



EERCSM

UNIVERSITY OF
UND NORTH DAKOTA

Critical Challenges. **Practical Solutions.**



EERC



UNIVERSITY OF
NORTH DAKOTA

Energy & Environmental Research Center (EERC)

DEVELOPING AND VALIDATING PRESSURE MANAGEMENT AND PLUME CONTROL STRATEGIES IN THE WILLISTON BASIN THROUGH A BRINE EXTRACTION AND STORAGE TEST (BEST) – PHASE II

DE-FE0026160

John Hamling

Assistant Director For Integrated Projects

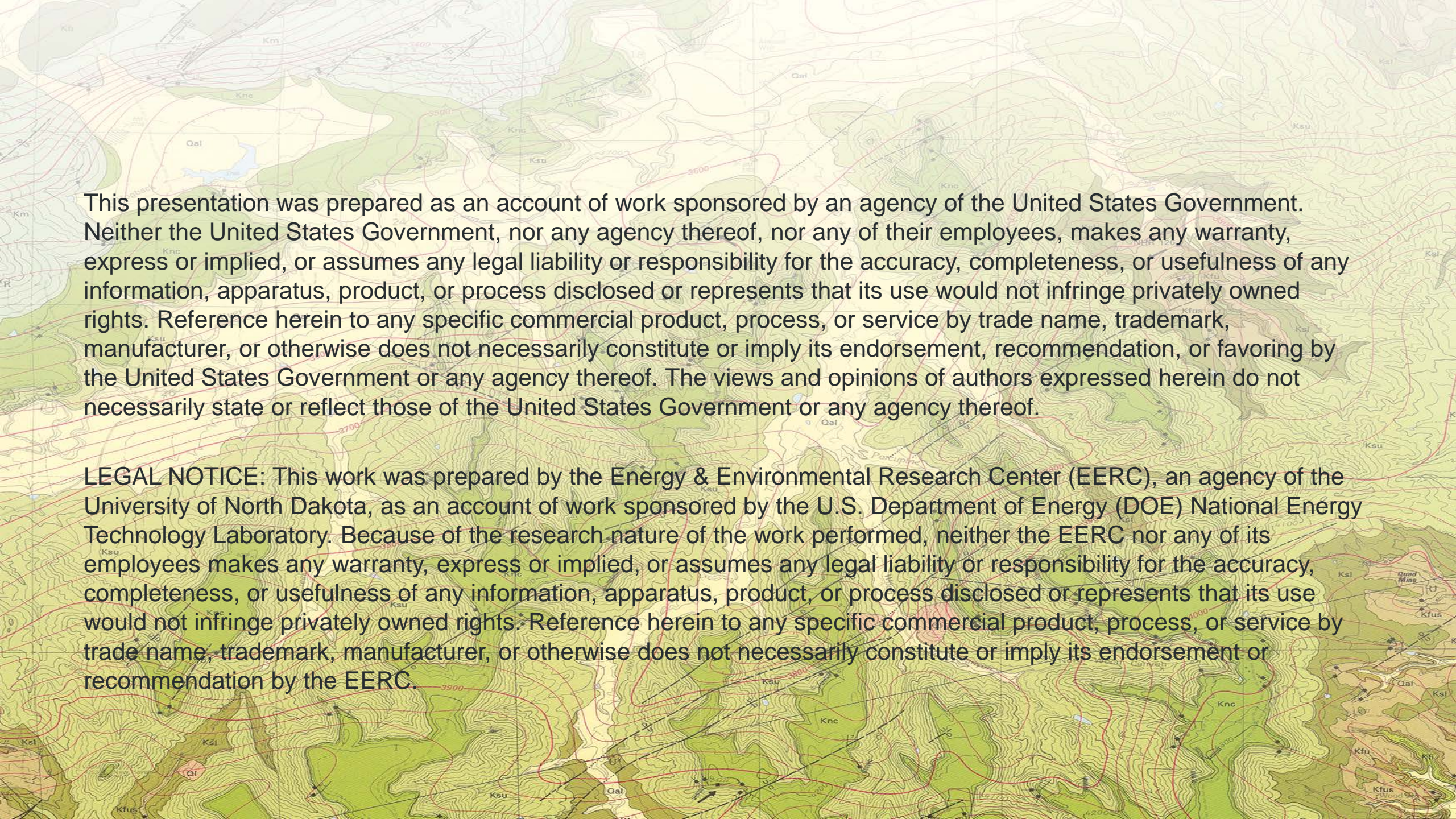
U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13–16, 2018

Critical Challenges. **Practical Solutions.**

A topographic map of a hilly region, likely in the western United States, showing contour lines and elevation markers. The map is overlaid with a semi-transparent white box containing text. The text is a disclaimer for a presentation prepared by an agency of the United States Government. The map features various contour lines in shades of green and brown, with elevation markers such as 3600, 3700, 3800, 3900, 4000, and 4200. There are also some place names and grid lines visible on the map.

This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

LEGAL NOTICE: This work was prepared by the Energy & Environmental Research Center (EERC), an agency of the University of North Dakota, as an account of work sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory. Because of the research nature of the work performed, neither the EERC nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement or recommendation by the EERC.



U.S. DEPARTMENT OF
ENERGY



**NATIONAL
ENERGY
TECHNOLOGY
LABORATORY**



EERCSM



Nuverra
Environmental SolutionsSM



Schlumberger
Carbon Services

This material is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Award No. DE-FE0026160.



EERC

UND UNIVERSITY OF
NORTH DAKOTA

DEDICATED GEOLOGIC CO₂ STORAGE CONSIDERATIONS

- Buoyant fluid
- Large volumes = large footprint
- Regulatory compliance and costs
- Conformance and efficiency
- Access to pore space
 - Leasing, unitization/amalgamation, trespass
- Assuring permanence for certification or credits
- Risk management



Because of a host of technical, social, regulatory, environmental, and economic factors, brine disposal tends to be more accessible and generally quicker, easier, and less costly to implement compared to dedicated CO₂ storage.

An aerial photograph of an industrial facility, likely a power plant or refinery, situated in a vast, arid desert landscape. The facility consists of several large, cylindrical storage tanks and various industrial buildings. A dirt road winds through the desert, with a single vehicle visible in the distance. The background shows rolling hills under a hazy sky. The text is overlaid on the upper portion of the image.

Brine extraction can enable dedicated CO₂ storage and improve the geologic CO₂ storage potential of a site.

TWO COMPLEMENTARY COMPONENTS

ARM Test

- Reduce stress on sealing formation
- Geosteer fluid plume
- Divert pressure from leakage pathways
- Reduce area of review (AOR)
- Improve injectivity, capacity, and storage efficiency
- Validate monitoring techniques, and forecast model capabilities

Brine Treatment Test Bed

- Alternate source of water
- Reduced disposal volumes
- Salable products for beneficial use

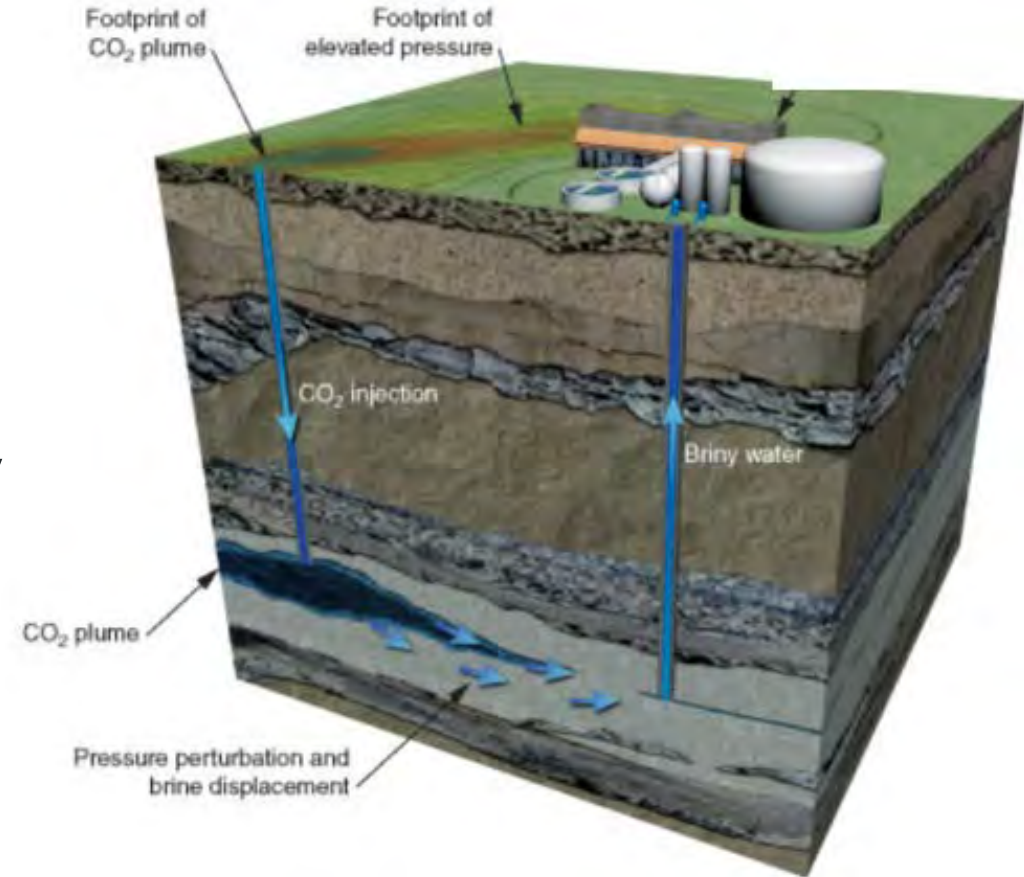
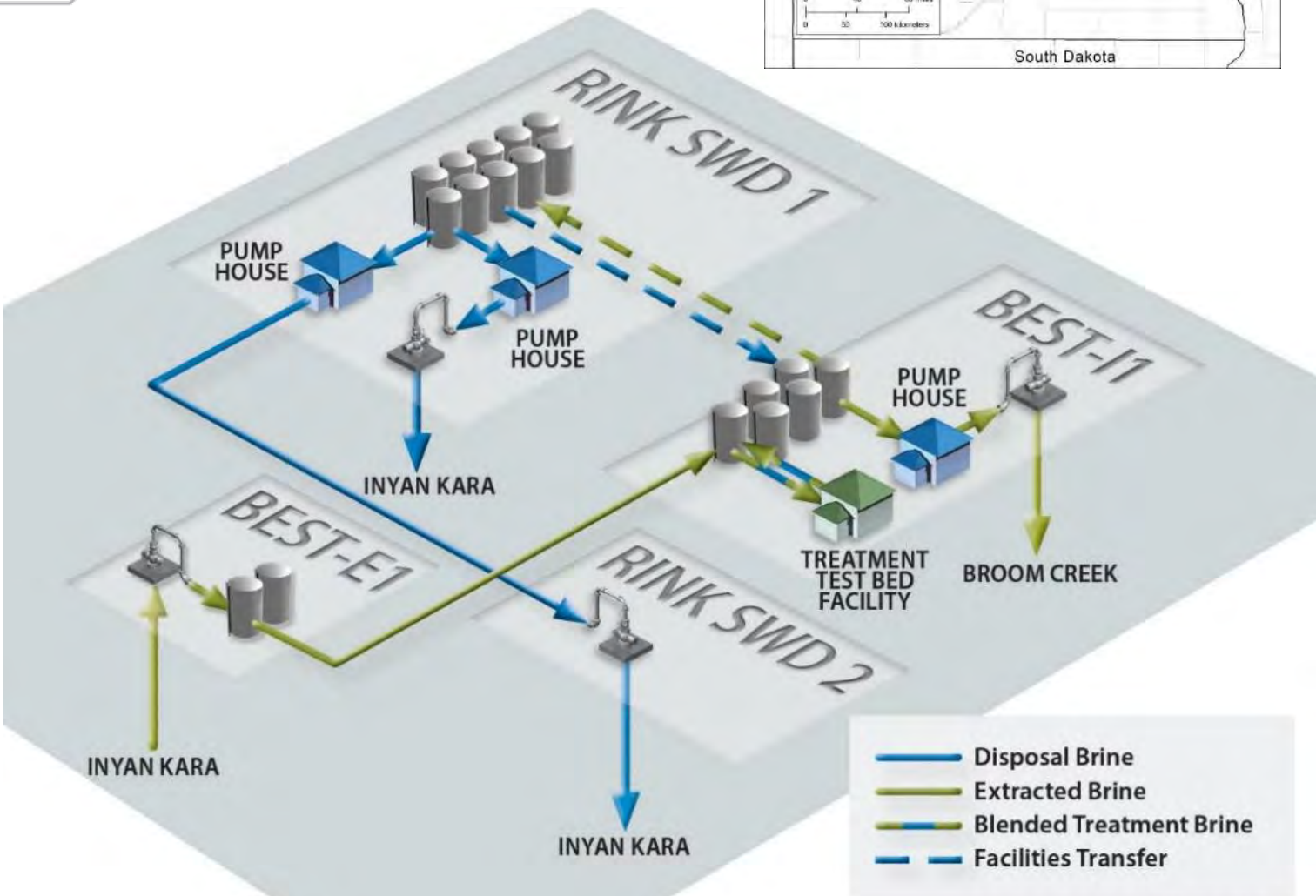


