



June 30, 2011

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Interim Progress Report for “Bakken Water Opportunities Assessment: Phase II”
EERC Fund 15738

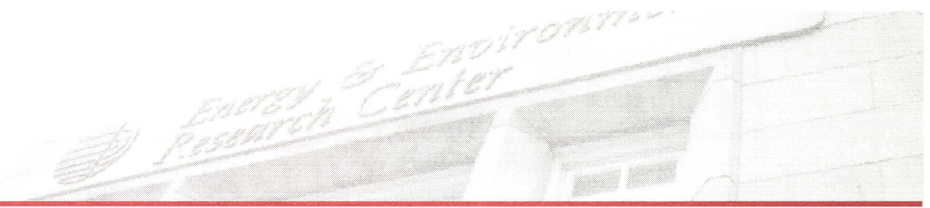
Enclosed please find the subject report. If you have any questions or comments, please contact me by phone at (701) 777-5050 or by e-mail at bkurz@undeerc.org.

Sincerely,

Bethany A. Kurz
Senior Research Manager

BAK/hmv

Enclosure



BAKKEN WATER OPPORTUNITIES ASSESSMENT: PHASE II

Interim Progress Report

(for the period of January 1, 2010, through June 30, 2011)

Prepared for:

Karlene Fine

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BAKKEN WATER OPPORTUNITIES ASSESSMENT: PHASE II

BACKGROUND

Water is the most critical limiting resource throughout the world. Sufficient quantities of good-quality water are needed for several competing uses, including energy production, growing and processing high-value crops, industrial manufacturing, and expanding populations. The Northern Great Plains Water Consortium (NGPWC) is a partnership between the Energy & Environmental Research Center (EERC), the U.S. Department of Energy (DOE), and key stakeholders representing oil and gas companies, power generation utilities, industry, municipalities, and other entities interested in addressing critical water issues in the north-central United States. The primary goal of the NGPWC is to assess, develop, and demonstrate technologies and methodologies that minimize water use and reduce impacted water discharges from a range of energy technologies, including coal combustion, coal gasification, coalbed methane, and oil and natural gas production.

One of the NGPWC's key activities is to evaluate potential sources of water for use in hydraulically fracturing the Bakken oil play, located in the Williston Basin of North Dakota, Montana, South Dakota, and Saskatchewan (Figure 1). The Bakken Formation is rapidly emerging as an important source of domestic oil with potentially recoverable reserve estimates ranging from 4 to 24 billion barrels (Oil and Gas Journal, 2011).

While the hydrocarbon resource within the Bakken is tremendous, the formation is characterized by very low porosity and permeability which necessitates hydraulic fracturing (fracking) to enhance the flow and recovery of oil. Water volumes for fracking the Bakken range from approximately 20,000 to 115,000 barrels (approximately 840,000 to 5 million gallons), depending on the number of stages in the fracture, with more stages requiring greater volumes of water. While these volumes of water are not especially high when compared to those needed for municipal and agricultural use within the western portion of North Dakota, there are a limited number of locations from which to obtain the freshwater. For water haulers, the lack of water resources translates to long transportation distances and excessive amounts of time spent waiting in lines at water depots. As a result, water acquisition costs for Bakken oil producers in the region can be quite high. Given the current demand for water resources and the high costs of acquisition and transportation, treatment of nontraditional water supply sources may be economically viable.

One of the first projects conducted by the NGPWC, the Phase I Bakken Water Opportunities Assessment, evaluated the potential to recover, treat, and recycle fracturing flowback water from Bakken oil wells (Stepan and others, 2010). The EERC assessed an array of water treatment technologies, primarily mobile treatment systems that could utilize the high-Btu associated gas generated during the flowback operations to thermally treat fracturing flowback. However, extremely high dissolved salts in flowback water, combined with a relatively low recovery of the flowback water, makes recycling very challenging and, in most cases economically unattractive.

