organization	Title	Project Responsibility
Joy Romero	CNRL	VP, Technology Development	Sponsor
Kavithaa Loganathan	CNRL	Process Development Specialist-Water	Project Manager
Vijay Pandit	CNRL-Contract	Process Engineer	Process Coordinator
Alexandre Goldszal	Total E&P	Water Specialist	Advisor
Chris Li	Total E&P	Water Specialist	Advisor
Prit Kotecha	Suncor	Water Specialist	Advisor
Mike Rogers	CNRL-CSA	Water Specialist	Advisor
Lee Ward	EPCOR	Project	Program coordinator

		Development	
Ryan Litwinow	EPCOR	Project Manager	Construction coordinator
Brent Leinan	EPCOR	Project Manager	Pilot Co-ordinator
Jamie Gingrich	EPCOR	Operations Manager	Pilot operations planner
Ryan Thomas	EPCOR	Lead hand Operator Shift 1	On-site Pilot Operations Lead
Andrew Rose	EPCOR	Lead hand Operator Shift 2	On-site Pilot Operations Lead
Saif Molla	EPCOR	Process Engineer	Process Coordinator
Glen Sinclair	LSI	Project Engineer	Project support
Garry Germscheid	LSI	Construction Manager	Project support
Eric Monteith	Stantec	Project Engineer	Engineering Support
Matt MacPhail	Stantec	Engineer	Engineering Support
Ryan Colley	Veolia Water Solutions	Technical Engineer	Operator & technical support
Martin Gendron	Veolia Water Solutions	Technical Engineer	Operator & technical support
Jeremy Jones	Veolia Water Solutions	Technical Engineer	Operator & technical support
John Korpiel	Veolia Water Solutions	Technical Engineer	Operator & technical support
Guillaume Hainault	Veolia Water Solutions	Technical Engineer	Operator & technical support
Daniel Apostol	Veolia Water Solutions	Technical Engineer	Operator & technical support
Garry Haacke	Veolia Water Solutions	Technical Engineer	Operator & technical support
Tracey Williams	Veolia Water Solutions	Technical Engineer	Operator & technical support
Jean-François	Veolia Water	Technical Engineer	Technical Support

Beaudet	Solutions		
Brad Biagini	Veolia Water Solutions	Technical Engineer	Technical Support

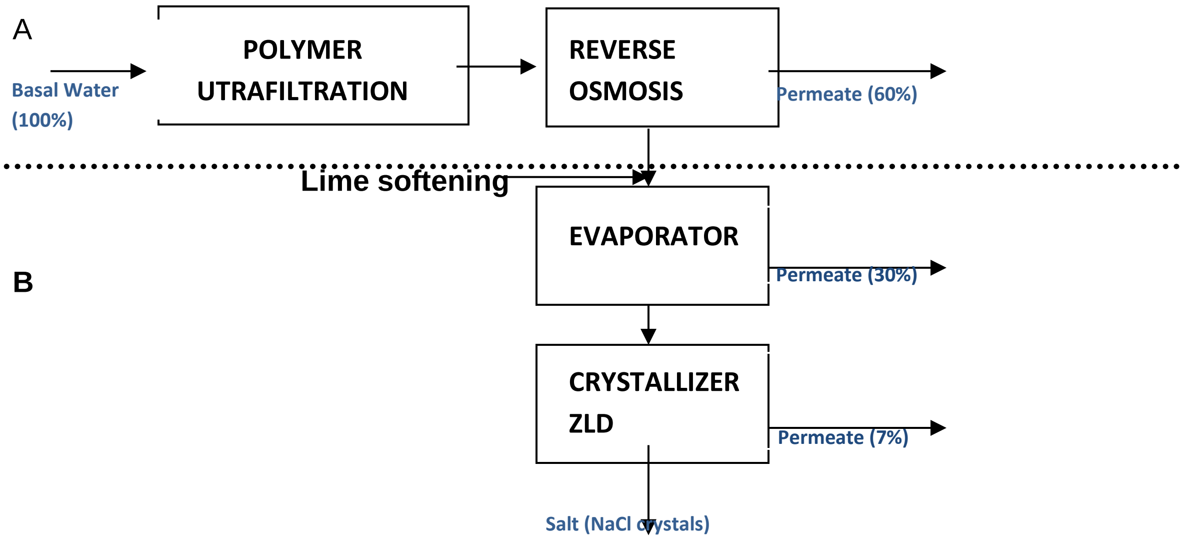
2.2 A chronological report (in point form) of all activities and operations conducted since the project was initiated up to completion, with separate reference to what occurred in the various years for which details are provided in subsequent sections of the final report (as outlined below)

Project Activity	Initiation Period	Completion Period
Development	Jan 2012	Feb 2012
Design	March 2012	April 2012
Procurement	March 2012	October 2012
Construction	March 2012	October 2012
Operations	June 2012	March 2013
Decommissioning and Demobilization	April 2013	August 2013
Report review, revisions and Final report Completion	December 2013	March 2014
Salt waste disposal study	Jan 2014	August 2014

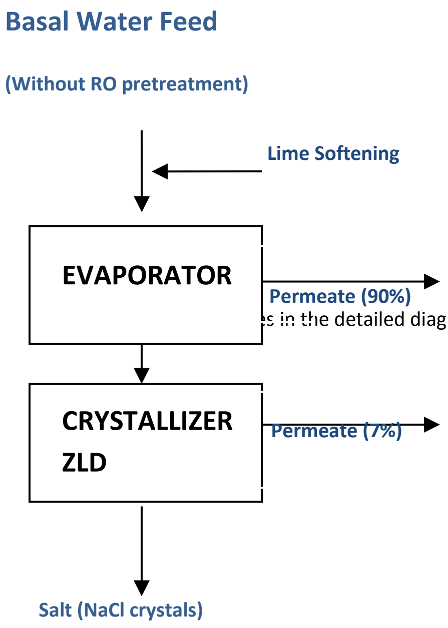
3 TECHNOLOGY FLOW SCHEMES PILOTED

The following flow schemes were piloted for the treatment of basal water.