Illustration modified from Lawrence Livermore National Laboratory <https://str.llnl.gov/Dec10/aines.html>

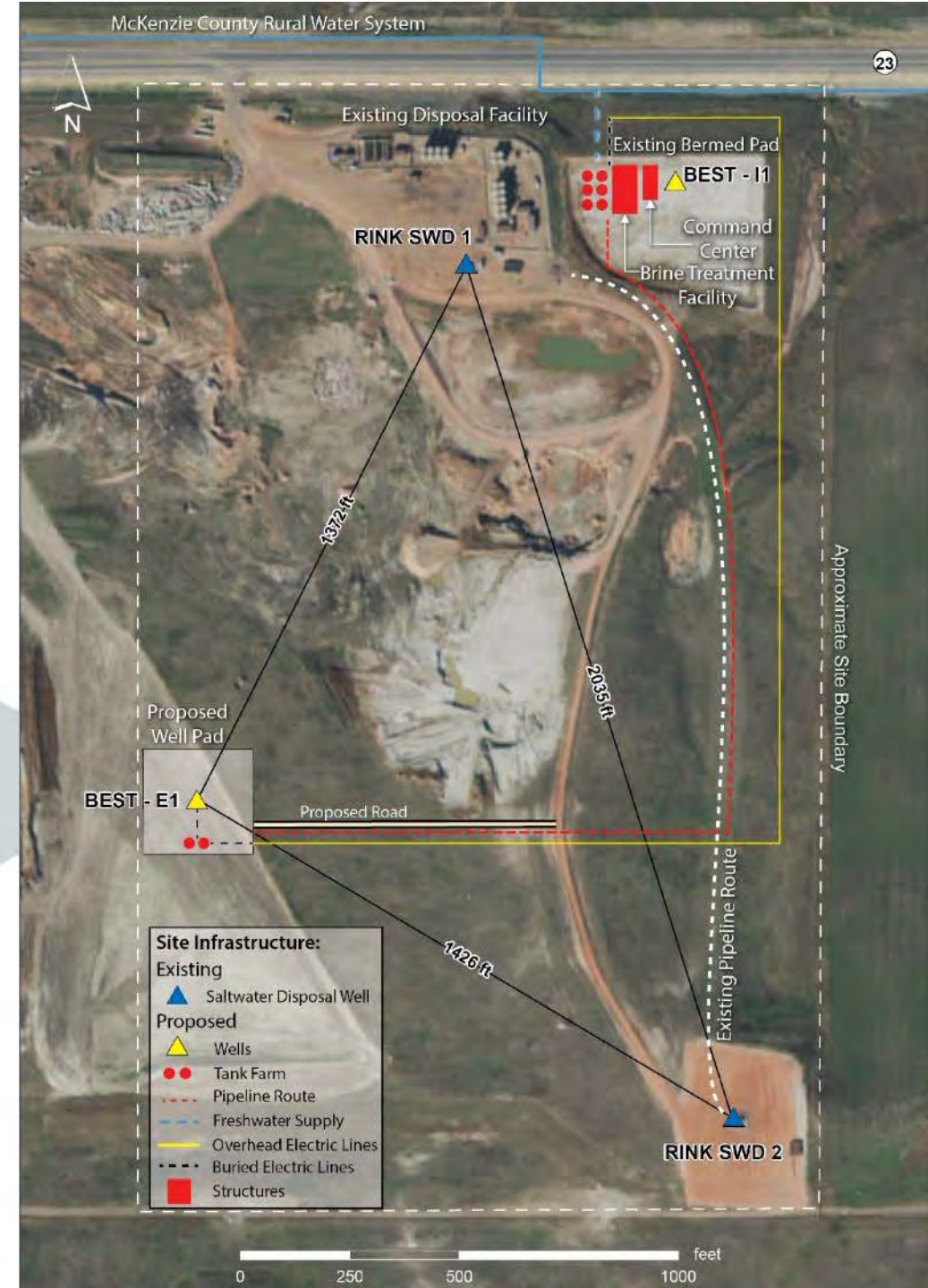
An aerial photograph of an industrial facility, likely a water treatment plant or refinery, situated in a vast, arid, and hazy landscape. The facility features several large cylindrical storage tanks and various industrial buildings. A dirt road winds through the foreground, with a small vehicle visible in the distance. The overall atmosphere is misty and overcast, with a pale, hazy sky. In the top-left corner, there is a black rectangular graphic element with a white border.

ACTIVE WATER DISPOSAL SITES AS A PROXY FOR DEDICATED CO₂ STORAGE

THE SITE



EERC WP52503A.AI



- Site Infrastructure:**
- Existing**
 - ▲ Saltwater Disposal Well
 - Proposed**
 - ▲ Wells
 - Tank Farm
 - - - Pipeline Route
 - - - Freshwater Supply
 - Overhead Electric Lines
 - - - Buried Electric Lines
 - Structures

Approximate Site Boundary

SITE GEOLOGY

Inyan Kara Formation (ARM Test)

- Nearshore/shallow marine sandstone
- 1568-m depth (5145 ft)
- ~120 m thick (400 ft)

Broom Creek Formation (Extracted Water Disposal)

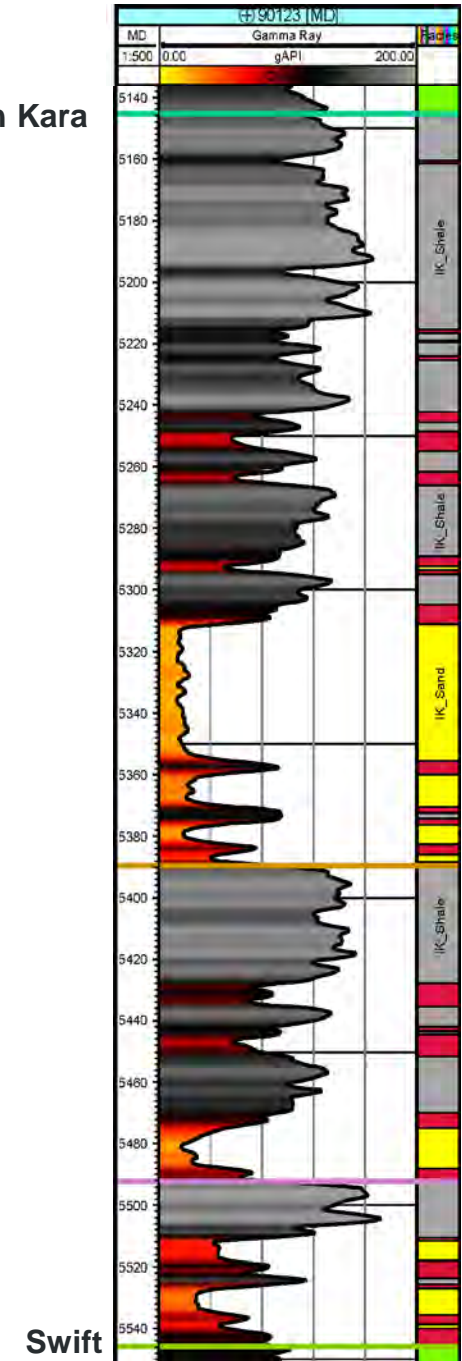
- Eolian/nearshore marine sandstone
- 2277-m depth (7470 ft)
- ~20 m thick (65 ft)

Both formations have thick sealing units and are potential CO₂ storage targets in the Williston Basin.

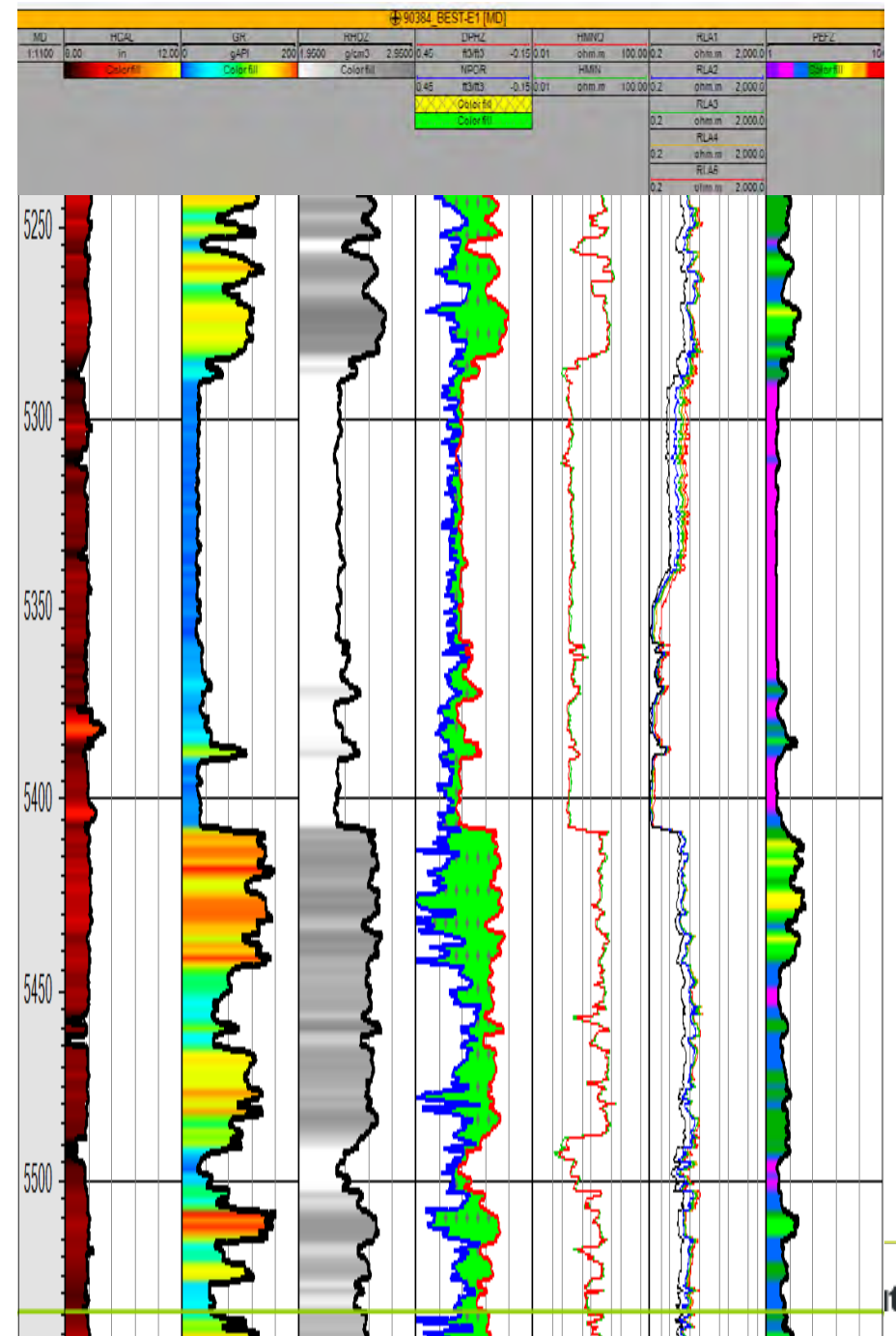
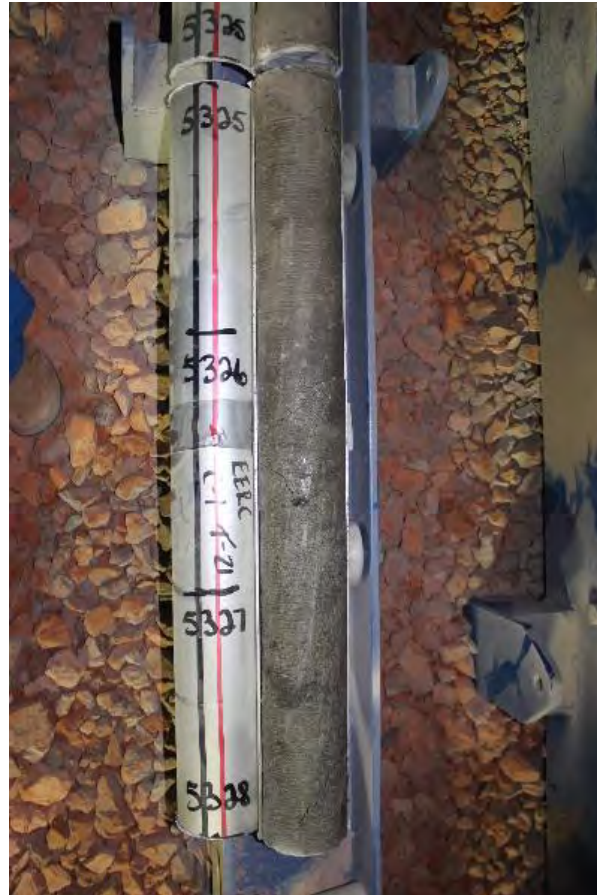
EERC WP53220.AI

Stratigraphic Column				
Period	Rock Unit	Depth m (ft)	Thickness m (ft)	Storage Assessment Unit
Cretaceous	Dakota Group	1463 (4800)		Upper Sealing Formations
		1568 (5145)	105 (345)	
	Inyan Kara	1692 (5550)	123 (405)	ARM Testing Formation
Jurassic	Swift		585 (1920)	Sealing Formations
	Rierdon			
	Piper			
Triassic	Spearfish			
Permian	Opeche			
	Broom Creek	2277 (7470)	20 (65)	Saline Injection Formation
Pennsylvanian	Amsden	2297 (7535)		Lower Seal