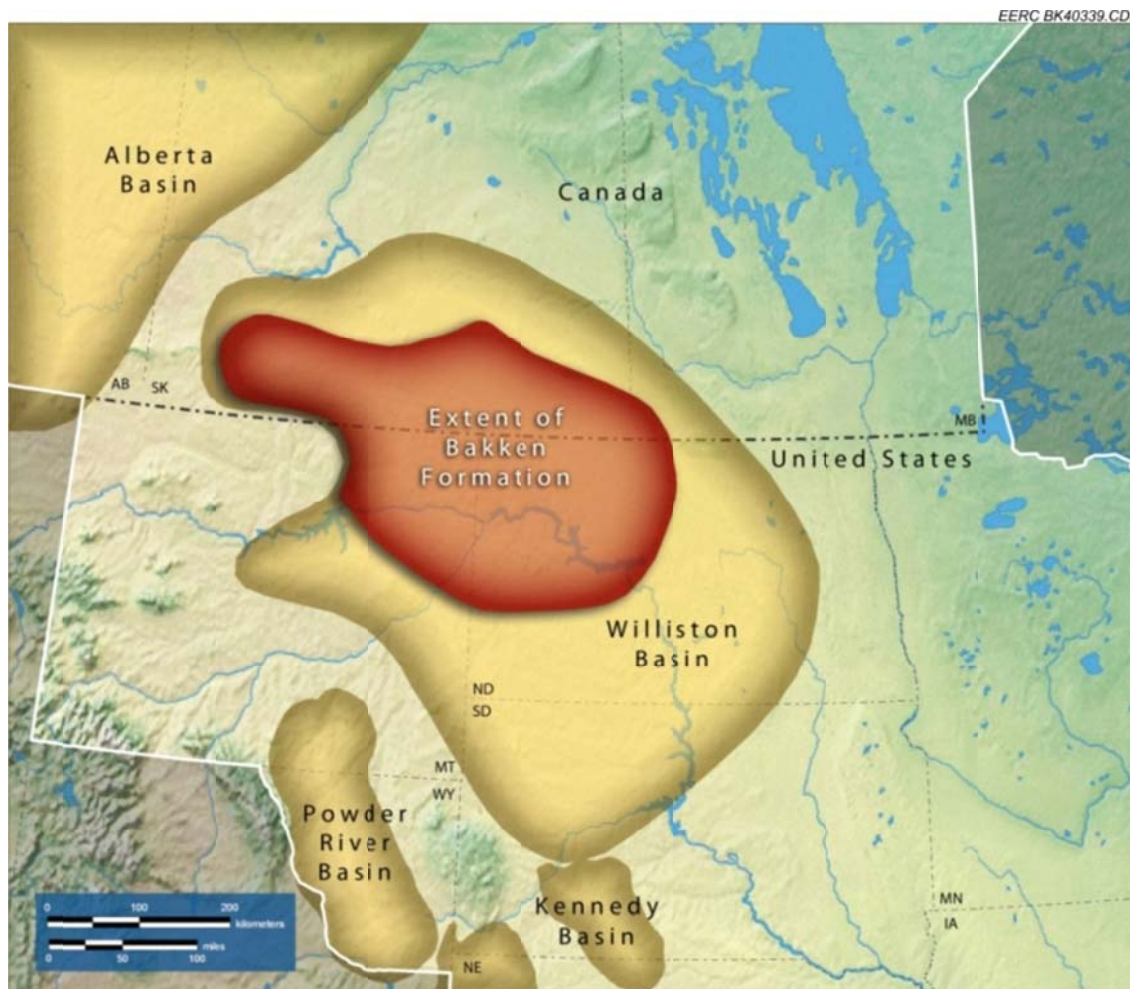


Figure 1. The location of the Bakken Formation within the Williston Basin.

As part of a continuing effort to evaluate water supply options for oil producers and other industries in the region, the EERC teamed with Hess Corporation (Hess) to conduct a pilot treatment project using reverse osmosis (RO) to evaluate the technical and economic feasibility of treating brackish groundwater as a water supply source for fracking. This effort is being funded by DOE and the North Dakota Industrial Commission (NDIC) Oil and Gas Research Council (OGRC), with cost share provided by Hess. The pilot system has been in operation since July of 2010 and will continue to operate through the summer of 2011 and perhaps longer, given the success of the project and the utility of the freshwater being produced.

This interim report was prepared to meet the reporting requirements of the NDIC and to provide a summary of the project activities since inception. The full results and conclusions of the project and any supporting research conducted by the EERC will be contained within the project final report. The EERC's ultimate goal will be to evaluate the technical and economic feasibility of this treatment approach for providing a freshwater supply source for the oil industry as well as other industrial and/or municipal applications, such as cooling water for coal-fired electrical generation.

OVERVIEW OF WATER USE PRACTICES IN THE BAKKEN

Fracking is increasingly being employed by oil producers in western North Dakota to produce the tremendous oil and gas resources of the Bakken Formation. Fracking entails the injection of water, proppants, and various other chemical constituents at high pressures into reservoir rock in order to increase the permeability of the formation and enhance the flow of oil. Common constituents of fracturing fluid makeup are shown in Table 1, with water and proppants typically comprising 99.5% of the fracturing fluid makeup (U.S. Department of Energy, 2009). Fracturing fluid makeup water must typically contain low total dissolved solids (TDS), be free of bacteria, and be of consistent quality to ensure the ability of individual producers to generate and replicate the desired fracture results.

Within western North Dakota, common freshwater acquisition points for fracture fluid makeup are existing water depots and municipalities; however, these have a limited capacity to supply the large demand for water. Those depots and municipalities that have extra capacity to provide water to the oil industry must first request an industrial permit from the North Dakota State Water Commission (SWC), which can be time-consuming. In response to the increasing demand for freshwater, the SWC has received numerous permit applications for additional groundwater appropriation for withdrawals at existing water depots as well as permit applications for new water wells. Prescribed permitting procedures require a published public notice, followed by a 30-day comment period. New permit applications are typically contested by environmental groups, which results in significant delays in the overall permitting process. Permits that would normally be issued within a 70- to 90-day period are taking in excess of 12 months.

In addition, the SWC is reluctant to permit new allocations from potable groundwater resources for use in the oil industry because of concerns over depletion of the resource and declining hydraulic pressures of the aquifers. With the exception of the Missouri River system, most regional surface waters do not provide a reliable source of water because of seasonal flow variations. Sufficient flows typically exist only in the spring of the year, during periods of snowmelt.

Table 1. Common Constituents of Fracture Fluid Makeup

Fracture Fluid Component	Purpose
Freshwater	The primary mechanism for delivering the desired proppants and chemicals into the formation; usually high quality
Proppant	Typically sand or ceramic beads that help keep the fractures open upon release of pressure from the fracking operation
Biocides	Reduces the risk of well souring from microbes
Friction-Reducing Agents	Surfactants that promote fracture fluid flow
Polymers	Form gels to keep proppants in suspension
Scale Inhibitors	Reduces scale formation in pipes
Weak Acids	Helps dissolve minerals that cement formation pore spaces

Given the concerns over mining of surficial aquifers, groundwater-permitting issues, and the relative lack of surface water supplies in many areas of the state, SWC is encouraging the oil industry to seek withdrawals from the Missouri River System for use in Bakken development. The Missouri River System, specifically Lake Sakakawea, is a tremendous resource that is located adjacent to many of the Bakken drilling areas (Figure 2). However, there are several issues related to using Lake Sakakawea water, key among them being access to the lake and looming fees for use of the resource. While SWC handles water appropriations from the lake, permission for access at a particular point of diversion must be granted by the U.S. Army Corps of Engineers (Corps). This creates additional delays in accessing the resource because having to obtain permission from multiple agencies can slow the permitting process. In addition, it is not yet clear where access to the lake may or may not be allowed so as not to disturb existing cultural sites and/or threatened and endangered species. While the Corps is studying the potential impacts of increased access to and water use from the lake (estimated to be a multiyear study), it agreed to allow a temporary annual allocation of water from the lake for municipal, rural, and industrial (MR&I) use for a fee. The state of North Dakota strongly objected to the Corps' plan to charge a fee for access to water that is being stored on North Dakota lands. It is unclear at this time when the issues surrounding access to Lake Sakakawea will be resolved.

While there are some projects in the works that will improve the availability of freshwater resources for use in Bakken development, in the near-term, there appears to be a significant water shortage. The Missouri River system has more than enough water available for Bakken development, but access issues and potential fees associated with this water use remain unresolved. In addition, the Missouri River and Lake Sakakawea are not always adjacent to areas of Bakken drilling, and therefore, the high costs associated with long transportation distances may diminish the appeal of the resource.

As part of the EERC study to evaluate the feasibility of fracturing flowback recycling, cost data for water acquisition were provided by several producers working in North Dakota (Stepan and others, 2010). The reported costs of current water handling for hydraulic fracturing can vary significantly, depending on acquisition costs and transportation costs (including wait time). Table 2 lists a range of current water-handling costs for Bakken fracture water. The cost to purchase raw water ranged from \$0.25/bbl up to \$1.75/bbl (\$5.95 to \$25 per 1000 gallons), and the cost of transporting that water to the fracture location ranged from \$0.63/bbl up to an estimated \$5.00/bbl (\$15 to \$119.05 per 1000 gallons). Transportation costs represented the highest level of variability in water acquisition costs and depend on several factors, including trucking charges, haul distances, and wait time. Trucking charges were reported to range from \$110 to \$150/hr, and the charges that are incurred during wait time are included in the overall transportation costs.