Basal Flow Scheme 3-1

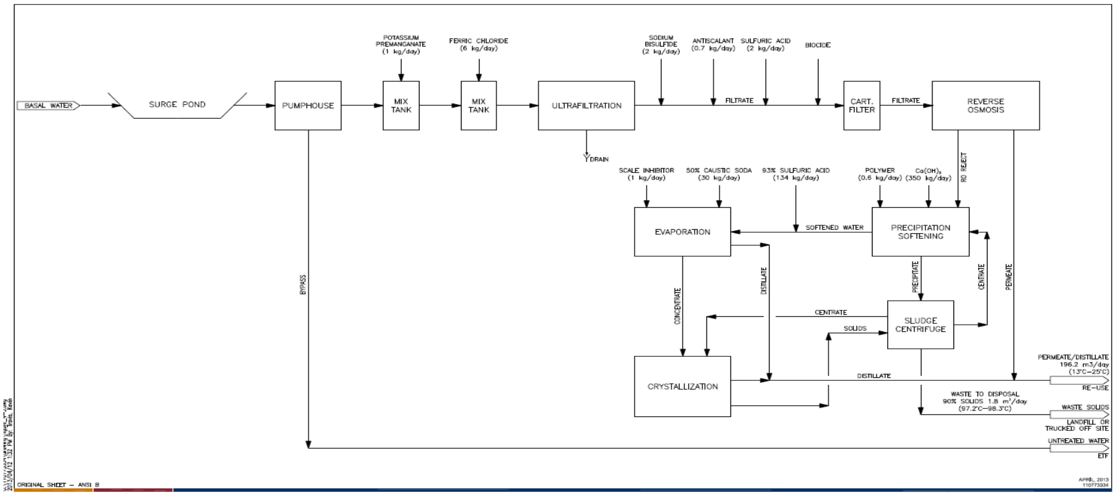


Basal Flow Scheme 3-2



Basal Scheme 3- 1 with more details

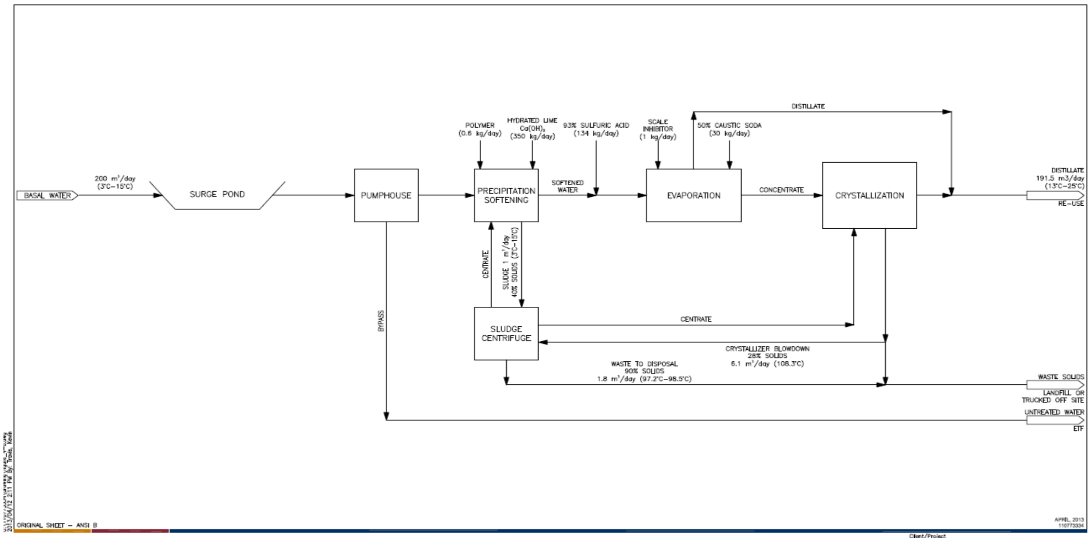
s in the detailed diagram refer to flow rate of 200 m^3 per hour)



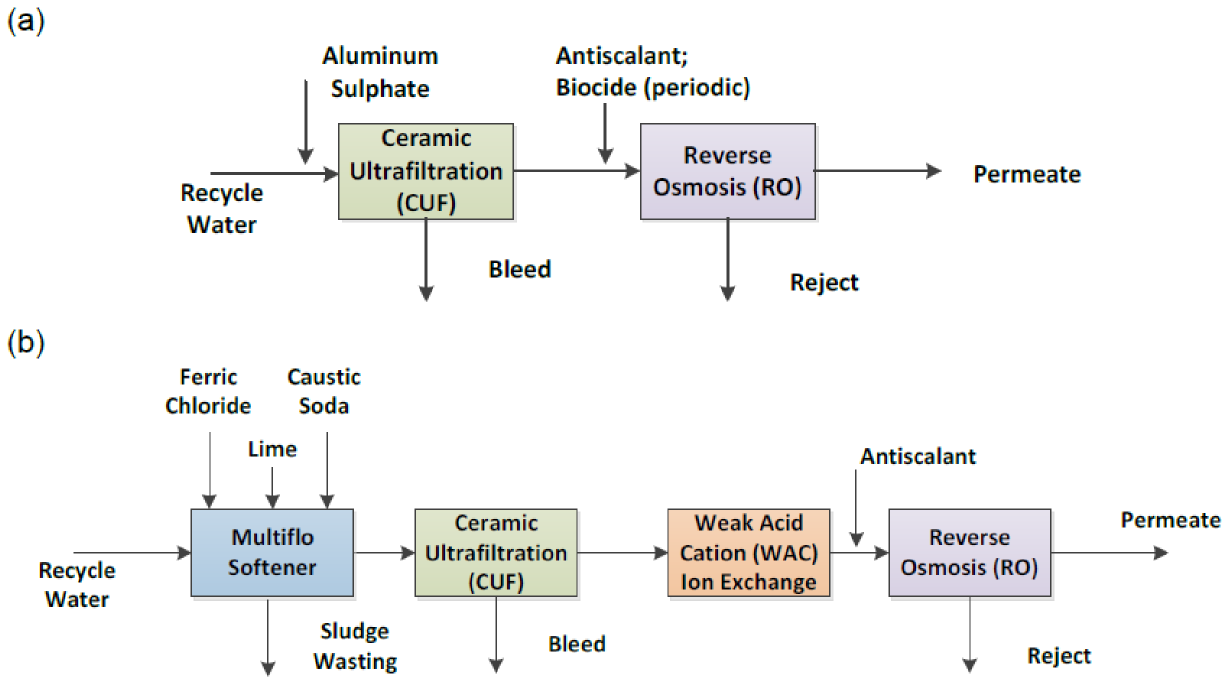
- Permeate water can be used as a partial replacement of river water wherever river water is
- Salt from the ZLD process is to be disposed in a landfill (can pass TCLP test requirements see report for composition of salt). Off-site disposal other than to a landfill requires further investigation
- Details of pilot configuration are found in the appendix and important ones are outlined below:
  - Polymer Ultrafiltration membrane DOW SFD 2860; PVDF-0.03 microns pore size)
  - Single pass RO rated for 1000 psig; 3x2x1 configuration; 4” DOW sea water RO membrane (SW30-4040) elements per vessel
  - Evaporator metallurgy higher alloyed stainless steel with 6% molybdenum; trade name- Al6XM
  - Crystallizer metallurgy Nickel alloy; trade name INCONEL 625

Basal Scheme 3- 2 with more details

Chemical feed rates in the detailed diagram refer to flow rate of 200 m^3 per hour)



Tailings Flow Scheme 3-3



3.1 Major Process Units and Description

Item	Process Unit	Description
1	Chemical Oxidation	• Removal of Iron, Manganese and sulfides present in basal water • Required to prevent fouling of Reverse Osmosis membranes • Chemicals used are caustic to maintain pH and potassium permanganate
2	Chemical Coagulation	• Removal of Total suspended solids • Required as a pretreatment to ultrafiltration • Chemicals used ferric chloride
3	Polymer Ultrafiltration	• Removal of Total Suspended Solids (TSS). Target Slit Density Index SDI of <3 • Required to prevent fouling of Reverse Osmosis membranes • Chemicals used citric acid and sodium bisulfite
4	Reverse Osmosis	• Removal of Total Dissolved Solids (TDS) • Required to reduce volume to evaporator by 50% • Chemicals used Antiscalant, biocide, sulfuric acid (to achieve neutral pH as an alternative to softening), sodium bisulfite, citric acid and sodium bisulfite
5	Softening	• Performed to remove potential scaling to evaporator • Chemicals used lime
6	Evaporator	• Concentration of reverse osmosis reject • Required to further extract water to improve recovery • Chemicals used antiscalant
7	Crystallizer	• For zero liquid discharge (ZLD) • Chemicals used antifoaming agent

3.2 Operational/Technology Selection Challenges

Risks	Recommendations
Raw basal water feed quality changes, particularly sulfides, Fe and Mn	These contaminants required adequate control if RO system is employed for future plant. Control of these contaminants can be ensured by introducing a

	neutralization of the feed water by oxygenation prior to chemical oxidation
Basal feed from an open pond	Noted algae in the process that caused problems For the full scale plant removal of algae is required by filtration or store feed water in closed tanks in the absence of sunlight
Reverse osmosis pretreatment for Evaporator to reduce volume to Evaporator (also to reduce evaporators CAPEX and OPEX)	Economic analysis required for introducing RO pretreatment considering basal water volume and future volume and quality (TDS) changes • RO is unsuitable for higher TDS (>50,000 ppm) • RO pretreatment will not be economical for the treatment of low basal volume (< 3000 m^3/day)
Evaporator Process cost contributors • High TDS • Volumes • Metallurgy • Blowdown treatment	Ideal for low volumes and high TDS concentrations (Use Evaporator only design for TDS ranging between 50,000 and up to 200,000 ppm) High TDS concentrations should be taken into account for metallurgy of the future treatment plant Disposal options for evaporator blow down must be considered before designing full scale treatment plant • Disposal of blowdown could save >50% of CAPEX costs by eliminating ZLD process If evaporator only option is used for basal treatment evaluate power source to reduce OPEX costs
Crystallization Process • Conventional Crystallizer vs. Saltworks Saltmaker	Integration of Salt maker process (from flow scheme 2B) unit with evaporator (flow scheme 1-1/1-2) should be considered for future treatment plant Use Crystallizer only design for TDS greater than 200,000 ppm) Saltmaker technology has potential for higher CAPEX and lower OPEX costs when compared to conventional crystallizer because of low temperature operations. Use of waste heat should be considered for the full scale plant • Suncor is planning to use Saltmaker technology for treating OTSG blowdown and is going for a commercial pilot of capacity 20 cubic meters in 2015. This could present an opportunity for further evaluation by Horizon.