Inyan Kara



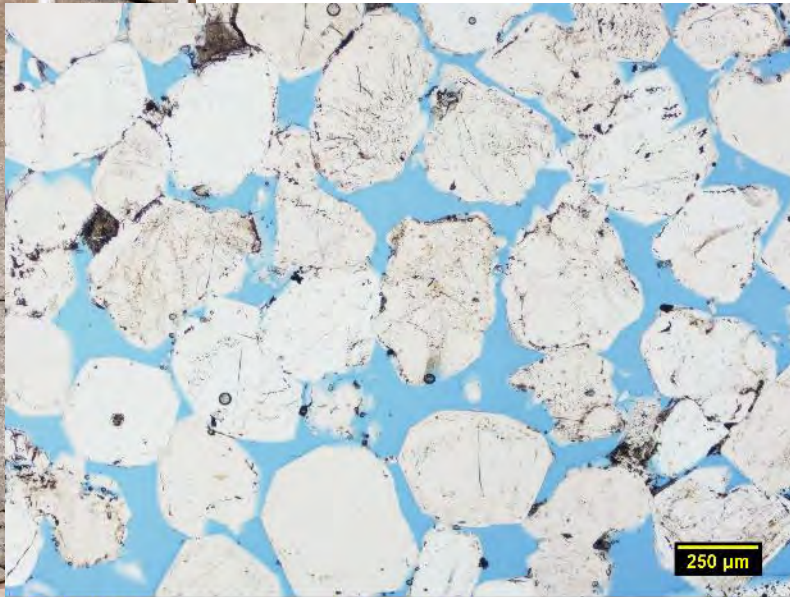
BEST-1, BEST-E1



CORE – UNDER ANALYSIS



Inyan Kara



Well BEST I1
Inyan Kara
Sample #124653
Scene 1
5317.5 ft
5x PP



Broom Creek



Well BEST I1
Broom Creek
Sample #124664
Scene 1
7502.0 ft
5x PP

PROVISIONAL FIELD IMPLEMENTATION PLAN (FIP)

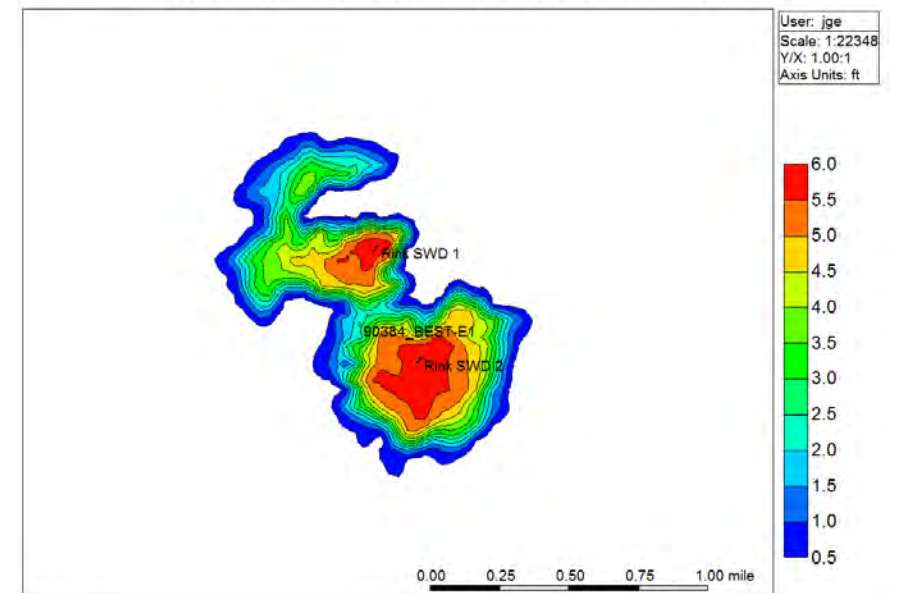
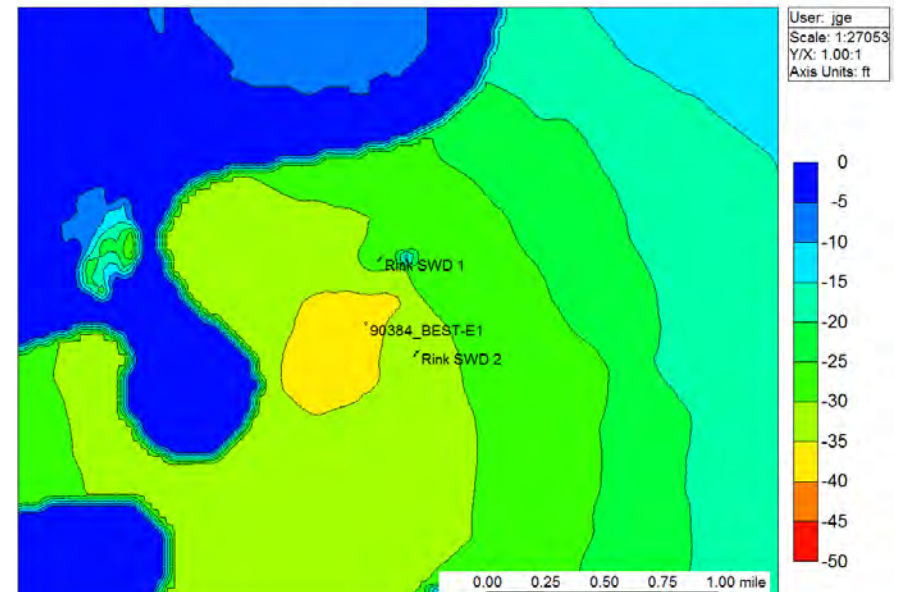
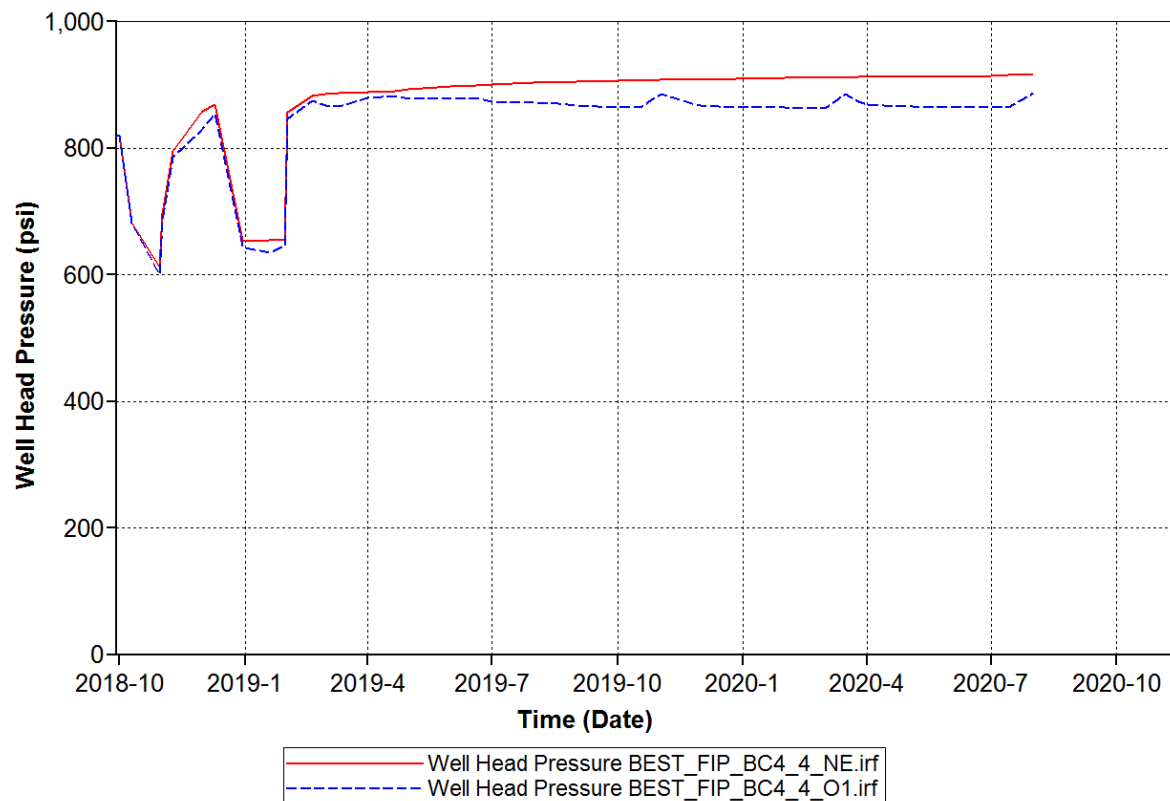
Revised to account for:

- Changes in injection rates and an additional years injection data.
- Revised implementation schedule.
- New characterization data.

BEST indicative field experimental scenario 1 (1 October 2018 – 31 July 2020) DRAFT							
Test	Days	End date	Description (BWPD)				Comment
			BEST-E1	BEST-I1	RINK-1	RINK-2	
	0	1-Oct-18	Stage One				Start data collection
1	10	10-Oct-18	0	0	7100	7400	Observe
2	20	30-Oct-18	-5000	5000	7100	7400	Begin interference test
3	10	9-Nov-18	0	0	7100	7400	Inject tracer
4	21	30-Nov-18	-5000	5000	7100	7400	Maximum rate test
5	10	10-Dec-18	0	0	7100	7400	Observe
6	20	30-Dec-18	0	2000	7100	5400	Rink-1 test begins
7	20	19-Jan-19	-3000	5000	7100	5400	
8	11	30-Jan-19	0	2000	7100	5400	Rink-1 test ends
9	20	19-Feb-19	0	2000	5100	7400	Rink-2 test begins
10	20	11-Mar-19	-3000	5000	5100	7400	
11	11	22-Mar-19	0	2000	5100	7400	Rink-2 test ends; interference test ends
	30	21-Apr-19	Stage Two				
12	60	20-Jun-19	-2500	2500	7100	7400	Minimum pump rate step
13	60	19-Aug-19	-4000	4000	7100	7400	Middle pump rate step
14	60	18-Oct-19	-5000	5000	7100	7400	Maximum pump rate step
15	15	2-Nov-19	0	0	7100	7400	Observe
16	120	1-Mar-20	-5000	5000	7100	7400	Long-duration test 1
17	15	16-Mar-20	0	0	7100	7400	Observe
18	120	14-Jul-20	-5000	5000	7100	7400	Long-duration test 2
19	17	31-Jul-20	0	0	7100	7400	Observe - end of extraction program
	670		-2,215,000	2,419,000	4,442,000	4,634,000	Totals. End of test.