Given the current need for water, coupled with high water acquisition, transportation, and disposal costs, nontraditional options for water supplies may be viable, such as treatment of nonpotable groundwater resources.

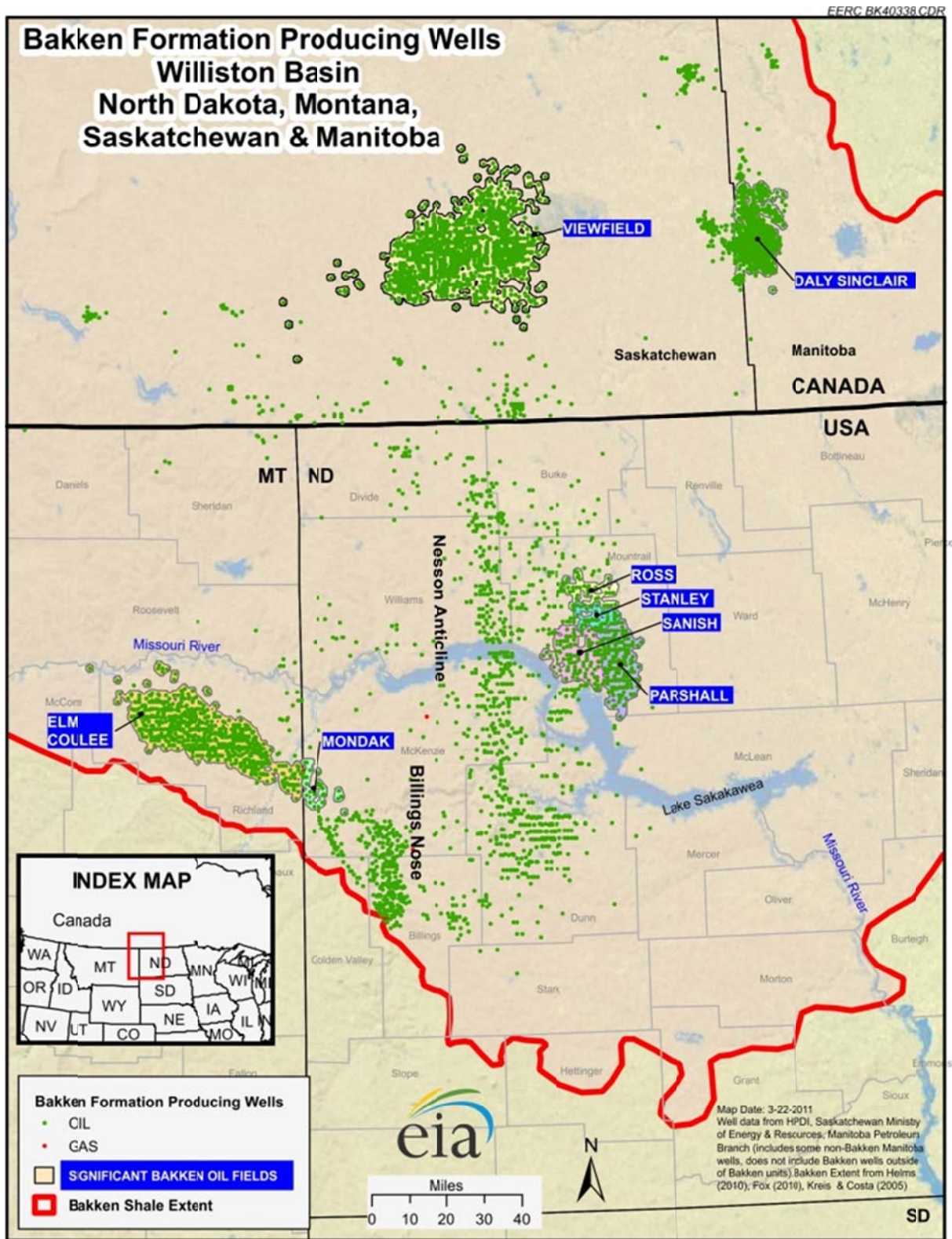


Figure 2. The location of the Missouri River system and Lake Sakakawea with respect to Bakken drilling locations (Source: Energy Information Administration, 2011).

Table 2. Water-Handling Costs

Acquisition Costs	Cost, \$/bbl	Cost, \$/1000 gallons
Raw Water	0.25–1.05	5.95–25.00
Transportation	0.63–5.00	15.00–119.05
Total Costs	0.83–6.05	20.98–144.05

PILOT PROJECT OVERVIEW AND PROGRESS UPDATE

This project is being conducted near Tioga, North Dakota, at an existing groundwater well site that is screened at a depth of approximately 5500 feet in the Dakota Formation (Dakota). The Dakota is one of the most widespread aquifers in North America and is present in most states of the Great Plains, from western Iowa to Montana and from the Arctic Circle to New Mexico (Kansas Geological Survey, 1996). In eastern North Dakota, groundwater from the Dakota has been used as a water source for livestock since the beginning of the 20th century, but because of its marginal quality and increased costs associated with treatment and pumping, it has been marginalized as a municipal or industrial water source. However, recent developments in water treatment technologies, coupled with the current water acquisition costs of water for Bakken fracking, may render treatment of the Dakota and other brackish groundwater formations as economical for oil industry uses.

The well at the Tioga location provides water that is used as part of a secondary oil recovery operation (waterflood) and is capable of sustaining moderate to high yields. The well has been pumped nearly continuously at a rate of 11,000 to 12,000 bbl a day (320 to 350 gallons per minute [gpm]) for several decades with no measurable impacts to hydrostatic water levels; therefore, the additional pumping rate required for the relatively short duration of the pilot project was inconsequential.

Water samples collected from the well revealed that the water chemistry is predominantly sodium chloride in nature, with lesser amounts of sulfate and bicarbonate. TDS average about 8500 mg/L. (More specific formation on water chemistry is listed in Table 4 later in this paper.) Because the Dakota Formation is at such a great depth beneath the surface, the water exits the well at a temperature of approximately 155°F (68°C).