Well information (Initial planned and final actual).

N/A for this project

Production performance and data for each project calendar year and cumulative project totals, including:

N/A for this project

5. Pilot Data

5.1 Pilot Study

The pilot study was divided into two phases based on the source water type: Phase 1 involved the treatment of BAW, while Phase 2 included the treatment of RCW. The pilot facility was located on CNRL Horizon site, next to plant 99A, adjacent to a tailings pond. The different projects conducted under this pilot study, equipment vendors, and study dates are presented in **Table 1**.

Table 1. Projects conducted under the pilot-scale study.

Phase	Project	Equipment Vendor
Phase 1: Treatment of Basal Aquifer Water (BAW)	Treatment of BAW using polymeric ultrafiltration (PUF) and reverse osmosis (RO)	Veolia Water Solutions & Technologies North America, Inc.
	BAW solidification tests	Veolia Water Solutions & Technologies North America, Inc.
Phase 2: Treatment of Recycle	Treatment of RCW using nanoflotation	David Bromley Engineering
	Treatment of RCW using Multiflo^{TM} softening, ceramic ultrafiltration (CUF), ion	Veolia Water Solutions & Technologies North America,

Water (RCW)	exchange, and RO	Inc.

a) <u>Treatment of BAW Using PUF/RO</u> (**Figure 1**): This study was designed to assess the performance of a treatment train consisting of an oxidation step (potassium permanganate) followed by PUF and a RO system. The UF system was a polyvinylidene fluoride hollow fiber outside-in type (DOW SFD 2860 module) membrane, while the RO unit consisted of a three-stage design with fiberglass pressure vessels containing polyamide thin-film composite elements (DOW Filmtec SW30-4040). The main objective of the oxidation step was to precipitate out sulfides, iron, and manganese, which had the potential to negatively impact fouling rates on the UF and RO membranes. The purpose of the PUF system was solid removal, while the primary goal of the RO unit was to reduce the total dissolved solids (TDS). The treated water quality goals for this treatment train were to achieve effluent TDS < 1000 mg/L, sodium levels < 500 mg/L, and the maximum possible recovery for reuse.

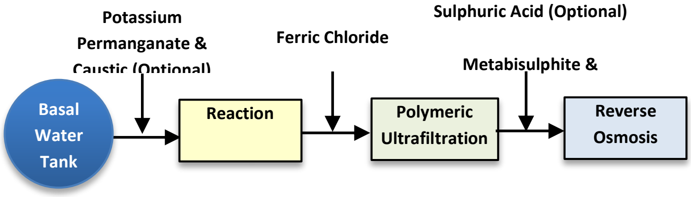


Figure 1. Treatment of BAW using PUF and RO.

b) <u>BAW Solidification Tests</u>: Bench-scale tests were conducted to confirm the feasibility of solidification of BAW (**Figure 2**). The goal of these tests were to reduce the volume of concentrated BAW, while using aggregates and additives to generate a final product which was able to reach the solid characteristics and be easily handled and disposed of at the mine pits.

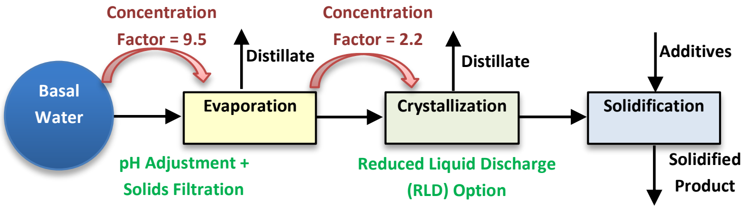


Figure 2. Train for the BAW solidification tests.

c) <u>Treatment of RCW Using Nanoflotation</u> (**Figure 3**): The nanoflotation system was a stand-alone unit fed with untreated RCW, and

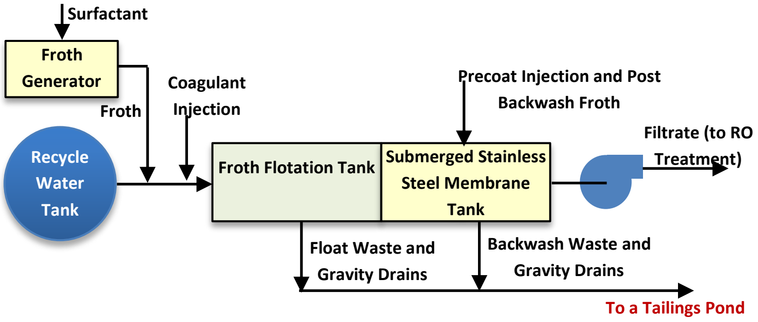


Figure 3. Treatment of RCW using nanoflotation.

incorporated three major processes: froth flotation; filtration using a precoat material applied directly on the membrane surface; and filtration through submerged stainless steel membranes. The main purpose of the froth flotation was solid-liquid separation. The froth was intended to capture the flocs and help the captured solids to rise to the surface of the flotation tank where the float layer was effectively removed using a skimmer system. The precoat layer applied to the membrane surface was designed to prevent colloidal particles and other scalants to deposit on the membrane surface. The submerged membrane system was composed of stainless steel tubes with microscopic perforations and was designed to reject particles sized 1 µm and higher. The target for effluent quality was to consistently achieve silt density index (SDI) values of less than 5 (i.e., requirement for RO feed water).

d) <u>Treatment of RCW Using Softening, CUF, Ion Exchange, and RO</u>: Two distinct treatment trains were assessed to treat RCW: a neutral pH treatment train (**Figure 4a**) configured to provide minimal pretreatment in front of an RO system; and an OPUS II treatment train (**Figure 4b**) designed to provide a high level of pretreatment in front of a RO system, with the ultimate goal of validating whether the system was able to achieve zero liquid discharge (ZLD). The treated water quality goals for both treatment trains were: TDS < 50 mg/L, sodium < 30 mg/L, and maximum possible recovery for reuse.

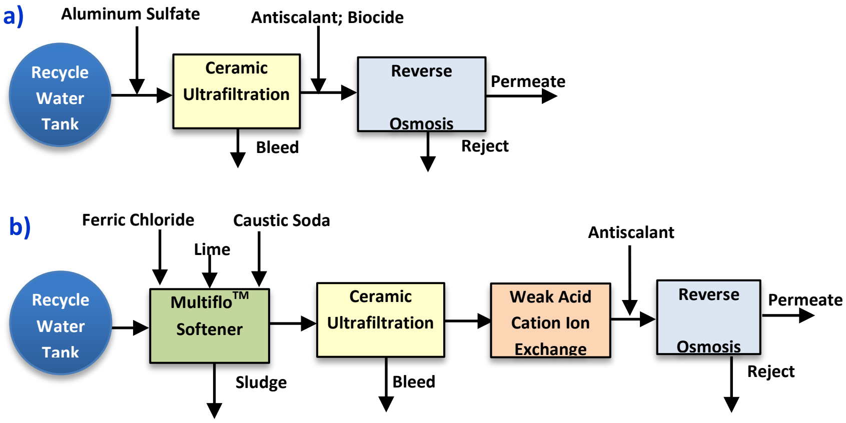


Figure 4. Treatment of RCW using softening, CUF, ion exchange, and RO.