SIMULATION RESULTS

Rink SWD 2



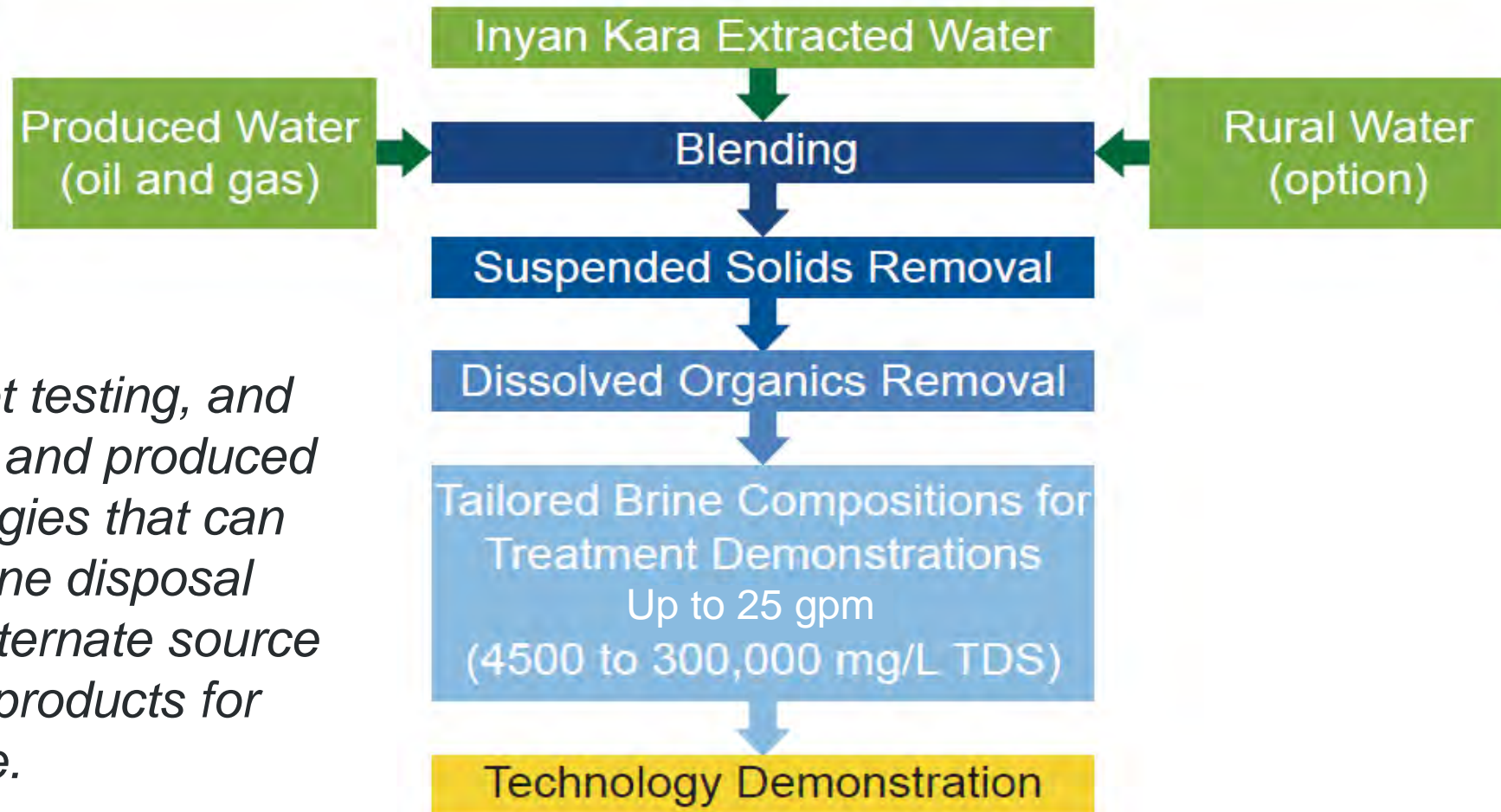
PIPELINE



INFRASTRUCTURE



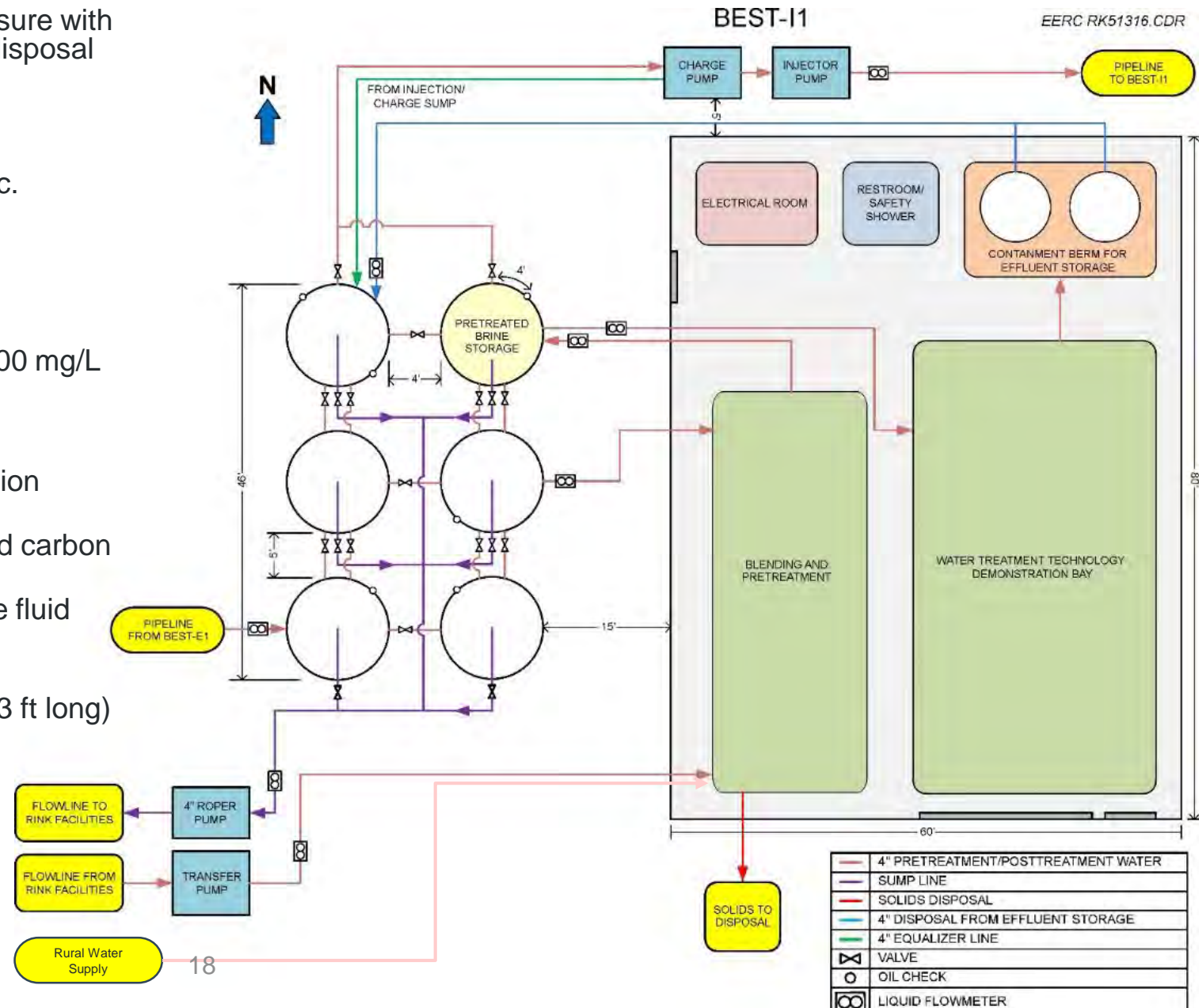
BRINE TREATMENT TEST BED



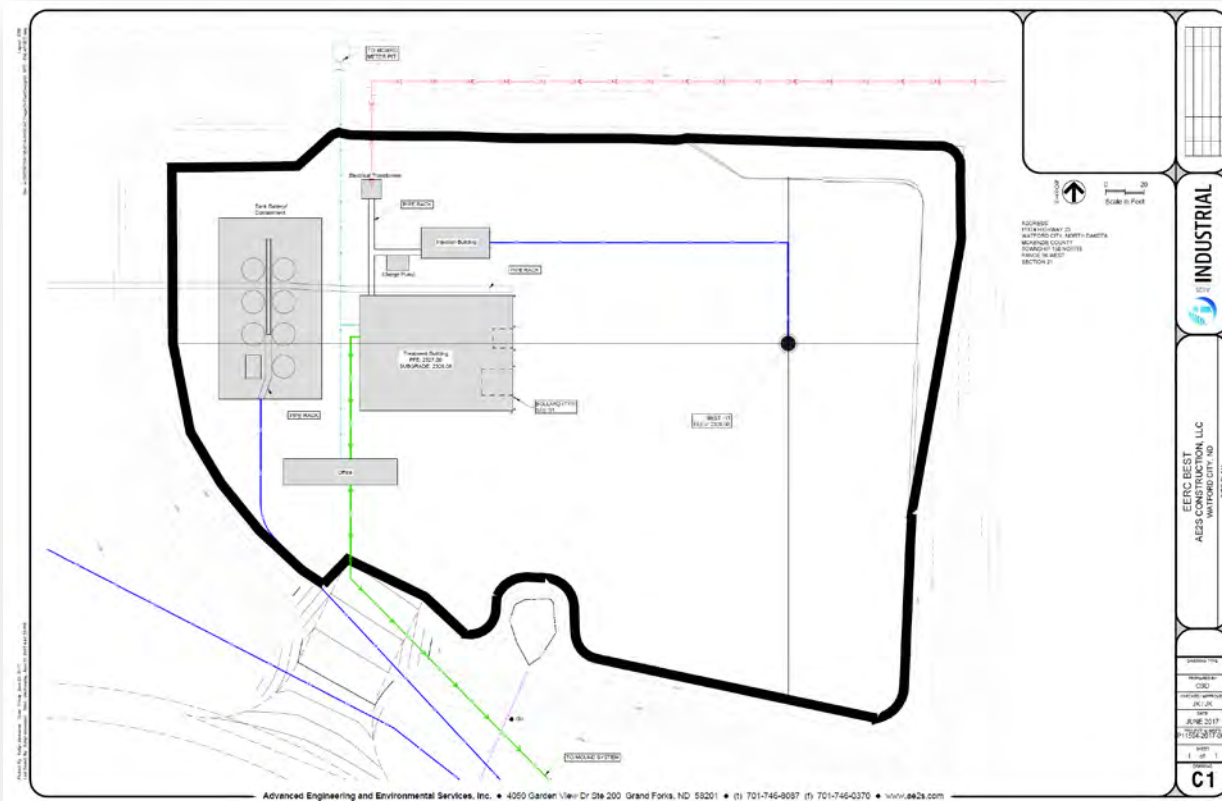
Enable development, pilot testing, and advancement of extracted and produced water treatment technologies that can meaningfully reduce brine disposal volumes and provide an alternate source of water and/or salable products for beneficial use.

BRINE TREATMENT TEST BED

- Permanently installed heated environmental enclosure with concrete floor integrated with ARM and saltwater disposal (SWD) infrastructure
 - 30–60+ day extended-duration tests.
 - 24/7/365 operations-capable.
 - Monitoring of energy, flow, chemical usage, etc.
 - Waste management and SWD on-site.
 - Workspace, control room, restroom.
- Pilot treatment rates up to 25 gpm
- Pretreatment
 - Blending of water to target TDS level of 180,000 mg/L or tailored blends ranging between <5000 and >300,000 mg/L TDS to suit capabilities and/or limitations of selected technologies.
 - Suspended solids removal (dissolved air flotation [DAF]).
 - Dissolved organics removal (granular activated carbon [GAC]).
 - Facility could be adapted for use with alternate fluid compositions and treatment processes.
- Technology demonstration bay
 - Accommodates standard semitractor trailer (53 ft long) inside the building.
 - 300 kW electric power
 - Propane (5000-gal tank).
 - Noncontact cooling water (30 gpm).



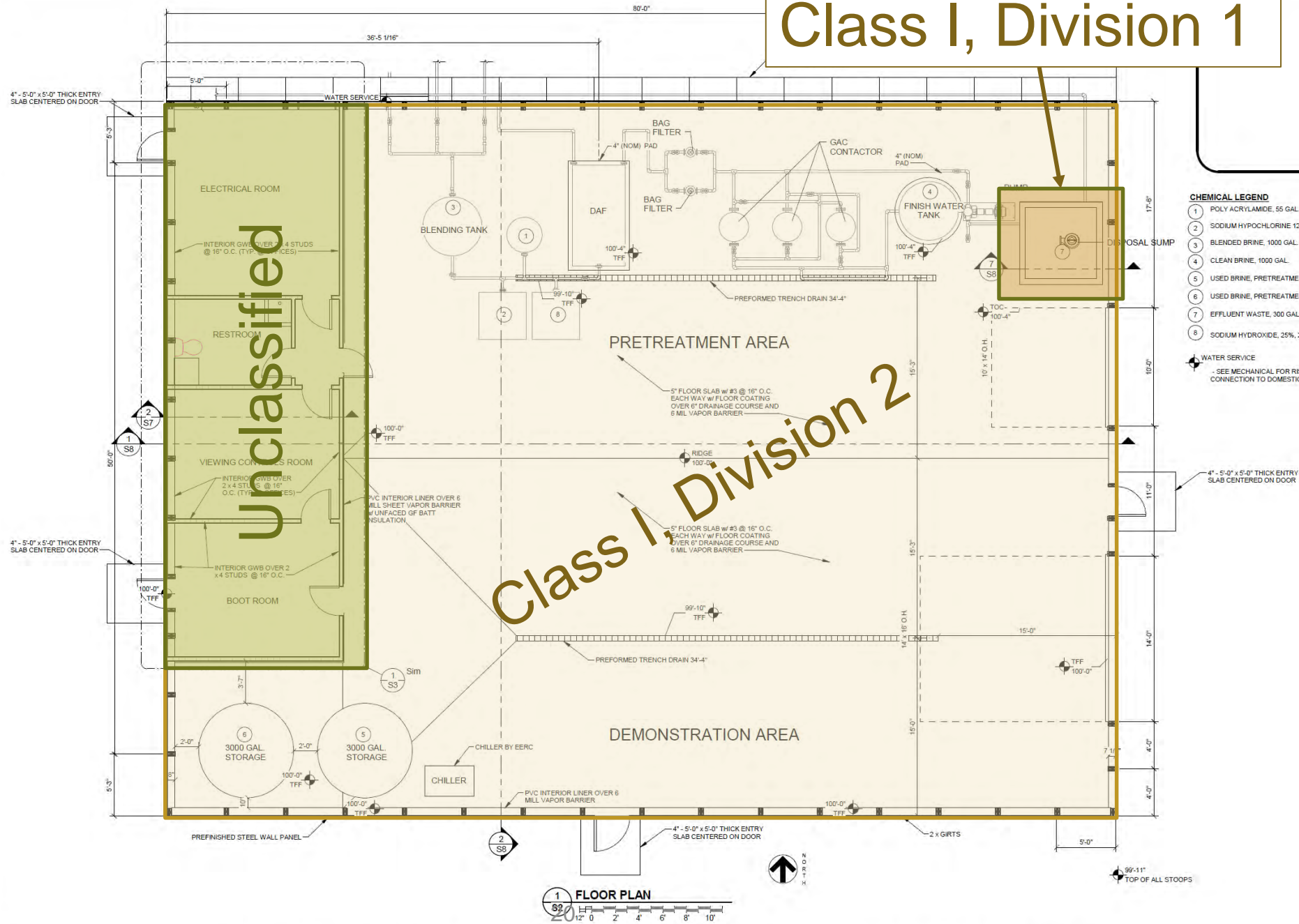
BRINE TREATMENT TEST BED



- 60 ft x 80 ft with 18-ft walls
- Two large overhead doors
- Heated environmental enclosure with air handling/exchange
- 53-ft test bay



Class I, Division 1



CHEMICAL LEGEND

- 1 POLY ACRYLAMIDE, 55 GAL.
- 2 SODIUM HYPOCHLORINE 12.5% SOLUTION, 275 GAL.
- 3 BLENDED BRINE, 1000 GAL.
- 4 CLEAN BRINE, 1000 GAL.
- 5 USED BRINE, PRETREATMENT EFFLUENT, 3000 GAL.
- 6 USED BRINE, PRETREATMENT EFFLUENT, 3000 GAL.
- 7 EFFLUENT WASTE, 300 GAL. QTY.
- 8 SODIUM HYDROXIDE, 25%, 275 GAL.