Task 1: Selection of Treatment Technology System

After evaluating several mobile technology treatment system providers, Hess selected General Electric (GE) Water and Process Technologies as the preferred pilot system provider. GE's MobileRO[®] is a mobile RO water treatment system, consisting of two semitrailers and several skid-mounted components, including all the hardware and electronics necessary to monitor the system operation and performance. Given the quality of the feedwater at the pilot project site, GE estimated that, at full capacity, the system would be capable of producing approximately 160 gpm of permeate (treated water) at a 75% recovery rate. Because the system contains two independently operated filter arrays, it can also be operated at reduced capacity, equivalent to approximately 80 gpm of permeate at a 75% recovery rate. The mobile system contains all necessary prefilters, the antiscalant treatment system, controls, piping, valves, and

instrumentation. All operations associated with the mobile RO unit were the responsibility of GE personnel for the duration of the pilot test.

Task 2: Site Preparation

In order to prepare the site for the pilot project, several activities were conducted, including:

- Installation of the RO treatment and pretreatment units.
- Installation of the feedwater cooling system and heat exchangers.
- Construction of a lined and covered pond for storage of the treated water (RO permeate).
- Installation of five 400-barrel tanks that are used to store the feedwater, excess permeate (if needed), and RO concentrate. (The RO concentrate tank is designed to meet saltwater storage standards.)
- Installation of the necessary piping to connect the system components.
- Installation of the electrical power supply and necessary connections.
- Construction of a truck-loading station that is used to transport the RO permeate to fracking locations within the Bakken play.
- Installation of corrosion test racks to evaluate the corrosivity of the feedwater, permeate, and concentrate on various metals and metal alloys.

One of the challenging aspects of the pilot project is the cooling of the feedwater, which exits the production well at a temperature of approximately 155°F (68°C), down to the required 90°F (32°C) prior to membrane treatment. While the high temperatures of the feedwater present a problem for the membrane modules, the heat from the water can also be a potential resource, given that the desired temperature of the fracturing fluid prior to injection is approximately 80°F (27°C). During the winter months, the cost to heat the fracturing fluid prior to injection is considerable and can sometimes exceed \$150,000 or more to heat the water required for one well fracturing (Hess, personal communication, 2010). Therefore, heat exchangers were installed at the pilot project site to partially cool the feedwater using the RO permeate, which exits the system at approximately 90°F (32°C), and, in turn, to heat the permeate prior to use as fracturing water makeup.

Another issue of concern related to treatment of brackish groundwater (especially when dealing with elevated temperatures) is corrosion of piping, pumps, cooling system components, and other materials that come in contact with the water. Because salinity levels of the formation water are elevated, corrosion could lead to costly equipment failures and corresponding inability to produce permeate at a higher rate. Corrosion can be affected by chemical composition,

temperature, pH, degree of aeration, flow velocity, and pressure. Therefore, system-specific testing is helpful to most accurately evaluate corrosion potential. As such, the EERC conducted corrosion rate testing of the feedwater, concentrate, and permeate streams to determine proper heat exchanger, piping, and valve material selection for a full-scale plant.

As part of the corrosion testing research, the EERC conducted aqueous chemistry modeling calculations using OLI Systems, Inc., Stream Analyzer and Corrosion Analyzer software to predict the potential for scale formation and corrosion based on the chemistry of the formation water and the predicted concentrate chemistry (at 60% recovery). The potential corrosion rates of 19 metals and alloys when exposed to the system feedwater at a range of temperatures (70° to 170°F [21° to 77°C]) and flow velocities (0 to 20 feet/second) were modeled. The results of the modeling were used to select and order metal and metal alloy test coupons that were installed in test racks at the pilot test site to evaluate the corrosion and scaling potential of the feedwater, RO permeate, and RO concentrate. A total of six test racks, each equipped to hold either three or five test coupons, were installed at various locations in the treatment train at the pilot site (Figure 3). The metal/alloy coupons selected for evaluation include some standard materials, like carbon steel (API 5LX42), stainless steel (316L), copper–nickel alloy (CDA706), and titanium (Ti), as well as a more exotic alloy (Hastelloy C276) that is designed to be resistant to saltwater corrosion. The corrosion testing results are being used to assess the best materials to use for a full-scale RO treatment system using groundwater of this chemistry.

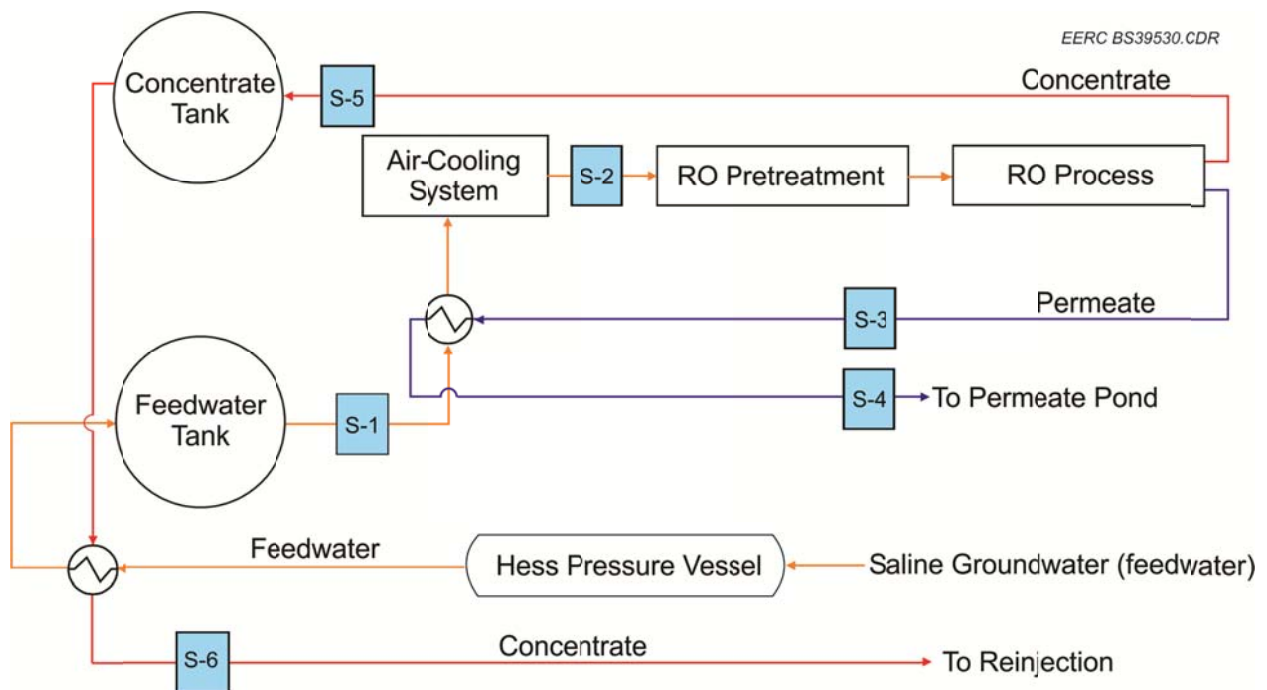


Figure 3. Flow diagram with rack locations.