5.2 Interpretation of Pilot Data

5.2.1 Water Quality of Untreated Basal Aquifer Water and Recycle Water

Basal aquifer water (BAW) was typified by neutral pH, low to moderate total suspended solids (TSS) and high TDS (**Table 2**). TDS was primarily composed of sodium, chloride, bicarbonate and hardness-causing compounds. Organic compounds were present at low concentrations. The levels of total organic carbon (TOC) were lower than the detection limit (13 mg/L) for 88%

of samples. Oil and grease was consistently low. As shown in **Table 2**, the recycle water (RCW) had a pH of 8.1, high alkalinity, low to moderate TSS and turbidity, as well as high TDS and TOC. TDS was primarily composed of sodium chloride, bicarbonate and hardness-causing compounds, while TOC was primarily composed of naphthenic acids.

Table 2. Characteristics of untreated BAW and RCW.

Parameter	Unit	Basal Aquifer Water Value (Average ± Std. Dev.)	Recycle Water Value (Average ± Std. Dev.)
pH	-	7.3 ± 1.6	8.3 ± 0.1
Total suspended solids (TSS)	mg/L	23.4 ± 81.5	359 ± 315
Total dissolved solids (TDS)	mg/L	21,300 ± 3,457	2,094 ± 284
Turbidity	NTU	22.8 ± 20.1	489 ± 312
Chloride	mg/L	12,456 ± 509	450 ± 47
Bicarbonate	mg/L as $CaCO_3$	3,638 ± 193	876 ± 32
Total hardness	mg/L as $CaCO_3$	1,450 ± 102	47 ± 14
Total Alkalinity	mg/L as $CaCO_3$	2,975 ± 157	725 ± 32
Total organic carbon (TOC)	mg/L	6.9 ± 2.8	47 ± 14
Naphthenic acids (NAs)	mg/L	3.5 ± 1.2	54 ± 11
Oil & grease (O&G)	mg/L	2.1 ± 1.4	25 ± 6

5.2.2 Treatment of BAW Using PUF/RO

In this study, the optimal operation of the oxidation step was achieved by maintaining a neutral pH in the oxidation/precipitation stage, by adding permanganate at a fixed dose (between 1 to 1.5 mg/L) in order to precipitate iron and sulphides, and by keeping manganese in dissolved form.

Solid removal was consistently good, with the UF filtrate turbidity averaging 2.0 NTU and SDI averaging 0.9 over the course of the pilot study. RO feed requires an SDI of less than 5 at a minimum and ideally less than 3. Pilot data and the results of a membrane autopsy (**Figure 5a**) indicated that iron was the primary foulant of the UF membrane, with a notable concentration of sodium present as well.

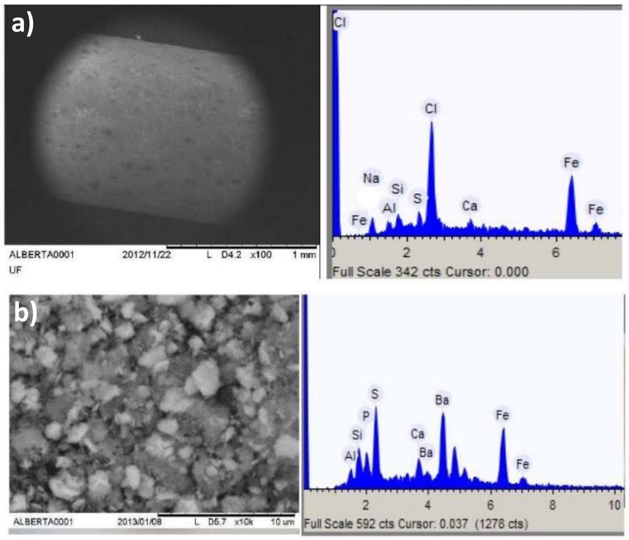


Figure 5. Autopsy of a) UF and b) RO membranes.

At all times, the RO permeate was below the 1,000 mg/L target for TDS and 500 mg/L target for sodium. At 50% recovery, the permeate conductivity was reduced to 593 μS/cm (a 98.4% reduction relative to UF filtrate and untreated BAW). TDS was reduced to an average of 304 mg/L, while total sodium was reduced to an average of 123 mg/L. The operation of the UF unit at 60% recovery was for a brief period, but similar rejections were observed compared to those recorded at 50% recovery.

The pilot data did not indicate irreversible fouling of the RO membranes. The membrane autopsy (**Figure 5b**) identified iron and barium as the primary scalants of the RO membrane. The use of pH adjustment and antiscalant dosing during the pilot study appeared to effectively manage the impact of hardness-causing ions on the RO membrane.

5.2.3 Basal Water Solidification Tests

The solidification tests were performed with different combinations of additives and variable amounts of: (1) water: concentrated BAW with 21.9% TDS (considering evaporation followed by solidification option) and slurry with 48% TDS (considering evaporation/ crystallization reduced liquid discharge (RLD) followed by solidification option); (2) hydraulically bound mixtures: Portland cement, class “F” fly ash, softening sludge, and clay; and (3) inert compounds: sand and small mining aggregates.

To select the most suitable combination of additives, paint filter, penetrometer, compressive strength, and leaching tests were conducted. An example of confined compressive strength results obtained with penetrometer is presented in **Figure 6**. The increase of the ratios of inert compounds to hydraulically bound mixture (R) from 3 to 6 did not result in an increase of the compressive strength development of samples with clay. The results also indicated that hydraulically bound mixtures, including fly ash and clay substituting for part of the cement had no positive effect on the water demand. However, when softening sludge was added, lower amount of hydraulically bound mixture was required. Inert compounds such as sand and small mining aggregates helped to increase the concentrated BAW (considering evaporation followed by solidification option) or slurry (considering evaporation/crystallization RLD followed by solidification option) demand and thus to decrease the amount of hydraulically bound mixtures required to reach solidification.

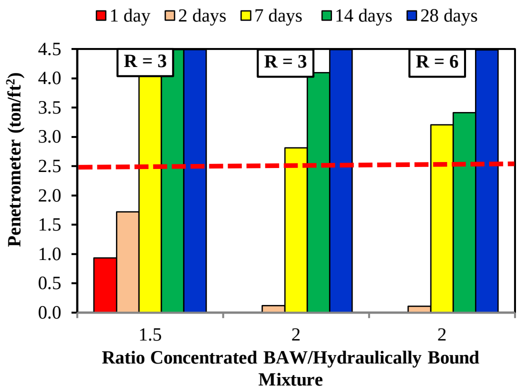


Figure 6. Penetrometer test on concentrated BAW + 75% Portland cement + 25% clay + 100% small mining aggregates

The four successful recipes of the solidification test program were as follows:

- 2.5 kg of concentrated BAW mixed with 1 kg of Portland cement and 6 kg of small mining aggregates.
- 1.5 kg of concentrated BAW mixed with 1 kg of Portland cement and 3 kg of small mining aggregates or sand.
- 1.5 kg of concentrated BAW mixed with 1 kg of hydraulically bound mixture including 75% of Portland cement and 25% of clay and 3 kg of small mining aggregates.
- 2.5 kg of slurry mixed with 1 kg of Portland cement and 3 kg of small mining aggregates.

The results of this testing program indicated that solidification processes were effective for the conversion of concentrated BAW and slurry to a strong, stabilized solid waste suitable for class II landfill disposal.

5.2.4 Treatment of RCW Using Nanoflotation

This study was the first pilot-scale testing of a nanoflotation technology ever conducted to demonstrate the ability of a system consisting of froth flotation combined with filtration through submerged stainless steel membranes to treat RCW. The results indicated that the most important factor affecting the performance of the nanoflotation system was the influent water quality. Any rise in the TSS or TOC of the feed water resulted in changes of chemical consumption rates, flux rates, and operating cycle durations.