WATER SERVICE

- SEE MECHANICAL FOR RISER AND CONNECTION TO DOMESTIC WATER



EERC BEST
AE2S CONSTRUCTION
WATFORD CITY, ND
FLOOR PLAN

DRAWING TYPE	PRELIMINARY
PREPARED BY	KW
CHECKED / APPROVED	JK / JK
DATE	JUNE 2017
PROJECT NUMBER	710828-2016-000
SHEET	2 of 8
DRAWING	S2

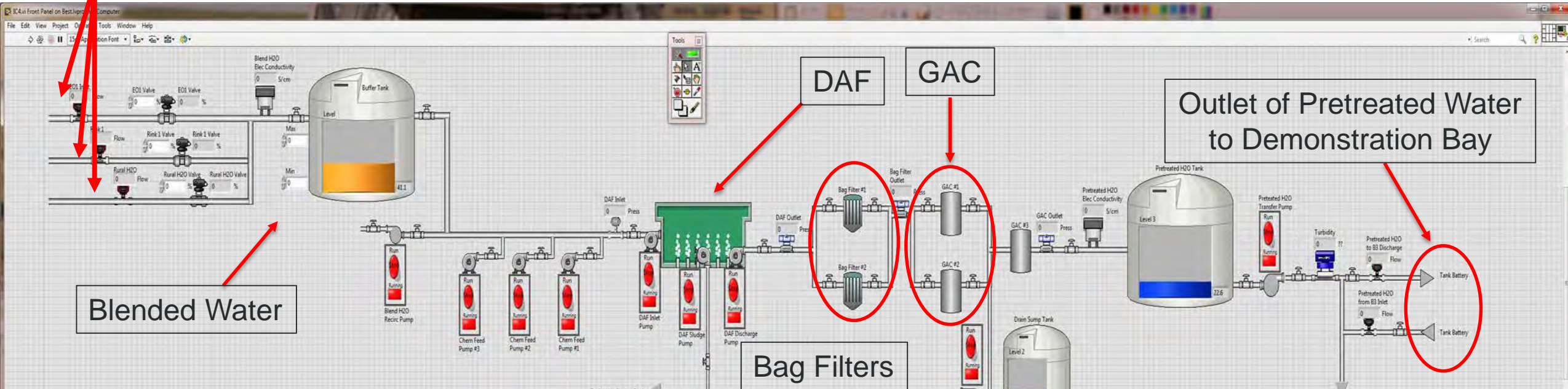
SYMBOL	DATE	DESCRIPTION	APPROVED

1 FLOOR PLAN
Scale: 1/8" = 1'-0"

BLENDING AND PRETREATMENT

- Blending of water to target TDS levels of 180,000 mg/L or other tailored blend to suit capabilities and/or limitations of selected technologies.
 - Water blending will take advantage of a combination of produced water (~300,000 mg/L TDS), extracted formation water (~10,000–100,000 mg/L TDS) and freshwater sources available on site.
- Suspended solids removal (DAF).
- Filter bags
- Dissolved organics removal (GAC).

Extracted, Produced, and Freshwater Source



Blended Water

DAF

GAC

Bag Filters

Outlet of Pretreated Water to Demonstration Bay

Tank Battery

Tank Battery

1000 CAD Digital Structural/MECHANICAL Building of

02/20/11 10:34:14 AM

Electrical Room

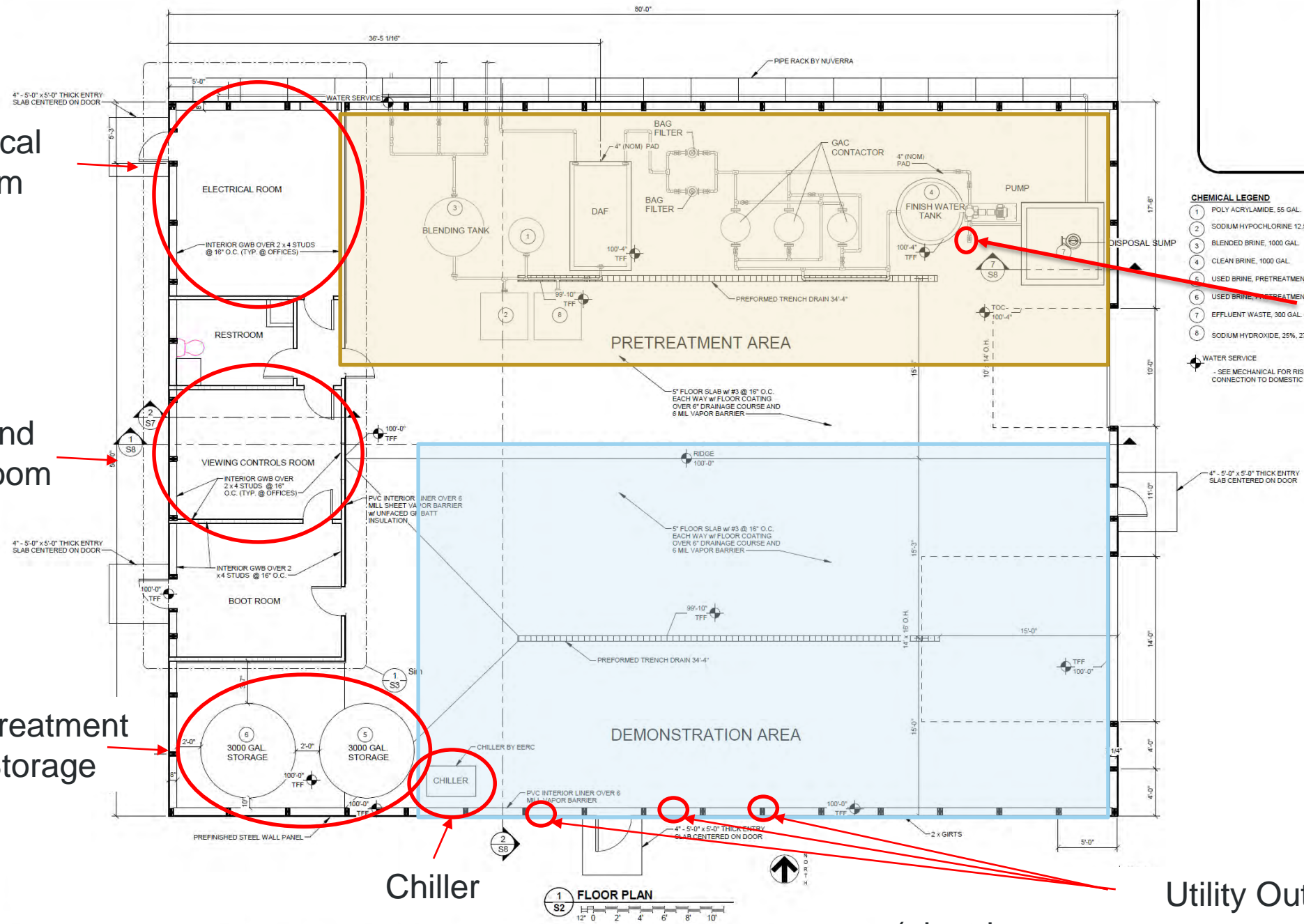
Viewing and Control Room

Pretreatment Storage

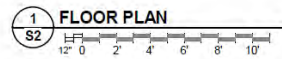
Chiller

Utility Outlets
(electric power, propane, water)

Pretreated Water Supply Outlet



- CHEMICAL LEGEND**
- 1 POLY ACRYLAMIDE, 55 GAL.
 - 2 SODIUM HYPOCHLORINE 12.5 % SOLUTION, 275 GAL.
 - 3 BLENDED BRINE, 1000 GAL.
 - 4 CLEAN BRINE, 1000 GAL.
 - 5 USED BRINE, PRETREATMENT EFFLUENT, 300
 - 6 USED BRINE, PRETREATMENT EFFLUENT, 300
 - 7 EFFLUENT WASTE, 300 GAL. QTY
 - 8 SODIUM HYDROXIDE, 25%, 275 GAL.
- WATER SERVICE
 - SEE MECHANICAL FOR RISER AND CONNECTION TO DOMESTIC WATER






TECHNOLOGY PROVIDER CONTACTS

- The EERC and EPRI collaborated with NETL to jointly develop a list of potential technology providers, a treatment technology-screening questionnaire, project fact sheets, and a technology demonstration screening and selection process.
 - NETL approved questionnaire and the screening and selection process in February 2018.
 - The EERC and EPRI are collaborating on engagement of potential brine treatment technology providers .
 - Technology providers were contacted and provided with the project fact sheets and questionnaire between April and June 2018.
- Several technology providers responded with questions, and three (out of 20) responded to the questionnaire.
 - Engagement is ongoing.

**WILLISTON BASIN
WATER TREATMENT
TECHNOLOGY TEST BED**



WE SEEK TO PILOT-TEST TECHNOLOGIES CAPABLE OF TREATING HIGH-TDS WATER.


TREATMENT AND HANDLING of high-TDS (total dissolved solids) waters associated with energy production are challenging and not readily or economically accomplished using conventional water treatment techniques. Geologic injection is often required to effectively manage fluids associated with electrical power generation, oil and gas production, and active reservoir management for geologic CO₂ storage.

As part of a public-private collaboration, a facility is being constructed in western North Dakota to pilot-test high-TDS water treatment technologies that can:

- Produce alternate sources of water for industrial or domestic use.
- Produce salable products.
- Meaningfully reduce brine disposal volumes.

Pilot testing provides critical understanding of technology performance under field operating conditions. This understanding enables the advancement and commercial adoption of viable technologies capable of treating these challenging waters for beneficial use.

The Energy & Environmental Research Center (EERC) is seeking companies interested in pilot-testing water treatment technologies at the facility. This is a collaborative effort with Nuverra Environmental Solutions (Nuverra) and the U.S. Department of Energy (DOE) National Energy Technology Laboratory.




The extracted water treatment test bed facility is located approximately 13 miles east of Watford City, North Dakota, immediately adjacent to North Dakota Highway 23 on the Johnsons Corner site, a Nuverra-operated commercial saltwater disposal (SWD) facility.

The test bed will feature the ability to blend extracted and produced waters in order to generate tailored brine compositions ranging from ~4500 to ~300,000 mg/L TDS. The facility is anticipated to be operational by summer 2018.

EERC engineering staff will be on-site during all demonstration activities to assist with connections to the test bed facility and to monitor and gather process performance data. Technology developers are expected to provide their own operations staff. During steady-state operation, EERC engineering staff will conduct energy and material balances (power consumption, process flows, and influent and effluent quality analyses).

A report summarizing demonstration activities and detailing performance data and technology capabilities will be prepared and submitted to DOE. Non-disclosure and site access agreements between the EERC, Nuverra, and technology developers will be negotiated prior to demonstration.

Currently, no guarantee is offered that DOE or other funding will be available to assist interested treatment technology developers. However, the field site and facilities for water treatment demonstrations, including potential cost offsets for power, cooling water, and effluent disposal, may be made available at no or reduced cost to selected demonstrations.



Conceptual extracted water treatment flow diagram.

Technology Providers Contacted by EERC

- ABR Process Development
- AE₂S, Inc.
- Caloris Thermal Process Technology
- Encon Evaporators
- Illinois State Geological Survey
 - University of Illinois at Urbana-Champaign
- Los Alamos National Laboratory
- Mantra Energy Alternatives
- MGX Minerals
- NETL
- Nuverra Environmental Solutions, Inc.
- Oasis Water
- Ohio University
 - Russ College of Engineering and Technology
- RTI International
- RWL Water
- GE Global Research
- Slipstream ZLD
- University of Pittsburgh
 - Department of Civil and Environmental Engineering

MAJOR ACCOMPLISHMENTS TO DATE (ARM)

- All design, permitting, and bonding complete.
- Drilled two new wells (BEST-E1 and BEST-I1).
 - Extraction well and extracted water injection well.
 - Conducted DST in Broom Creek interval.
 - Casing conveyed pressure/temperature gauge installed in BEST-E1.
- Collected new characterization data
 - 190 feet of core representing Inyan Kara and Broom Creek Formations.
 - Well logs.
 - Laboratory analysis ongoing.
 - Completed an update to field implementation plan (FIP).
- Installed water handling infrastructure (pipeline, pumps, tanks, monitoring equipment, etc.).
- Utilities installed.

MAJOR ACCOMPLISHMENTS TO DATE (TEST BED)

- Water treatment test bed demonstration facility constructed and internals fitted.
- Pretreatment equipment installed
- Utilities hookups complete.
- Initiated solicitation of water treatment demonstrations.