Task 3: On-Site Pilot Test

Site Design and Operation

The pilot project system began treating water on July 21, 2010, at a permeate flow rate of 80 gpm and 50% recovery. Higher permeate recovery rates were not achievable until GE performed system modifications (specifically orifice plate replacement) on August 3, 2010, at which time the recovery rates increased to approximately 70%. GE continues to operate the RO system at a flow rate (80 gpm of permeate production) to be consistent with the truck hauling cycle demands and maintain a more constant, steady operation. The permeate produced from the system is used for fracking of the Bakken, and the concentrate is blended with the waterflood injection system feedwater into an oil reservoir.

Shortly after start-up of the system, six corrosion test racks were installed at the subject site. A description of each rack is included in Table 3. The discharge from Racks S-1–S-4 were manifolded together and plumbed to discharge into the feed tank. Figure 4 is a photograph of Rack S-2, a 5-place corrosion test rack assembly. The discharge from Racks S-5 and S-6 were plumbed to discharge into the reject tank. During the installation and testing of the racks, EERC personnel were unable to attain enough water flow through Racks S-3 and S-4. This was caused by insufficient water pressure on the influent side of the rack to overcome the pressure at the discharge point. While the test racks could have been relocated, it would have entailed shutting down the system. Additionally, the permeate corrosivity was expected to be minimal; therefore, no test coupons were installed in Racks S-3 and S-4.

Following installation of the corrosion test racks, water was allowed to flow through the racks for several weeks prior to coupon installation to flush the system, as recommended by the test rack manufacturer. The test coupons were installed in the racks in the order shown in Table 3, which represents their anticipated resistance to corrosion from most to least. This was done to minimize the potential of corrosion from one test coupon influencing the corrosion rate of subsequent test coupons. The only notable issue observed during coupon installation was the presence of a black residue on the Rack S-1 flowmeter and coupon holders. This residue was later determined to be some form of hydrocarbon, although detailed testing to determine the exact nature and source of the compound was never conducted.

After approximately 37 days of RO operation, water samples of the feedwater, permeate, and concentrate were collected and submitted to a commercial laboratory for analyses. A summary of the results of these analyses is shown in Table 4.

The RO system continued to operate at a permeate flow rate of 80 gpm with 70% permeate recovery until September of 2010, when the system was shut down to make adjustments to the permeate-holding pond, to address electrical issues at the truck-loading station, and to winterize the site. Based on GE operational logs, from July 21, 2010, through September 6, 2010, a total of 6,084,700 gallons of groundwater were processed through the RO system resulting in approximately 4.26 million gallons of permeate and approximately 1.83 million gallons of concentrate. Although no flow measurements were recorded during the shutdown period, GE did operate the RO system approximately 1 hour each day to prevent membrane fouling.

Table 3. Corrosion Rack Description

Rack No.	Rack Material	Number of Coupons	Coupon Order	Fluid	Fluid Design Temperature	Observed Temperature
S-1	CPVC ¹	5	Ti C276 316L CDA706 API 5LX42	Feedwater	155°F (68°C)	127°F (53°C)
S-2	PVC ²	5	Ti C276 316L CDA706 API 5LX42	Feedwater	90°F (32°C)	80°F (27°C)
S-3	PVC	3	No coupons	Permeate	90°F (32°C)	–
S-4	CPVC	3	No coupons	Permeate	130°F (54°C)	110°F (43°C)
S-5	PVC	3	Ti 316L API 5LX42	Concentrate	90°F (32°C)	96°F (36°C)
S-6	CPVC	3	Ti 316L API 5LX42	Concentrate	155°F (68°C)	118°F (48°C)

¹ Chlorinated polyvinyl chloride.

² Polyvinyl chloride.

After all the necessary system modifications were made, GE began full capacity operation of the RO system on November 29, 2010, and as of April 13, 2011, had processed approximately 19 million gallons of Dakota Aquifer water. Since GE personnel observed lower flow rates, lower operating pressures, and higher permeate conductivity in RO Train 2, they primarily operated RO Train 2 and only occasionally operated Train 1 in order to prevent the accumulation of biological activity. The cause of the operational differences between the two trains is unknown at this time. Train 1 was operated for approximately 39 days, resulting in the treatment of 5.5 million gallons, and Train 2 was operated for approximately 88 days, resulting in the treatment of approximately 13.5 million gallons.

RO recovery rates remained relatively consistent while operating both trains, averaging nearly 72% over the current operating period. As indicated earlier, feedwater flow rates were lower while operating Train 1 (103 gpm) versus operating Train 2 (124 gpm). Resulting permeate flow rates were also impacted, averaging 73 gpm on Train 1 compared to 90 gpm on Train 2. Permeate conductivity also showed a difference, averaging 585 microseimens per centimeter ($\mu\text{S}/\text{cm}$) on Train 1 and 395 $\mu\text{S}/\text{cm}$ on Train 2.

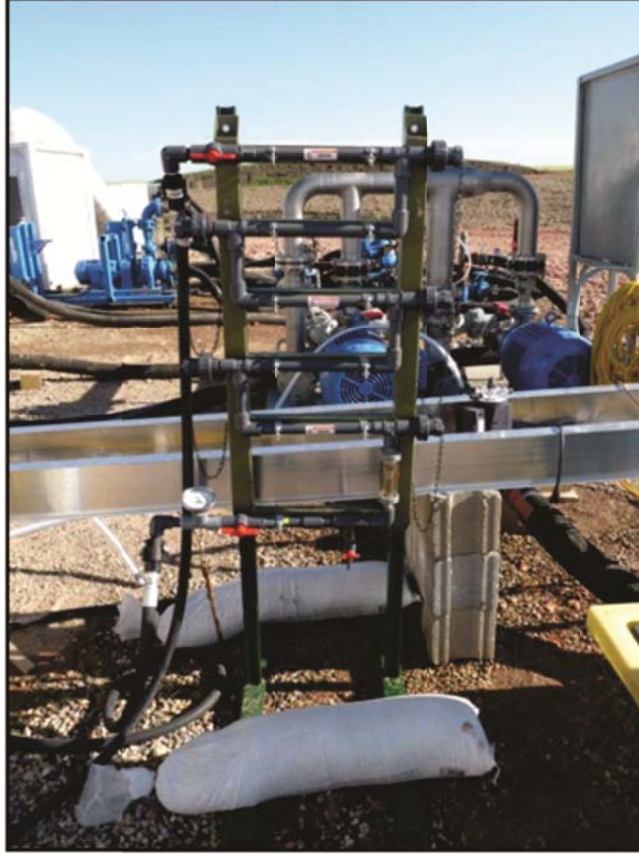


Figure 4. Picture of corrosion test Rack S-2.