Appropriate selections of chemical type and dosing rates were critical in achieving optimal performance. In particular, the froth application rate heavily affected the overall recovery of the nanoflotation system as well as the performance of the flotation process. Optimum surfactant usage to generate froth (per liter of nanoflotation treated water) was 0.25 mL/L at approximately 2,000 NTU of influent turbidity and 0.015 mL/L at approximately 200 NTU of influent turbidity. At the tested conditions, the optimal coagulant dose was 80 mg/L (as Al) at approximately 2,000 NTU of influent turbidity and < 40 mg/L (as Al) at approximately 200 NTU. Precoat loading per unit membrane surface area tested during the pilot study was approximately 30 g/m^2.

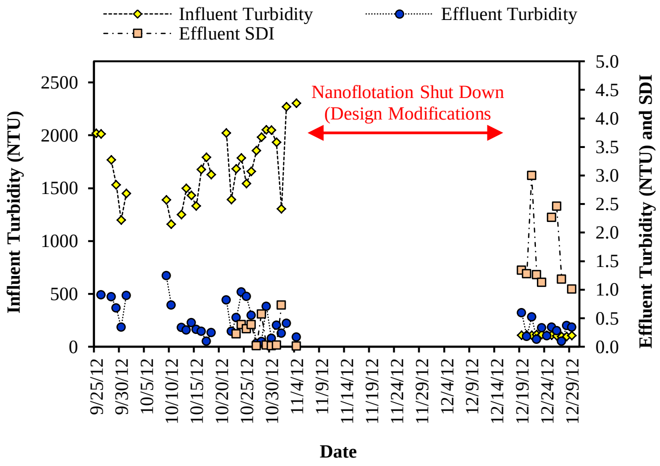


Figure 7. Influent and effluent turbidity as well as silt density index (SDI) during the nanoflotation pilot-scale study.

Figure 7 shows the turbidity and SDI of the nanoflotation effluent related to feed water turbidity conditions. The nanoflotation system was able to consistently produce effluent water with turbidity of less than 1.5 NTU and SDI less than 3. This confirmed that the treated water from the nanoflotation system could be considered for RO treatment. Treated water quality from the nanoflotation system indicated that this technology can potentially be considered as a pretreatment step for RO treatment of RCW.

5.2.5 Treatment of RCW Using Softening, CUF, Ion Exchange, and RO

In this study, two distinct treatment trains were assessed to evaluate the impact of pretreatments on the RO performance: neutral pH treatment train and OPUS II treatment train operated at alkaline pH. RO permeate fluxes normalized to 25 ^{o}C of approximately 31-39 L/m^{2}·h at 72% recovery and 38-52 L/m^{2}·h at 85% recovery were recorded for neural pH and OPUS II trains, respectively.

Normalized salt rejection (NSR) is a standard parameter used to assess the performance of RO membranes. Declines in NSR over time may indicate an issue with membrane fouling or degradation (i.e., loss of membrane polymer integrity). The results indicated that the RO membrane maintained its integrity throughout the course of the pilot study. The NSR was approximately 99.5% through the duration of the neutral pH treatment at 72% recovery. During the OPUS II treatment train, the NSR was relatively stable as shown in **Figure 8**. NSR was generally between 98.5% and 99.2% and did not undergo a reduction during the piloting period. This indicates that the membrane integrity remained intact.

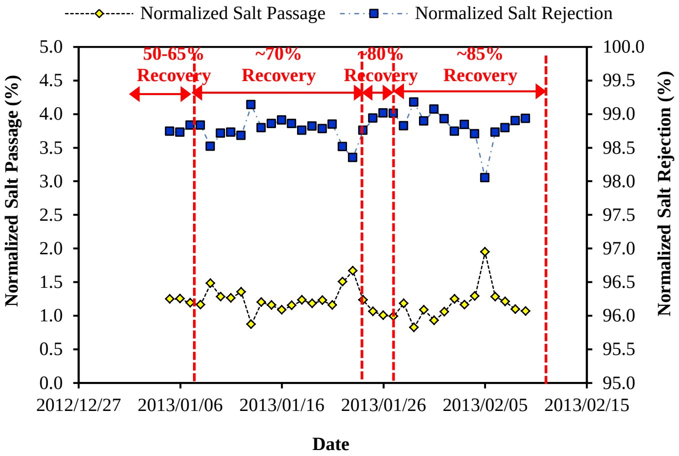


Figure 8. Normalized salt passage (NSP) and normalized salt rejection (NSR) over the course of the OPUS II treatment train.

At the tested conditions, the two treatment trains resulted in TDS lower than 18 mg/L, while the dissolved sodium concentrations were below 7 mg/L. During the pilot tests, clean-in-place procedures were not required for both treatment configurations, highlighting the effectiveness of the pretreatment steps to reduce the RO membrane foulants.

6 Pilot economics (by year and cumulative project total)

a. Capital costs

The capital cost for this project was $5,393,795. Detailed list as below:

Contrator	Scope of Work	Subtoal
EPCOR Water (Central) Inc	EPC and Commissioning	$ 4,701,354
Finning Canada	600KW/230KW Genset Rental	$ 58,328
SNC-Lavalin Inc.	Engineering Support for Installation of Supply Power	$ 29,313
Valard Construction LP	Installation of Powerline	$ 604,800
Grand Total		**$ 5,393,795**

b. Direct and indirect operating costs

The operation cost for this project was $3,991,977. Detailed list as below:

Contrator	Scope of Work	Subtoal
EPCOR Water (Central) Inc	EPC and Commissioning	$ 3,709,879
Finning Canada	600KW/230KW Genset Rental	$ 282,098
Grand Total		**$ 3,991,977**

c. Crown royalties

This project was eligible for the Royalty adjustment, here shows the crown royalty for year 2012 and 2013:

2012 Royalty Adjustment Earned/Carried Forward:

Total Costs	x	Crown %	x	30% (IETP)	
$8,096,795.73	x	100.00%	x	25%	$2,024,198.93

Prior month Royalty Adjustment Carry Forward	$0.00
Royalty Adjustment Earned	$2,024,198.93
Maximum Annual Royalty Adjustment	$1,372,800.00
Royalty Adjustment Carry Forward	$651,398.93

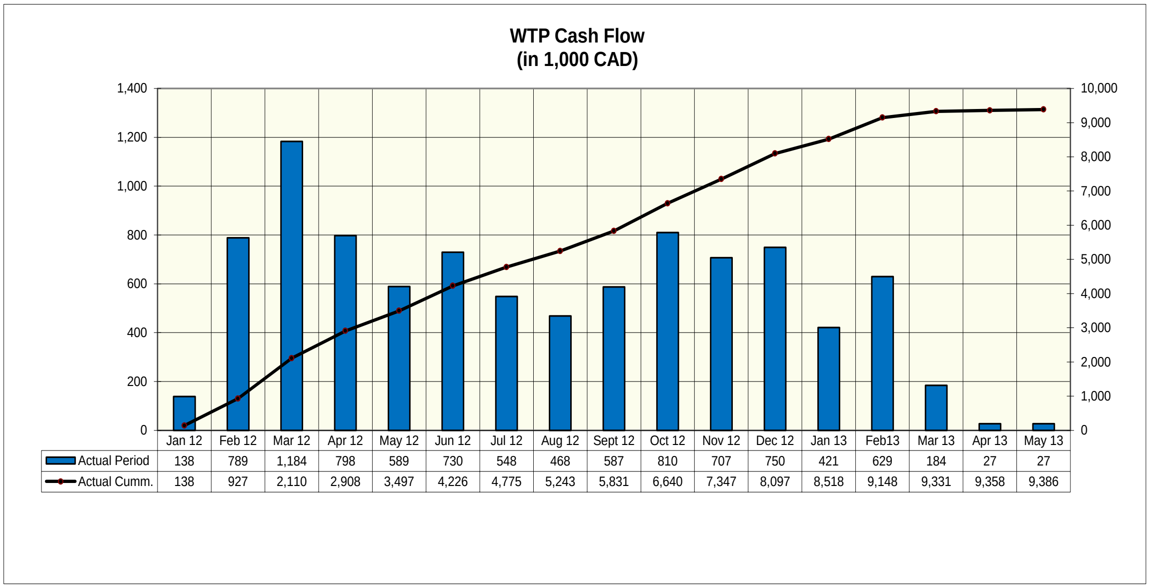
2013 Royalty Adjustment Earned/Carried Forward:

Total Costs	x	Crown %	x	30% (IETP)	
$1,288,976.36	x	100.00%	x	25%	$322,244.09

Prior month Royalty Adjustment Carry Forward	$651,398.93
Royalty Adjustment Earned	$973,643.02
Maximum Annual Royalty Adjustment	$1,123,200.00
Royalty Adjustment Carry Forward	-$149,556.98

d. Cash flow

The graph below shows the cash flow for the overall project cost:



	Jan 12	Feb 12	Mar 12	Apr 12	May 12	Jun 12	Jul 12	Aug 12	Sept 12	Oct 12	Nov 12	Dec 12	Jan 13	Feb13	Mar 13	Apr 13	May 13
▬ Actual Period	138	789	1,184	798	589	730	548	468	587	810	707	750	421	629	184	27	27
─●─ Actual Cumm.	138	927	2,110	2,908	3,497	4,226	4,775	5,243	5,831	6,640	7,347	8,097	8,518	9,148	9,331	9,358	9,386

e. Cumulative project costs

The cumulative project cost was $9,385,772. Details see below:

Contrator	Scope of Work	Subtoal
EPCOR Water (Central) Inc	EPC and Commissioning	$ 8,411,233
Finning Canada	600KW/230KW Genset Rental	$ 340,426
SNC-Lavalin Inc.	Engineering Support for Installation of Supply Power	$ 29,313
Valard Construction LP	Installation of Powerline	$ 604,800
Grand Total		**$ 9,385,772**

7 Facilities

f. Description of major capital items (including new facilities and additions /modifications to existing facilities) incurred in the reporting year
g. Capacity limitation, operational issues, and equipment integrity.
h. Process flow and site diagram identifying major facilities, including production equipment, connected pipelines, gathering and compression facilities.

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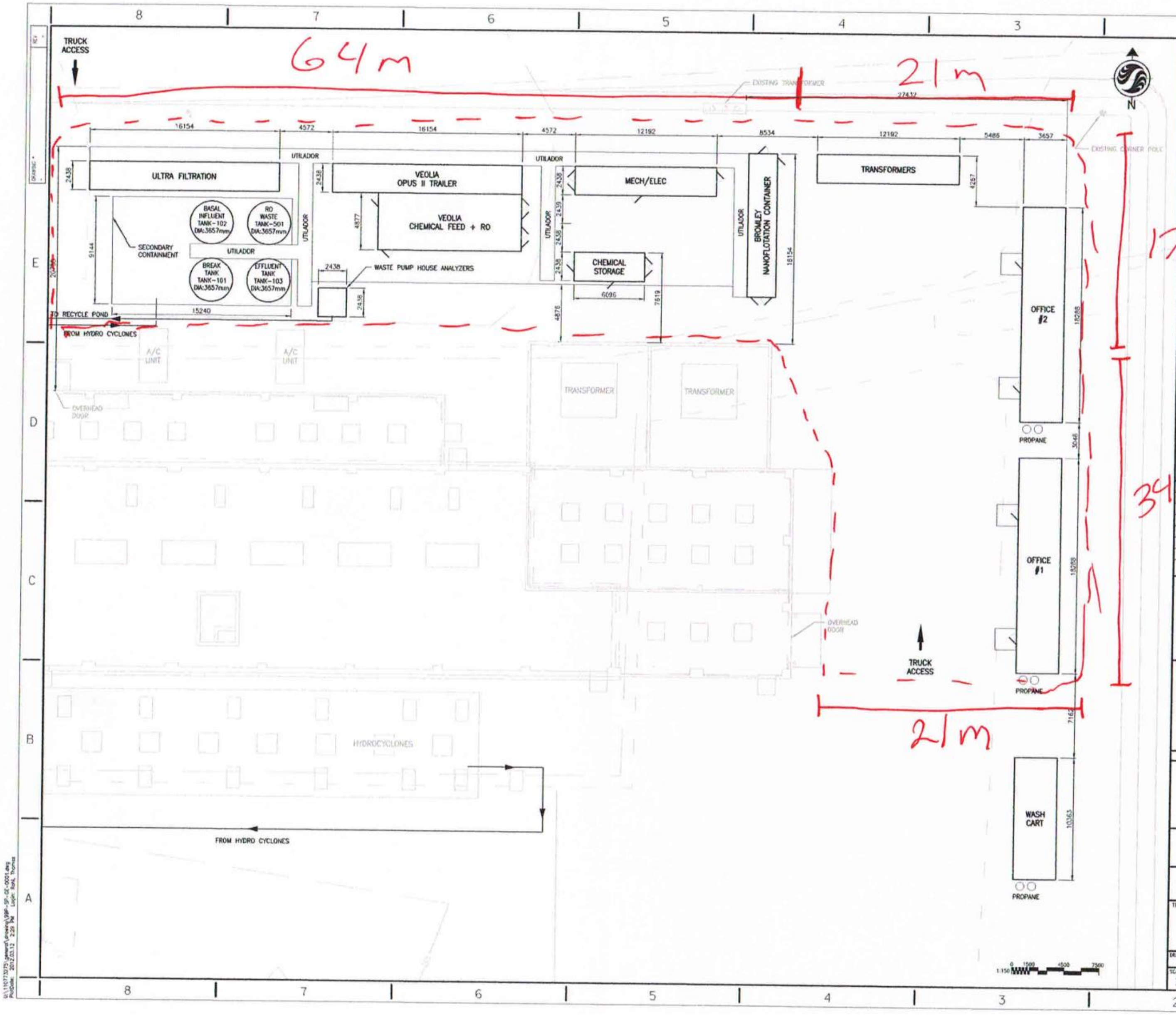

NOTES

\- - -
↳ SNOW FENCE AROUND SITE
→ MEASUREMENTS TO SNOW FENCE

NOT FOR CONSTRUCTION
RE-ISSUED FOR IFC REVIEW
2012 MARCH 12

REFERENCE DRAWINGS

DRAWING TITLE	DRAWING NUMBER

REV	DATE (dd mmm yy)			DESCRIPTION	BY	CHK	ENG	APP
-	-	-	-	-	-	-	-	-

Stantec
Lockerbie Stanley
EPCOR

ENGINEER'S SEAL

PERMIT STAMP

Canadian Natural
horizon
Canadian Natural Resources Limited
Oil Sands

TITLE
EXTRACTION
WATER TREATMENT PILOT
SITE PLAN

DRAWN BY	CHECKED BY	DESIGNED BY	APPROVED
TAR	EM	MM	-

SCALE	DRAWING NO.	REV.
1:150 (A1)	99P-SP-GE-0001	-

PROJECT NO.: -
PROJECT NAME: -

8 Environment/Regulatory/Compliance

i. Summary of project regulatory requirements and compliance status, including as required.