FUTURE ACTIVITIES

- Complete core testing
 - XRD, XRF, porosity, permeability, etc.
 - Fluid compatibility testing
- Update geologic models and field implementation plan (FIP).
- Complete wells (Perforate, acidize, test well, and install ESP).
 - BEST-E1 - Inyan Kara interval
 - BEST-I1 - Broom Creek and potentially Amsden intervals
- Install suspended gauges and conduct spinner survey in offset RINK SWD wells.
- Initiate FIP
- BSEM baseline survey and tracer injection.
- Shake down systems.
- Select and demonstrate water treatment technologies.

Operational
Fall 2018



CHALLENGES & LESSONS LEARNED

Infrastructure installation is nearly complete; major research activities will initiate fall 2018.

- Flexibility to adapt operations and ARM to evolving operational and commercial conditions is critical for success.
- Designs cannot fully account for the real world. Have contingency plans in place and use them, be adaptive as conditions change
- Manage risk, cost, and objectives
- Hands-on involvement with drilling and construction pays dividends. Communicate with stakeholders regularly and often.
- Mother nature! (winter construction delays; some infrastructure has sustained wind damage; temporary brine storage (100°F to -50°F).
- Potential for fluid interactions, scaling, and TNORM.

- Geology can be unpredictable – may need to complete Amsden interval to achieve extraction target.
- Water treatment of target 180,000 mg/L TDS is challenging and generally not commercially economic.
- Field demonstration can be a technical, logistical and financial challenge for many technology providers lacking the strong market pull from a yet emerging industry.



SYNERGY OPPORTUNITIES

- Opportunity to advance understanding of the impact of ARM on CO₂ injection operations.
- Opportunity to adapt facility to demonstrate water treatment technologies for multiple industries.
 - Produced water treatment and use
 - Industrial or municipal wastewater
 - Other chemical treatments
 - Formation effects (e.g. homogenization and filtering)
- Collaboration with EPRI-led Florida project.
 - e.g., technology vetting, complementary ARM test program, knowledge-sharing, etc.



OUTREACH AND INFORMATION

IMPLEMENTING AND VALIDATING RESERVOIR PRESSURE MANAGEMENT STRATEGIES IN THE WILLISTON BASIN

John A. Hamling, Ryan J. Kasperich, Daniel J. Seaman, Loney L. Johnson
Energy & Environmental Research Center - 15 North 23rd Street, Stop 9016 - Grand Forks, ND 58202-0916 - www.underc.org

OVERVIEW

The Energy & Environmental Research Center (EERC) is conducting a multi-year field demonstration to evaluate active reservoir management (ARM) strategies that could benefit geologic carbon dioxide (CO₂) storage practices. This effort, funded by the U.S. Department of Energy's National Energy Technology Laboratory, in partnership with Nuvera Environmental Solutions, Schlumberger, and Computer Modeling Group, will build and operate a brine extraction and storage test (BEST) site. The western North Dakota field site is expected to be operational by mid-2017, with testing scheduled through late 2019.

BEST will consist of two complementary components, an ARM test and a brine treatment test bed. Simultaneous injection and extraction of brine within the Iyuan Kara Formation, combined with a monitoring program, will be used to evaluate ARM performance. The formation fluids extracted as part of the ARM test will be used in conjunction with the brine treatment test bed facility to demonstrate emerging water treatment technologies capable of treating high-salinity brines. Together, these two components will serve as a proxy of a geologic CO₂ storage site employing ARM.



WATER TREATMENT TEST BED FACILITY

Treatment of high total dissolved solids (TDS) waters associated with energy production (extracted water management) for carbon storage, electric energy production, and oil and gas production and refining is a challenging and not typically or economically viable using conventional water treatment technologies. Therefore, geologic injection is often required to effectively manage these fluids. However, there is a growing demand for treatment approaches capable of treating these challenging waters. Successful treatment of high TDS waters can provide alternate sources of water for domestic or industrial use and/or create additional salable products, as well as meaningfully reduce disposal volumes.

The test bed facility is designed to generate performance data through a field demonstration for brine treatment technologies capable of treating these challenging waters for beneficial use and ultimately enable the development and adoption of commercially viable treatment technologies.



ACTIVE RESERVOIR MANAGEMENT

ARM has the potential to improve the commercial viability of geologic CO₂ storage. In addition, ARM has applications to geologic disposal of fluids associated with energy production and a broad cross section of other industries. This project will investigate the potential of controlled brine extraction as a means to manage reservoir pressure, reduce stress on sealing formations, control the footprint of the injected fluid within a formation, and improve overall injection performance. The scale of the test will approximate 250,000 acre-feet of CO₂ injection.

Forecast modeling suggests that the fluid injection and extraction program is expected to result in a measurable reduction in formation pressure within the study area and influence the development of the injected fluid plume. Several monitoring techniques, including tracers, downhole pressure gauges, and a borehole to surface electromagnetic survey, will be used to validate both performance forecast models and ARM performance.



Stratigraphic Column	Rock Unit	Thickness (ft)	Porosity (%)	Permeability (md)	Notes
Broom Creek Formation	Shale	100	0	0	Sealing
	Sandstone	100	15	10	Injection
	Sandstone	100	15	10	Injection
Iyuan Kara Formation	Sandstone	100	15	10	Injection
	Sandstone	100	15	10	Injection
Bakken Formation	Sandstone	100	15	10	Production
	Sandstone	100	15	10	Production
Dakota Formation	Sandstone	100	15	10	Production
	Sandstone	100	15	10	Production
Williston Formation	Sandstone	100	15	10	Production
	Sandstone	100	15	10	Production

FIELD IMPLEMENTATION PLAN

The field implementation plan will leverage an existing pressure plume generated by two existing commercial saltwater disposal wells completed in the Iyuan Kara Formation. These wells, in conjunction with a new brine extraction well (BEST-E), will be used to conduct ARM testing. Water extracted from BEST-E1 will be injected into a second new well (BEST-F1) completed in the deeper Broom Creek Formation. Injection and extraction rates into each well will be independently controlled through a range of operational parameters, and a flowback of the extracted water will be diverted to the water treatment test bed facility.

The four-well design provides operational flexibility and the monitoring capabilities necessary to evaluate brine extraction as a viable ARM technique. The monitoring program will be used to develop specific understanding of reservoir performance and the influence on the injected fluid footprint and pressure differential induced in the Iyuan Kara Formation. A comprehensive health, safety, and environmental monitoring program is also being employed as part of an extensive risk mitigation program.



WILLISTON BASIN WATER TREATMENT TECHNOLOGY TEST BED

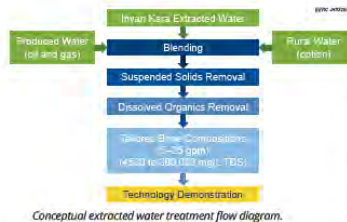
WE SEEK TO PILOT-TEST TECHNOLOGIES CAPABLE OF TREATING HIGH-TDS WATER.

TREATMENT AND HANDLING of high-TDS (total dissolved solids) waters associated with energy production are challenging and not readily or economically accomplished using conventional water treatment techniques. Geologic injection is often required to effectively manage fluids associated with electrical power generation, oil and gas production, and active reservoir management for geologic CO₂ storage.

- As part of a public-private collaboration, a facility is being constructed in western North Dakota to pilot-test high-TDS water treatment technologies that can:
- Produce alternate sources of water for industrial or domestic use.
 - Produce salable products.
 - Meaningfully reduce brine disposal volumes.

Pilot testing provides critical understanding of technology performance under field operating conditions. This understanding enables the advancement and commercial adoption of viable technologies capable of treating these challenging waters for beneficial use.

The Energy & Environmental Research Center (EERC) is seeking companies interested in pilot-testing water treatment technologies at the facility. This is a collaborative effort with Nuvera Environmental Solutions (Nuvera) and the U.S. Department of Energy (DOE) National Energy Technology Laboratory.



If you are interested in demonstrating a brine treatment test bed facility, please contact:

DAN STEPHAN
Senior Engineer, Water and Wastewater Treatment
701.777.5347
dstepan@underc.org

JOHN HARLBY
Principal Materials Scientist
701.777.5159
jharlby@underc.org

The Energy & Environmental Research Center (EERC) and Nuvera Environmental Solutions (Nuvera) have partnered on a multi-year project to demonstrate new strategies and methods of injection well operation. These strategies could reduce the number of injection wells needed for fluid disposal and increase availability of water for beneficial use.



WHERE IS THE PROJECT HAPPENING?

The project will be conducted at the Nuvera-operated Johnsons Corner site, which was established in 2008 as a commercial saltwater disposal (SWD) facility. Nuvera operates two existing saltwater injection wells at its facility. These wells, regulated by the North Dakota Industrial Commission, inject into the thick Iyuan Kara sandstone at a depth of 5400 ft. Although most project activity will be conducted exclusively at the Nuvera site, some nonintrusive monitoring activities, such as the layout and retrieval of a surface monitoring array, would require temporary (a few weeks) access to surrounding private land. This monitoring survey is necessary to gather performance data from the injection zone. The monitoring activity will occur twice during the project. We will be contacting individual landowners to discuss our request for access.



Site map showing proposed site layout.

WHEN WILL THE PROJECT OCCUR?

The project is anticipated to last 4 years (July 2016 - July 2020), with field activities at the site planned between March 2017 and June 2020.

WHAT DO WE PLAN TO DO?

The project will include five main activities. First, two new wells will be drilled on the site of Nuvera's existing SWD operation: one extractor well into the Iyuan Kara Formation and one injection well into the Broom Creek Formation. Second, subsurface monitoring instruments will be installed in all four wells. Third, shallow probes and other monitoring equipment will be installed to monitor the project site. Fourth, a low-impact (small equipment and minimal intrusion

for landowners) survey will be conducted to map the injection formation. Fifth, a brine treatment facility will be built to test emerging water treatment technologies.

The test bed will feature the ability to blend extracted and produced waters to generate tailored brine compositions, ranging from ~50,000 to ~200,000 mg/L TDS. EERC engineering staff will be on-site during all demonstration activities to assist with connections to the test bed facility, monitor individual tests, and gather process performance data. During steady-state operation, EERC engineering staff will conduct energy and material balances (power consumption, process flows, effluents, and effluent quality analysis).

EERC engineering staff will be on-site during all demonstration activities to assist with connections to the test bed facility, monitor individual tests, and gather process performance data. During steady-state operation, EERC engineering staff will conduct energy and material balances (power consumption, process flows, effluents, and effluent quality analysis).

A report summarizing demonstration performance data and technology will be submitted to DOE. Nonfunded agreements between the EERC, Nuvera, and DOE will be negotiated prior to the start of the project. Currently, no guarantee is offered that the technology will be available to assist interested treatment technology developers. However, the field site and facilities for water treatment demonstrations, including potential cost offsets for power, cooling water, and effluent disposal, may be made available at no or reduced cost to selected demonstrators.

SITE TOUR - IEAGHG RISK AND MODELING NETWORK MEETING





THANK YOU!

CONTACT INFORMATION

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org
701.777.5472 (phone)
701.777.5181 (fax)

John A. Hamling
Assistant Director for Integrated Projects
jhamling@undeerc.org



APPENDIX

SUPPLEMENTAL SLIDES

TECHNICAL STATUS

Phase I – Complete

- Regional characterization
- Site screening and feasibility study
- Site selection
- Geologic modeling
- Reservoir simulation resulting in ARM schema
- Site infrastructure design and field implementation plan

Phase II – Under Way

- ARM site preparation
 - Permitting
 - Well drilling
 - Surface infrastructure installation
 - Site characterization/model updates
- Test site preparation
 - Permitting
 - Test bed facility installation
 - Solicitation of treatment technologies
- ARM operations
 - Injection/extraction testing
 - Monitoring, verification, and accounting (MVA) implementation
 - Model updates/history matching

- Test bed treatment operations
 - Facility shakedown/training
 - Long-term performance evaluations
- ARM site closeout
 - ARM site decommissioning
 - Finalization of ARM test results/data
- Brine treatment test bed site closeout
 - Treatment test bed decommissioning
 - Finalization of test bed results/data