To date, no membrane cleaning has been necessary and no scaling has been observed. GE personnel credited the low-turbidity feedwater for the lack of membrane fouling. Silt density index (SDI 15) averaged 3.00. GE performed backwash operations on a once-per-week basis as preventative maintenance. Since pressure readings did not indicate the need for more frequent backwashing, this frequency appeared to be sufficient to maintain appropriate operational pressures. GE's records also indicate that once the system was stabilized, the feedwater conductivity was consistently around 14,000 $\mu\text{S}/\text{cm}$, the permeate averaged 700 $\mu\text{S}/\text{cm}$, and the concentrate was approximately 39,000 $\mu\text{S}/\text{cm}$.

Corrosion Test Results

On November 9, 2010, the corrosion racks and associated piping were retrieved prior to any damage occurring from freezing temperatures. The corrosion coupons were removed from their respective racks, visually inspected, photographed, and allowed to dry overnight.

Upon retrieval, the corrosion coupons from Rack S-1 (127°F feedwater) were covered in the same black coating that appeared on the coupon holder and the flowmeter during the August 26, 2010, site visit. Coupons removed from Rack S-2 (80°F feedwater) also exhibited a slight

Table 4. Summary of Water Analysis Results

Analyte	Feedwater (S-1)	Permeate (S-4)	Concentrate (S-5, S-6)*	Units
Ca	15.8	3.0	44.4	mg/L
Na	3300	103	10,750	mg/L
K	9.9	<1	42.8	mg/L
Cl	3710	130	13,200	mg/L
SO ₄	456	<5	1460	mg/L
NO ₃	<0.1	<0.1	0.14	mg/L
HCO ₃	1220	74	3820	
Ba	<0.5	<0.1	<1	mg/L
F	3.57	0.14	12.8	mg/L
Fe	<0.5	0.66	<1	mg/L
Mg	2.6	<1	7.9	mg/L
Mn	<0.25	<0.05	<0.5	mg/L
P, Total	<0.1	<0.1	0.96	mg/L
Si	17.2	<1.1	56.3	mg/L
Cu	<0.25	<0.05	<0.5	mg/L
Sr	0.98	<0.1	2.92	mg/L
Temperature (field, °F)	127	110	96, 118*	
pH (lab)	7.4	6.2	7.8	
pH (field)	7.32	6.06	7.55	
Conductivity (lab)	13,590	568	37,700	μS/cm
Conductivity (field)	15,400	610	41,500	μS/cm
Total Dissolved Solids (calculated)	8230	280	27,800	mg/L
Alkalinity (as CaCO ₃)	1220	74	3820	mg/L
Hardness (as CaCO ₃)	50.2	7.49	144	mg/L
Total Organic Carbon	5.9	4.9	7.1	mg/L

* Because the water chemistry results from Racks S-5 and S-6 were not significantly different, they were averaged in this column, with the exception of temperature, which is listed separately for Racks S-5 and S-6, respectively.

black coating. The black residue was not observed in any of the other test racks. As previously mentioned, a sample of the black residue was collected, and some preliminary testing indicated that it was a type of hydrocarbon. Additional testing of the compound to determine its exact composition has not been conducted.

An initial visual corrosion assessment revealed that, in each case, the carbon steel (API 5LX42) and the copper–nickel, if present, showed significant corrosion, while the stainless steel, Hastelloy (if present), and the titanium coupons did not show visible corrosion although slight scaling was present.

Once the coupons were dry, they were individually weighed (without cleaning), placed in individual glass vials, and sent to the supplier of the corrosion coupons, Metal Samples Company (MSC) for postexposure analysis. MSC cleaned and weighed the coupons in accordance with ASTM International Standard G-1, provided the EERC with a corrosion analysis, and then returned the coupons upon completion of the analysis. The MSC results are shown in Table 5.

Table 5. Corrosion Coupon Results

Rack	Fluid	Coupon	Metal	Initial Weight, g	Final Weight, g	Mass Lost, g	Corrosion Rate, mil/yr
S-1	Feedwater, 127°F	Ti-2	Titanium	6.6614	6.6564	0.0050	0.0968
S-1	Feedwater, 127°F	C276	Hastelloy	12.6151	12.6104	0.0047	0.0472
S-1	Feedwater, 127°F	316L	Stainless steel	10.6845	10.6780	0.0065	0.0724
S-1	Feedwater, 127°F	CDA706	Copper–nickel	13.0487	12.9719	0.0768	0.7528
S-1	Feedwater, 127°F	API 5LX42	Carbon steel	16.9932	16.8693	0.1239	1.2684
S-2	Feedwater, 80°F	Ti-2	Titanium	6.6446	6.6413	0.0033	0.0639
S-2	Feedwater, 80°F	C276	Hastelloy	12.5855	12.5815	0.0040	0.0402
S-2	Feedwater, 80°F	316L	Stainless steel	10.7491	10.7438	0.0053	0.0590
S-2	Feedwater, 80°F	CDA706	Copper–nickel	13.0904	12.8610	0.2294	2.2485
S-2	Feedwater, 80°F	API 5LX42	Carbon steel	15.6065	15.4184	0.1881	1.9256
S-5	Concentrate, 96°F	Ti-2	Titanium	6.6287	6.6259	0.0028	0.0542
S-5	Concentrate, 96°F	316L	Stainless steel	10.7744	10.7690	0.0054	0.0601
S-5	Concentrate, 96°F	API 5LX42	Carbon steel	17.0656	16.8618	0.2038	2.0864
S-6	Concentrate, 118°F	Ti-2	Titanium	6.6681	6.6644	0.0037	0.0716
S-6	Concentrate, 118°F	316L	Stainless steel	10.7622	10.7577	0.0045	0.0501
S-6	Concentrate, 118°F	API 5LX42	Carbon steel	16.7854	16.5876	0.1978	2.0249

With an initial and final weight, the corrosion rates for the respective metal coupons were calculated using the following equation:

$$CR = (K \times W) / (A \times T \times D) \quad \text{Eq. 1}$$

Where:

CR = Corrosion rate (mils per year)
K = Conversion constant (3.45×10^6)
W = Mass loss (g)
A = Surface area (cm^2)
T = Exposure time (hours)
D = Density (g/cm^3)

Results from MSC (Table 5) clearly show that the carbon steel and copper nickel coupons corroded significantly more than the titanium, Hastelloy, or stainless steel samples, although even the higher corrosion rates are not considered to be excessive by industry standards. Interestingly, it appears that the more susceptible metals (carbon steel and copper–nickel) were protected somewhat from corrosion by the black substance that was present in the feedwater and coated the coupons in Rack S-1 (127°F feedwater).