- Procedures to address environmental and safety issues.
- Plan for shut-down and environmental clean-up

8.1 Safety Statistics:

KPI Summary Measurement Criteria LAGGING INDICATORS:	**Current to Date (Monthly)**	**Current to Date (Project)**	**Condition Status**
Number of Incidents:			
First Aid Cases (FA's)	0	1	GREEN
Medical Aid Treatments (Mas)	0	0	GREEN
Lost Time Incidents (LTIs)	0	0	GREEN
Restricted Duty Cases (RDC's)	0	0	GREEN
Near Miss events (NM) **See below**	0	1	GREEN
Other/Non-Recordable Incidents **See below**	0	3	GREEN
Recordable Incidents **See below**			
Total Recordable Incidents Frequency (TRIF)	0	0	GREEN
Hours Worked – TOTAL Site	**0**	**21390**	
-Hours Worked – Construction	**0**	**6467**	
-Hours Worked – Operations	**0**	**14923**	
OH & S Visits			
WCB Visits			
Frequency or Severity Rate:			
All Injury Frequency (AIF)			

Total Recordable Injury Frequency (TRIF)			
Lost Time Injury Frequency (LTIF)			
Lost Time Injury Severity (LTIS)			
Restricted Work Severity (RWS)			

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8.2 Contractor Near Miss Incident: *March 28, 2012, LSI Shop Fabrication Yard*

Description of Event: The Apprentice Electrical worker was observed nearing the top of a 10' step ladder preparing to step from the ladder to the top of a 9' high sea can. The ladder was opened fully and placed on the ground beside the sea can. The worker was not wearing safety harness and had not prepared to a tie off point on the top of the sea can in order to complete his work on the roof. The worker was asked to come down the ladder, LSI foreman was nearby and was called over to make certain this situation was corrected with the use of the proper ladder(14' extension) a harness and appropriate lanyard and establishing a suitable tie off point. His supervisor was informed.

Injury Severity/Treatment: None required
Immediate and Underlying Causes: People
Contributing Factors: Failure to Follow Safe Work Practice/Procedures and Supervision
Corrective Measures: Raise Awareness
Implemented Measures Proper ladder usage was discussed

Environmental Incident: *July 24, 2012 – Acid Spill at Horizon Project Site*

Description of Event: At approximately 08:00 an operator identified sulphuric acid (93%) was leaking from a fitting in the pH adjustment system. Approximately 7 to 14 L of acid is estimated to have spilled on to the adjacent gravel overnight. All parties were notified, an incident report was generated and a Root Cause Analysis investigation was initiated.

Daily rounds/lab testing/basal water delivery continued.

Sulfuric Acid spill was noticed. Spill was isolated, contained and cleaned up. Investigation was conducted to find out the faulty part. Acid dosing for the RO system was discontinued until appropriate parts and fittings are acquired.

<u>PPE Violation:</u> *May 12, 2012 at Horizon Project Site*

Description of Event: Contractor was working in PLC cabinet without proper PPE. When asked to comply with CNRL PPE Policy, contractor resisted and disputed the policy

Potential Severity CNRL-"C5"

Injury Severity/Treatment: None required

Immediate and Underlying Causes: People

Contributing factors: Failure to follow PPE policy

Corrective Actions: Informed contractor of CNRL/EPCOR PPE policy, Contractor asked to leave work site

<u>Other Recordable Incident:</u> *September 12, 2012 at Horizon Project Site*

Description of Event: Sulfuric acid fitting in OPUS II trailer came apart and approx. 140 mL dripped onto the floor of the trailer. Leak was contained and nothing went to the ground. All parties were notified and a Near Miss/Hazard ID card was filled out.

<u>EPCOR Operator First Aid Incident:</u> *October 15, 2012, at Horizon Project Site*

An operator came in contact with Sulfuric Acid and slightly burnt his right forearm. He was taken to the CNRL health center and was provided first aid treatment. All parties were notified and an incident report was generated.

Incident resulted in no impact on work performance.

EPCOR Root Cause Analysis completed of the incident.

The following changes to procedures were made:

1. Update SOP for chemical pumps priming.
2. Procure long sleeve chemical resistant gloves for handling chemicals.
3. Enforce proper use of PPE at all times.
4. Review first aid injury incident and corrective measures/lessons learned.

8.3 Root Cause Analysis

First Aid Injury of October 25, 2012

- **Standard Operating Procedure**
    - The SOP for chemical pump priming did not address, with enough details, issues related to very minor release of chemicals from pump discharge line when pump is shut off. Although such small release may not be hazard in most cases and can be wiped/cleaned after the task is complete but when dealing with a strong hazardous material they can cause injury and must be dealt with immediately.

- **Use of Personal Protective Equipment**
    - The worker was wearing proper PPE (coveralls, chemical resistant gloves, suits and boots, safety goggles, face shield etc.) as recommended by the MSDS for the chemical
    - The gloves were not worn effectively, which left an opening for the chemical to contact his skin. For dealing with chemicals, the gauntlet gloves should be worn over the sleeve of the shirt/suit minimizing the chance of contact. Furthermore long sleeve chemical resistance gloves should be used for such tasks which will further reduce/eliminate the hazard.

- Sulphuric Acid Spill Incident of July 24, 2014

- **Construction process**
    - Focus of commissioning was on functionality of systems and parts with non-corrosive liquids (portable water), with the base assumption that the equipment skids being provided were in compliance with the identified project standards
    - Compliance to standards can be difficult to confirm visually for certain types of material such as plastics if the material type is not stated on the part. If a part is

exposed to a highly corrosive chemical, it should be replaced if the material can not be confirmed to have sufficient chemical resistance

- **Operation**
  - Frequent inspections immediately after system start up and during regular operation are key to identifying a potential leak or corrosion issue before it becomes a spill

  - New systems should be started up for the first time at the beginning of the day when the pilot is fully staffed and visibility is not an issue

  - A rigorous inspection and parts verification system is required for provision of critical chemical delivery systems

  - Feedback should be provided to fittings manufactures on the benefits of colour coding fittings made of different materials

Summary - Operating Plan

j. Actual Project schedule including deliverables and milestones.
k. Changes in pilot operation (planned versus actual), including production operations, injection process, and cost
l. Optimization strategies.
m. Salvage update

Neutral pH Configuration

Optimal operational settings and chemical dosages identified in the pilot for each unit process are detailed in Tables E2 and E3.

Table E2. Optimal process settings for the ceramic ultrafication system (CUF)

Parameter	Optimal Setting
Aluminum sulphate dose	= 5mg/L as Al

Flux (normalized to 20°C)	= 127 to 130 lmh
Recovery range (not accounting for CEB water usage)	= 90% to 93%
Operational flow mode	= Dead end with constant bleed flow
BW frequency	= Every 15 min carry out a 5 second BW
CEB sequence	
- Acid CEB	• Caustic soda, • Sodium hypochlorite • Citric acid
- Caustic (+optional hypochlorite) CEB	• Backwash • Heated backwash (28°C) • Acid soak 10 min • Rapid system flush
CEB frequency	• Backwash • Heated backwash (28°C) • Caustic (+optional hypochlorite) • Soak 10 min • Rapid system flush
	• Caustic CEB every 24 hrs • Acid CEB approximately 3 times/week
CIP sequence	
- Acid CIP	• pH approximately 2.5
Caustic CIP	• pH approximately 13
CIP frequency	= Monthly

Table E3. Optimal process settings for the reverse osmosis system (RO)

Parameter	Optimal Setting
Anti-scalant dose (72% recovery) (Hydrex 4102)	= 10 mg/L
Biocide dose	= 200 mg/L for 30 min, approximately every 2

(Nalco Permaclean PC-11)	weeks
Time between CIPs	= Approximately every 6 to 8 weeks
Flux rate normalized to 25 °C	= Approximately 34 lmh

OPUS II Configuration

Optimal operational settings and chemical dosages identified in the puilot for the unit processes are detailed in Tables E4 to E7. The crystallizer tank is a component of the package softening system (Multiflo system) used in the pilot.