A surface analysis of select coupons was performed at the EERC using a Nanovea PS-50 Optical Profilometer. The profilometer measures the height of the sample surface in relation to a fixed optical assembly, with a horizontal detection limit of 0.1 μm and a vertical detection limit of 5 nanometers. Six corrosion coupons were analyzed for comparison: carbon steel and stainless steel coupons from Rack S-1 (127°F feedwater), carbon steel and stainless steel coupons from Rack S-6 (118°F concentrate), and unexposed carbon steel and stainless steel coupons. The resulting profilometer images provide a graphical comparison of corrosion between carbon steel and stainless steel in different water streams and are shown in Figures 5 and 6, respectively. It should be noted that the color height scales associated with each coupon are specific to that coupon and do not represent a common datum. More clearly explained, the profilometer scans a sample, and the deepest measured point on that sample is assigned the zero datum, and all other heights measured are referenced to that sample-specific zero datum.

As seen in Figures 5 and 6, the carbon steel exhibited more pitting corrosion than did the stainless steel (especially in Coupon No. 10 from Rack S-1). Figure 7 shows a more detailed projection of a highly corroded section of the carbon steel coupon from Rack S-1 (Coupon No. 10), illustrating the high degree of pitting observed for the carbon steel coupon.

Of all materials tested, the carbon steel and copper–nickel coupons exhibited higher rates of corrosion in all the water streams than did the titanium, Hastelloy, and stainless steel coupons. With that said, the most severe corrosion observed for carbon steel was around 2 mils per year. This corrosion rate may not be considered excessive if it occurred evenly on the surface of a material; however, that does not appear to be the case, as localized pitting was observed and may be of concern in a long-term application.

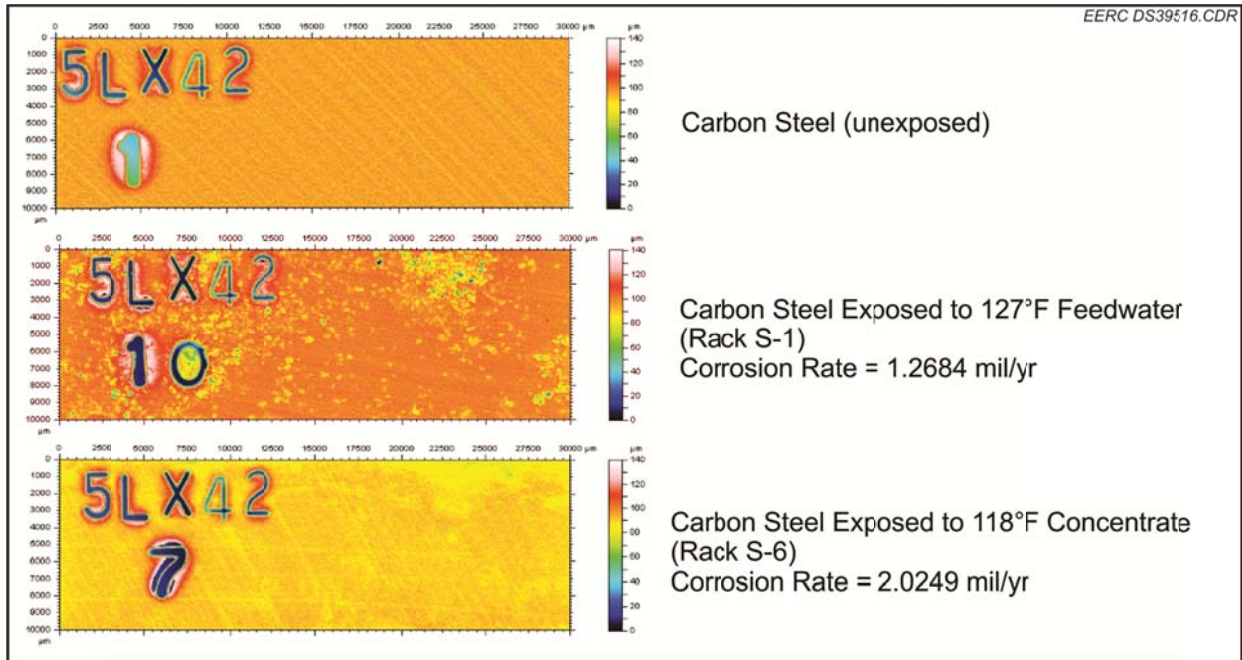


Figure 5. Profiler images of select carbon steel coupons.