Table E4. Optimal process settings for the softening system (Multiflo)

Parameter	Optimal Setting
Hydrated lime	= Approximately 600 mg/L
Caustic Soda	= Approximately 130 mg/L
Crystallizer tank solids concentration	= Approximately 2500 to 4000 mg/L Full scale concentration may vary for values observed in the pilot as the limitations of the pilot sludge recycle system would not be a factor

Table E5. Optimal process settings for the ceramic ultrafiltration system (CUF)

Parameter	Optimal Setting
Ferric chloride dose	= Approximately 75 to 85 mg/L as Fe (dependent on Multiflow effluent TSS)
Flux (normalized to 20 °C)	= 111 to 118 lmh
Recovery range (excluding cleaning water usage)	= 90% to 94%
Operational flow mode	= Dead-end with constant bleed flow
BW frequency	= Every 15 min carry out a 5 second BW
Cleaning chemicals	• Caustic soda,

	• Sodium hypochlorite • Citric acid
CEB sequence	
- Acid CEB	• Backwash • Heated backwash (28^{o}C) • Acid soak 10 min • Rapid system flush
- Caustic + hypochlorite CEB	- Backwash - Heated backwash (28^{o}C) - Caustic + hypochlorite soak 10 min - Rapid system flush
CEB frequency	- Caustic CEB every 24 hrs - Acid CEB approximately every 10 days
CIP sequence	
- Acid CIP	- pH approximately 2.5
- Caustic CIP	- pH approximately 13
CIP frequency	= approximately every 10 days

Optimal process settings for the WAC ion exchange system

Parameter	Optimal Setting
Configuration	=Two tanks in series
Resin type	=Lewatit CNP 80
Regeneration frequency	=Units sized so ion-site regeneration was not required
Linear feed velocity	=Approximately 4.7 m/hr Higher velocities may be possible (minimal experimentation with the WAC operating

	conditions was carried out)

Optimal process settings for the reverse osmosis system (RO)

Parameter	Optimal Setting
Anti-scalant dose (85% recovery) (Hydrex 4102)	=10 mg/L
Biocide dose (Nalco Permaclean PC-11)	=0 mg/L
Time between CIPs	=2 weeks Frequency of CIPs from pilot data is likely due to concentrate flow rate below membrane manufacturer recommendations. Without this deficiency present, longer durations between CIPs is likely possible.
Flux rate normalized to 25 C	=Approximately 43 to 47 lmh

Primary Factors Impacting Process Performance:

- Influent solids concentration
- Influent organics concentration
- Coagulant dose
- CUF flux rate
- CUF cleaning water usage
- CUF CEB and CIP frequency

- RO influent pH
- RO recovery
- RO anti-scalant type and dosage
- RO CIP frequency
- RO brine side flow rate

Operations Lessons Learned:

- Untreated recycle water is diluted with river water on occasion which can impact the performance of a treatment facility
- The water quality experienced during the course of this pilot was fairly stable with relatively low suspended solids concentrations during experimental trail periods, which is ideal for continuous operation of a treatment facility. TSS and other water quality trends should be compared to historical trends for the water source being considered for use as influent in any scaled up facility.
- Piloting data is reliable for the water quality conditions experienced during the experimental period. Significant deviations from those parameters require adjustments to scaled up facility designs to account for potential impacts on treatment process performance.
- In order to pilot the RO system at a 85% recovery, the brine flow rate was reduced to below the membrane manufacturer's recommended minimum flow rate. The pilot unit used in this project had physical limitations which made it difficult to operate at recoveries in excess of 70%. However, demonstration of the RO at a higher recovery with the upstream OPUS II treatment systems was identified as a project priority. Membrane manufacturer suggested that due to the extensive pre-treatment provided by the OPUS II system, scaling and fouling concerns were significantly reduced so sustainable operation may be possible. The risks highlighted by membrane manufacturer were that the brine could become polarized at the low flow which would increase scaling or fouling of the membrane. Though sustained operation at 85% was demonstrated for over 2 weeks, examination of RO Normalized Permeate Flow (NPF) indicates that the low flow rate likely did contribute to increased fouling and scaling.

10 Interpretations and Conclusions

n. An assessment of the overall performance of the pilot, including:

- Lessons learned
- Difficulties encountered.
- Technical and economic viability.
- Overall effect on overall gas and bitumen recovery.
- Assessment of future expansion or commercial field application and discussion of reasons.

The piloted basal water treatment train proved capable of meeting the water quality objectives of TDS < 1000 mg/L and sodium < 500 mg/L for all operational settings examined.

Economic analysis

Table 4

	Flow scheme options	**Materials Recovered**	**Vendor Supplied Capital Cost** (Plant Capacity m^3/day)**		**Annual Operating Cost** Plant Capacity m^3/day**		**Annual Value of Products (water for use and NaCl)* (10000 m^3/day plant capacity)**
			1000	**10000**	**1000**	**10000**	
Case 1 FS (1-1)	Pretreatment Units-RO	Water for reuse	$5.6M	$13.35M	$1M	$15M	$0.25M
	Softening Unit-Evaporator Unit	Water for reuse	$6.66M	$27.49 M			$0.20M
Case 2 FS (1-2)	Evaporator only Treatment (without RO pre-treatment)	Water for reuse	$10.89M	$44.07M	$2M	$31M	$0.45M
Case 1 &2 (optional items)	Crystallizer Unit	NaCl Water for reuse	$5.40M	$ 22.00M	$0.7M	$7M	$7.20M $0.05M

	Saltmaker unit	NaCl Water for reuse	$6.10M	$43.90M	$0.23M	$2.20M	$7.20M $0.05M

*****NaCl cost taken for calculation 60$ per ton; savings come from backing out river water

**Above Costs does not include electrical, mechanical, building costs etc. (see APPENDIX A for details) FS-Flow Scheme

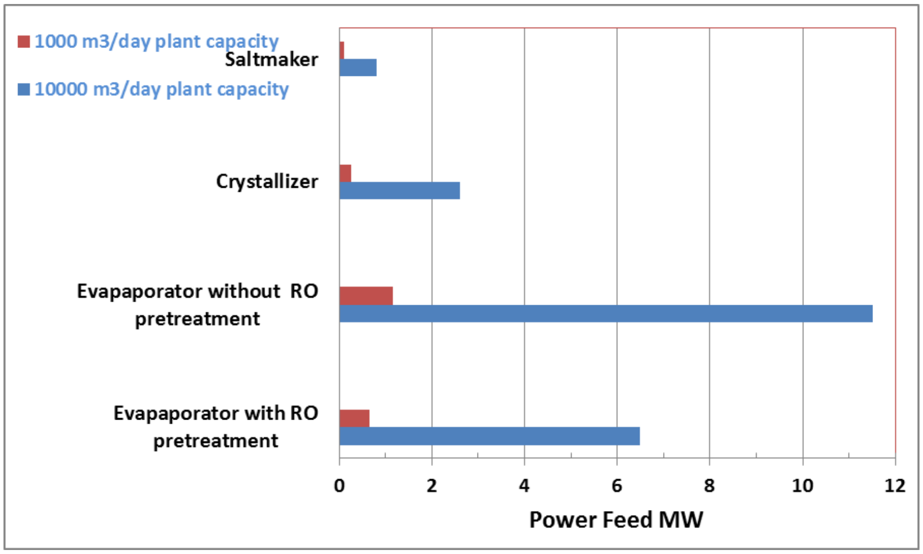

Figure 3: Power Consumption vs. Technologies

Table 4 shows the CAPEX comparison of using Evaporator with RO pretreatment (case1; flow scheme 1-1) and Evaporator without RO pretreatment (case 2; flow scheme1-2). For 1000 m^3/day treatment plant capacity (case 2; flow scheme 1-2) CAPEX costs are slightly lower than case1 ($12.2 M for Case 1 and $10.89 M for case 2). For 10,000 m^3/day plant capacity Case 1 CAPEX costs are lower than case 2 ($40.8 M for Case 1 and $44.07 M for case 2). This analysis indicates that for a treatment plant with 1000 m^3/day capacity installation of evaporator without RO pretreatment is advantageous. For higher capacity treatment plant, Evaporator with RO pre-treatment will lead to lower CAPEX and OPEX costs. It should be noted that the energy consumption for the evaporator without RO pre-treatment (10,000 m^3/day plant capacities) is 11.5 MW and this value is reduced to half when RO pretreatment is performed.

The piloted tailings water treatment train proved capable of meeting the water quality objectives of TDS<50 mg/L and sodium < 30 mg/L for all operational settings examined, for both the Neutral pH and OPUSII treatment train configurations.

Basal water treatment plant produces 500 tons of 85% dry salt per day for 10000 m3 plant capacity. The above economic analysis does not include waste disposal costs and strategies.

Future work will focus on assessing possible options for waste salt disposal, for example solidification of evaporator brine/crystalliser waste streams.