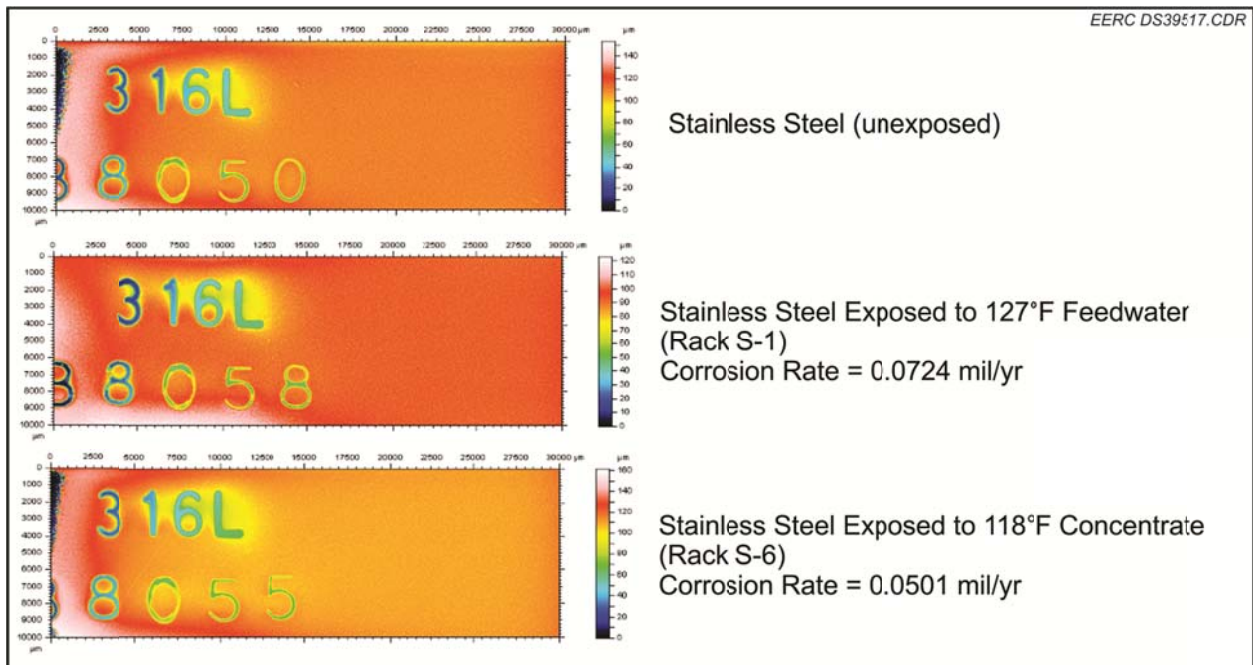


Figure 6. Profiler images of select stainless steel coupons.

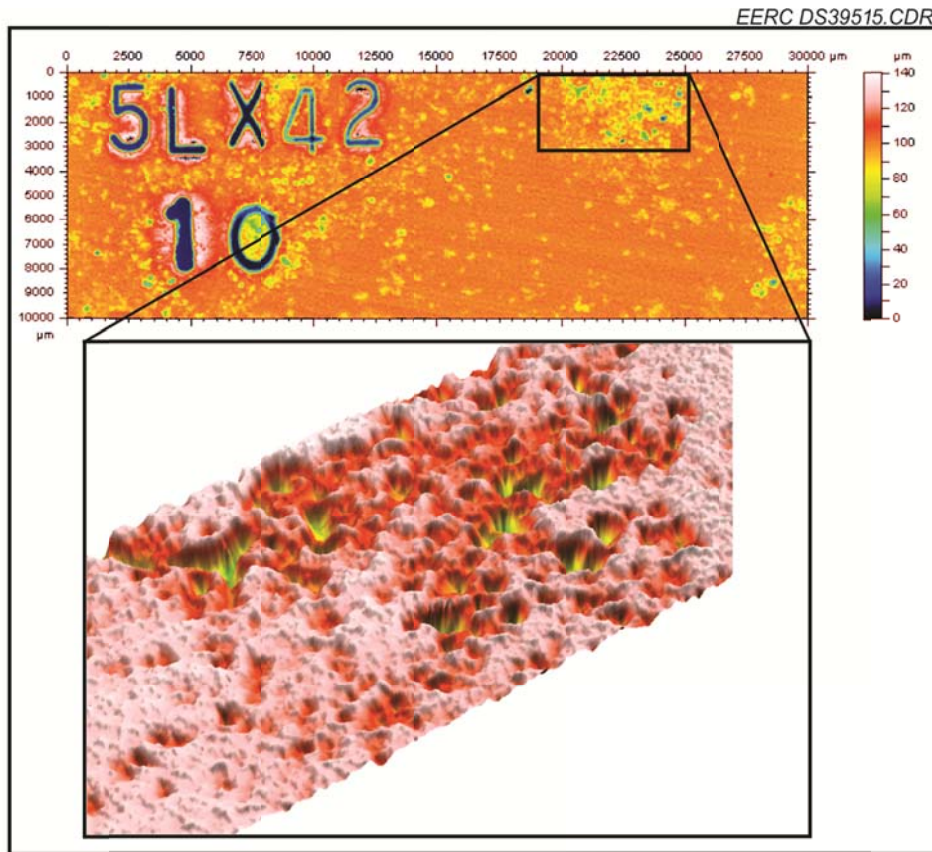


Figure 7. Profiler image of carbon steel coupon zoomed in to pitted area.

Corrosion results do indicate that stainless steel should withstand contact with the respective feedwater and concentrate streams quite well. Therefore, investment in more exotic (and expensive) materials such as Hastelloy and titanium are likely not warranted for use in the full-scale facility.

Task 4: Treatment Technology Performance Evaluation and Cost Assessment

As previously mentioned, the RO system was not operated continuously through the late summer and fall of 2010. As a result, the EERC decided to allow the system to run under steady-state conditions for a longer period of time prior to conducting a detailed assessment of system performance and economic viability. This assessment will be completed in the fall of 2011. That being said, some general conclusions on the system performance and economics can be made.

As a result of the system performance, the current shortage of water, and the amount of hauling time saved by having an on-site truck-filling station, Hess has decided to build a full-scale, 1-million-gallon/day RO treatment facility. For example, rather than paying for one water truck to drive 30 miles and wait in line for 1 to 2 hours, four trucks can fill at the site in 20 minutes. Preliminary calculations show that the water treatment costs for the pilot system are higher than the costs for conventional water supplies; however, the cost savings for reduced

hauling distances and waiting times more than make up for the difference. In addition, because of the economy of scale and the nature of the contract with GE to provide and operate the mobile RO system, the water treatment costs per gallon for this pilot plant are significantly higher than what they would be for a full-scale plant. As more data become available and bids are secured for the full-scale RO plant, an economic analysis of the concept will be conducted.

Given the high demand for fracturing water in western North Dakota and the widespread nature of brackish groundwater formations, like the Dakota, this approach may be economically and technically feasible for other producers and/or other industries in the region. While case-by-case assessments will likely be needed, it is encouraging to know that this resource is available and may be economically competitive.

Task 5: Project Reporting

As part of the EERC’s reporting requirements, quarterly summaries of the project activities are provided to DOE. Two reports have been provided to NDIC to date: a semiannual report documenting progress from January 1 to July 31, 2010, and an interim report documenting progress from January 1 through December 31, 2010. This interim report summarizes all project activities that have been conducted from January 1, 2010, through June 30, 2011.

EXPENDITURES TO DATE

Funding Source	Expenditures through June 15, 2011
DOE	\$154,555
NDIC	\$94,743
Hess (cash-equivalent cost share)	\$3,692,468**

** This amount only includes Hess’ expenditures for capital construction costs and general contractor labor through March 30, 2011.

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