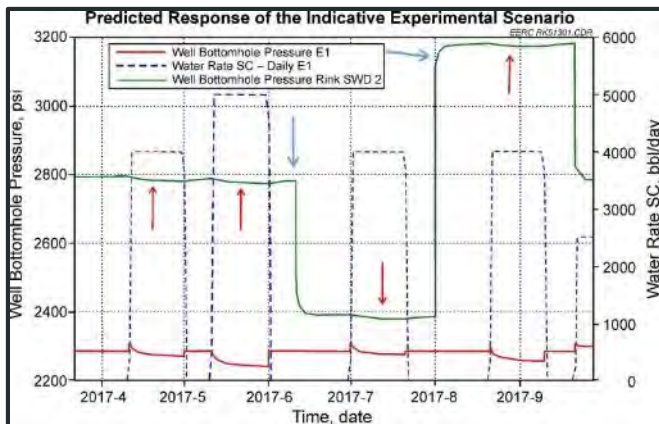
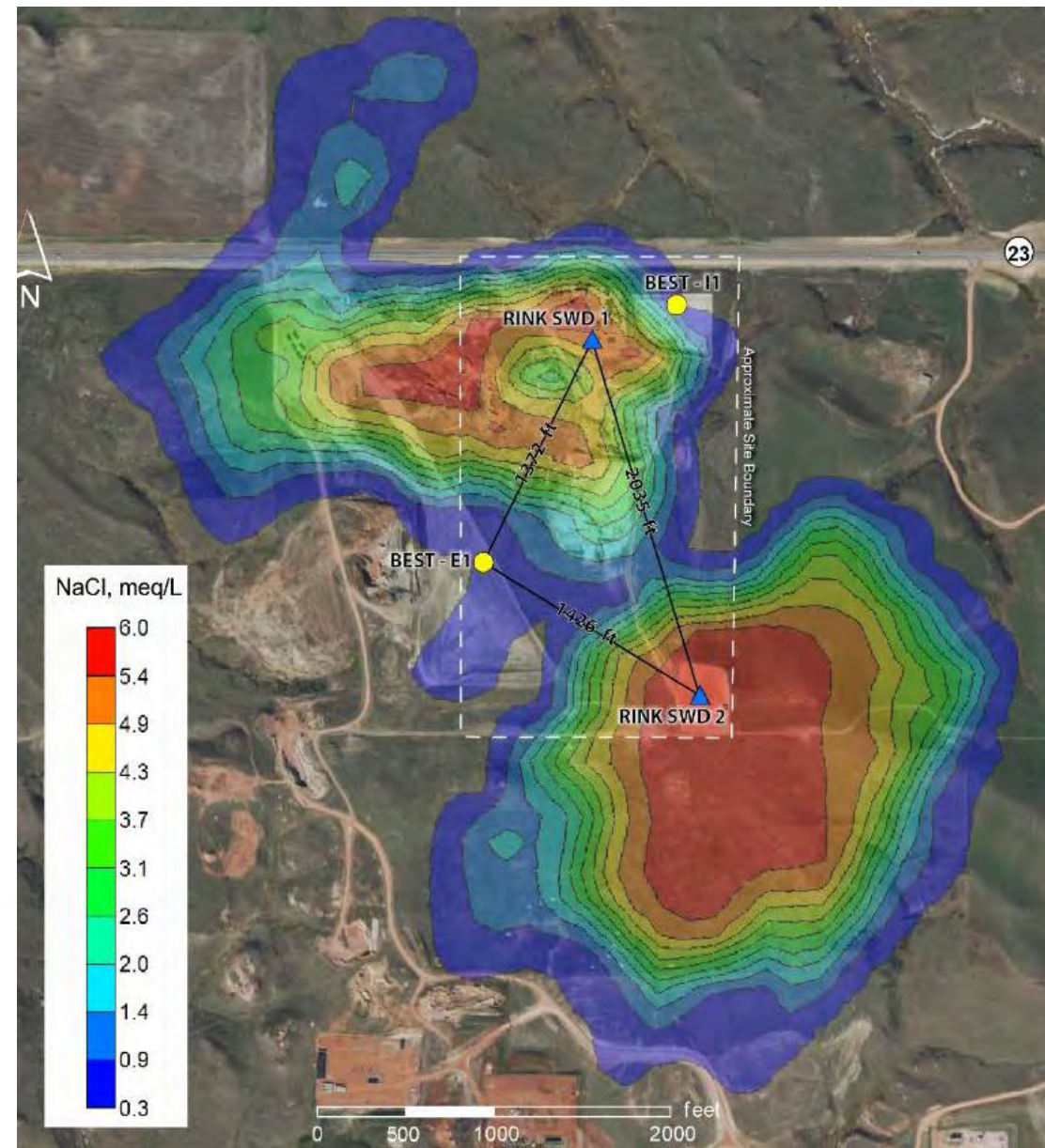
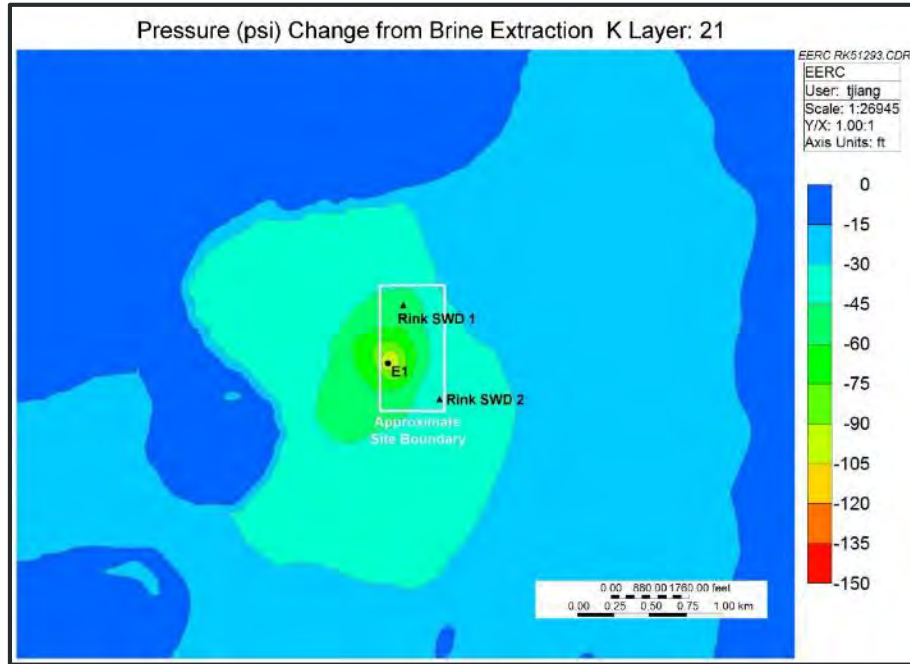
BRINE EXTRACTION FOR PRESSURE MANAGEMENT

- Incremental cost
 - Wells and infrastructure
 - Operating and energy
- Disposal of extracted brine
 - Treatment and discharge
 - Reinjecting into a different suitable geologic formation
- Efficiency losses
 - $bbl_{out} > \text{incremental } bbl_{in}$
- Complicates project
- Additional health, safety, and environmental risk

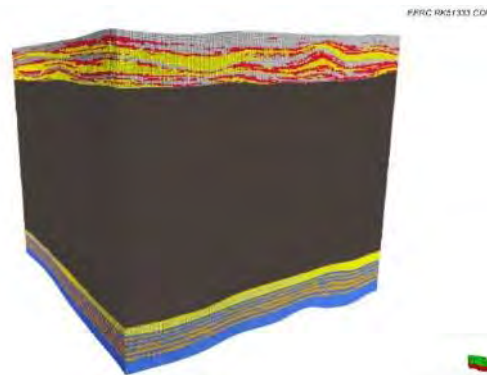


Brine extraction can enable dedicated CO₂ storage and improve the geologic CO₂ storage potential of a site.

THE DESIGN (BALANCE)



- Facies
- Inyan Kara Sand
 - Inyan Kara Silty Sand
 - Inyan Kara Shale
 - Interburden
 - Bloom Creek Sand
 - Bloom Creek Shale
 - Araden Reservoir
 - Araden Nonreservoir



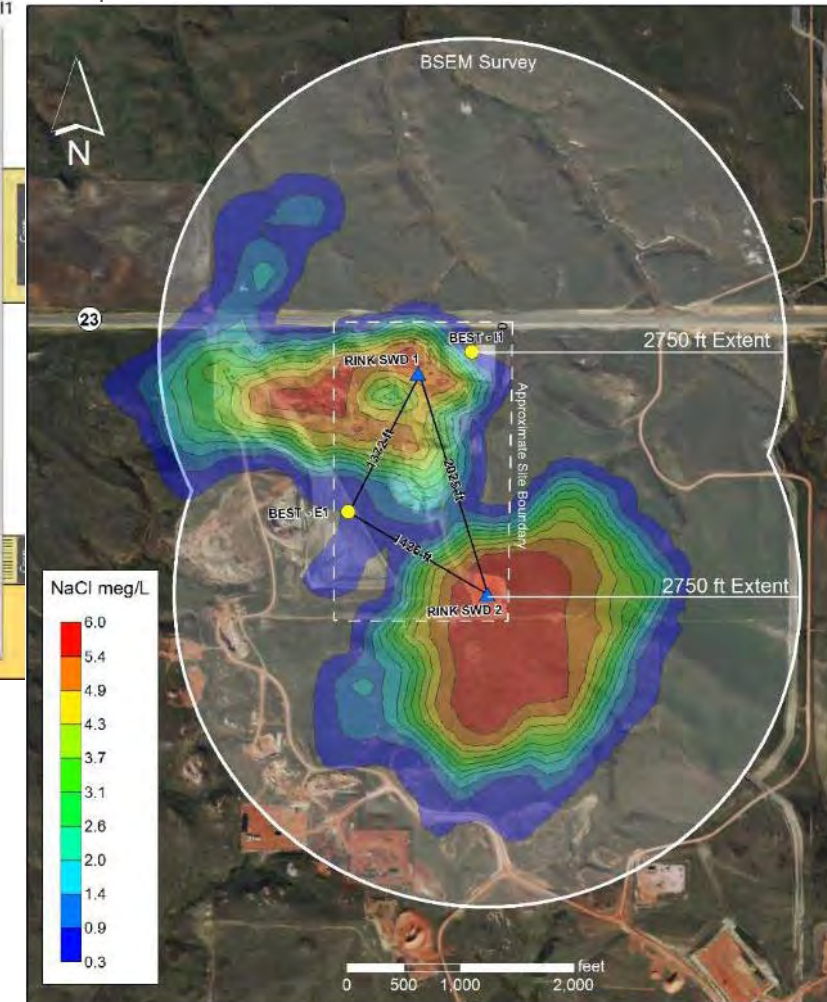
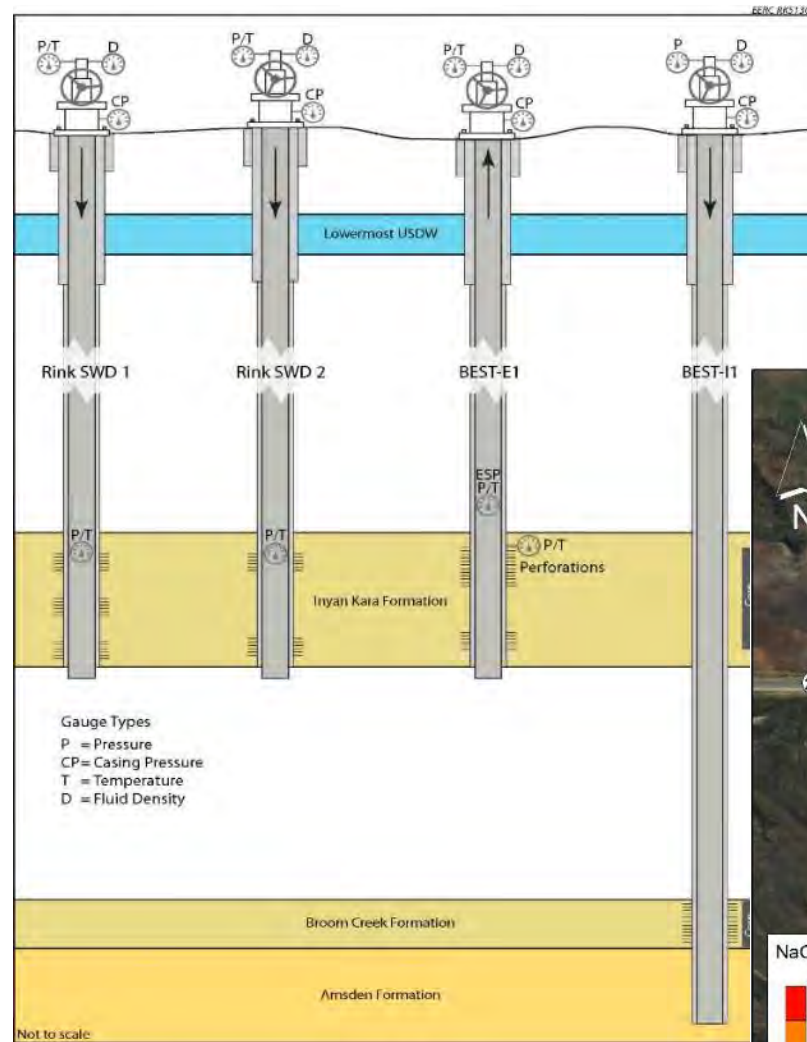
MVA PROGRAM

Reservoir Surveillance

- Well evaluation
 - Logging, coring, testing
- Borehole to surface electromagnetic (BSEM)
- Active reservoir surveillance
 - Pressure, temperature, flow rates, fluid density
- Tracer survey
- Fluid sampling

Safety and Performance

- Tank and pipeline monitoring and response plans
- Dual containment pipeline
- Flow and density meters
- Power and chemicals
- Pipeline monitoring
- High-level/low-level shutdown
- Remote sensing



REGIONAL CHALLENGES: EXTRACTED WATER TREATMENT

Technological:

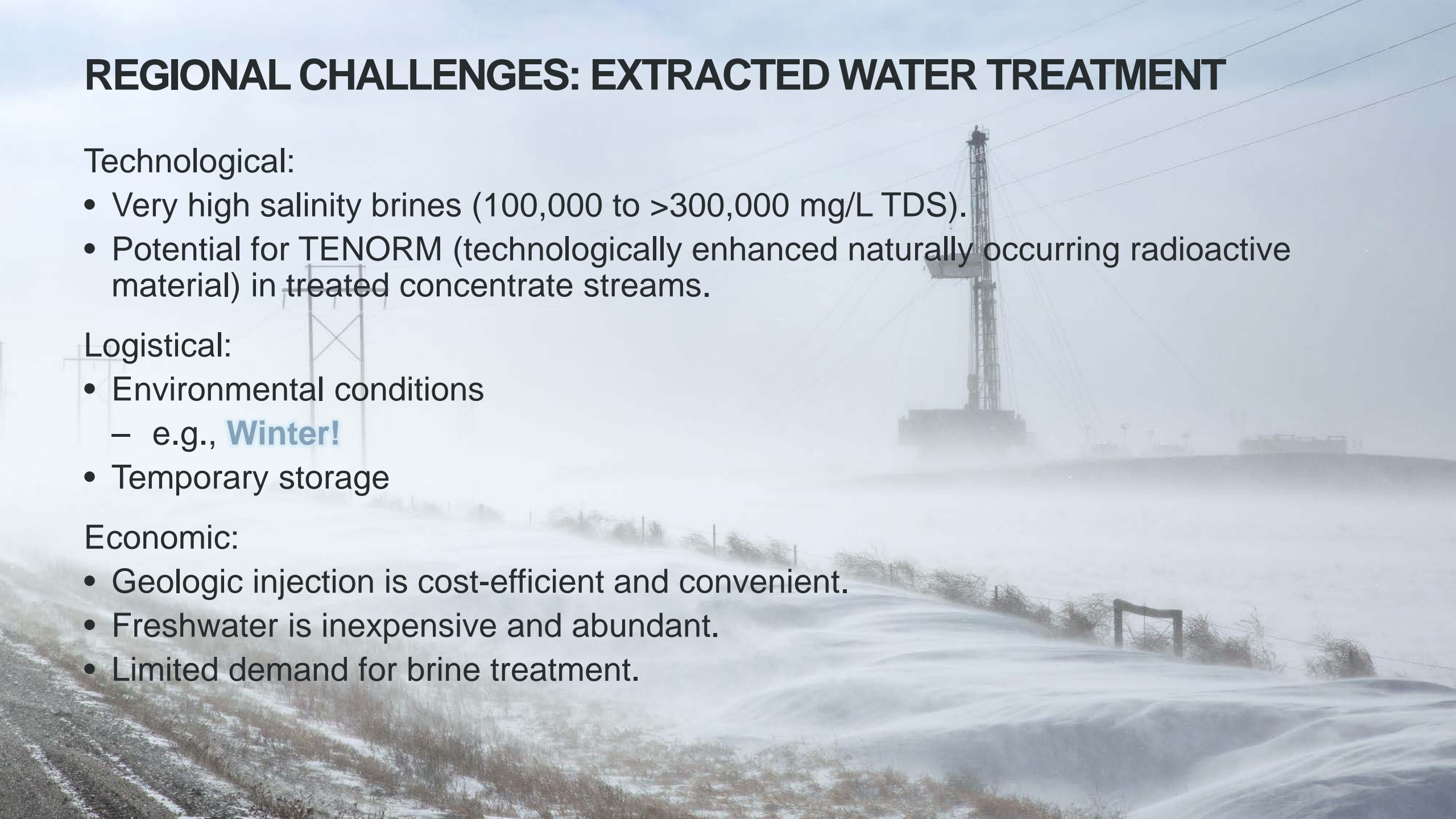
- Very high salinity brines (100,000 to >300,000 mg/L TDS).
- Potential for TENORM (technologically enhanced naturally occurring radioactive material) in treated concentrate streams.

Logistical:

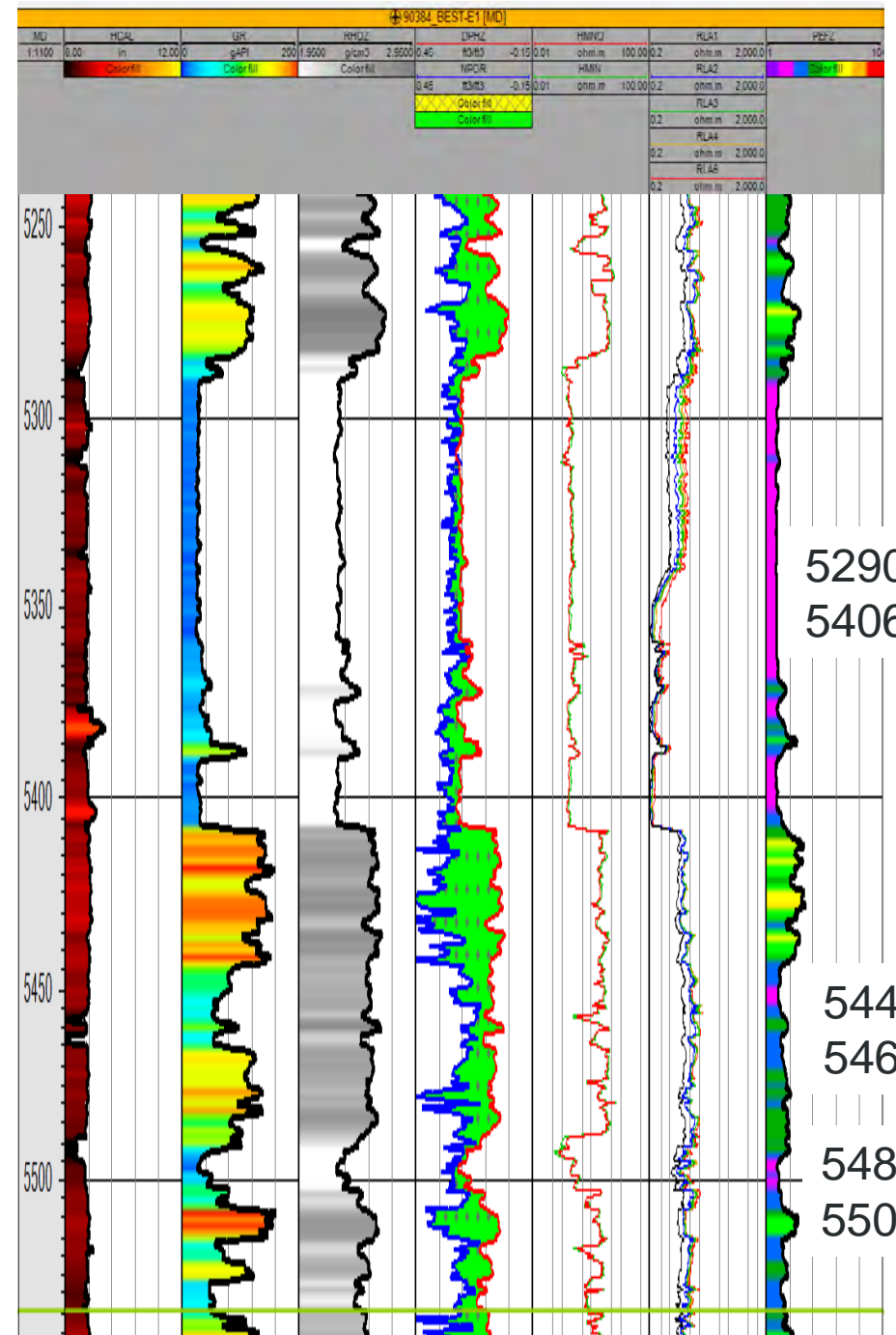
- Environmental conditions
 - e.g., **Winter!**
- Temporary storage

Economic:

- Geologic injection is cost-efficient and convenient.
- Freshwater is inexpensive and abundant.
- Limited demand for brine treatment.



BEST-E1



DRILLING PICTURES



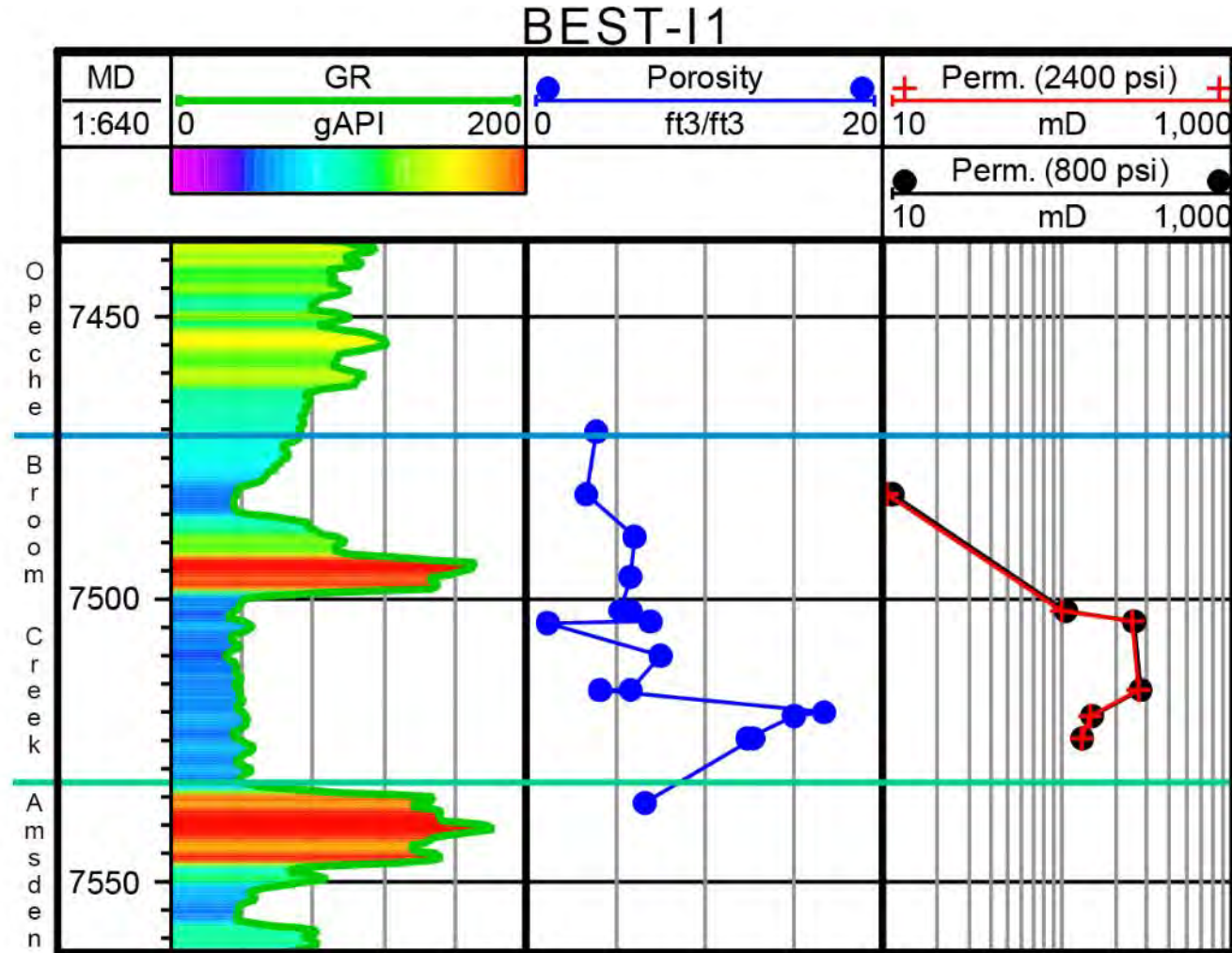




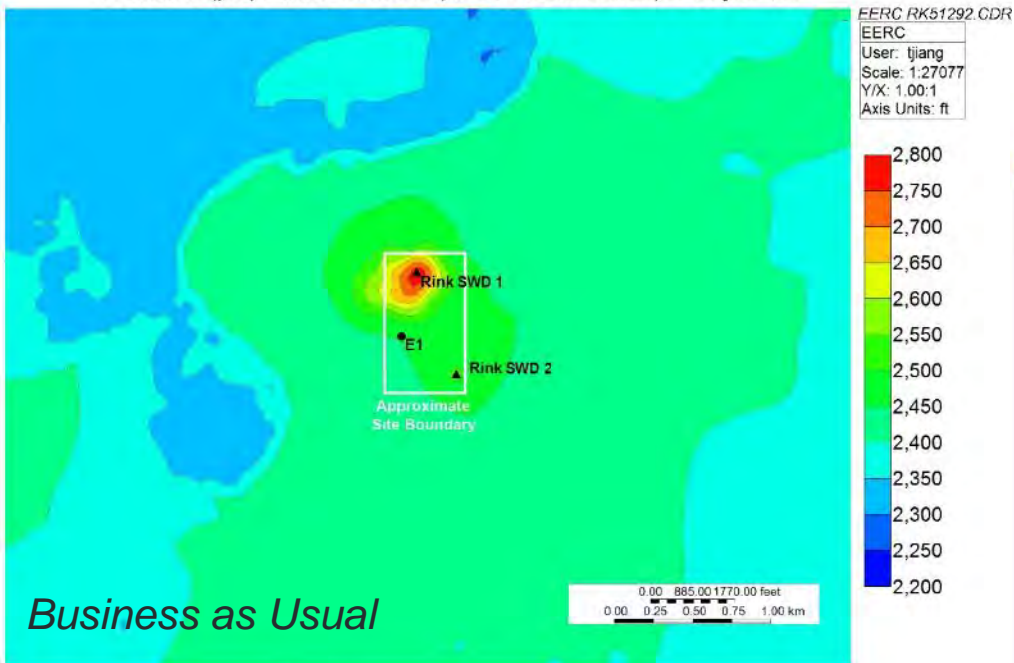




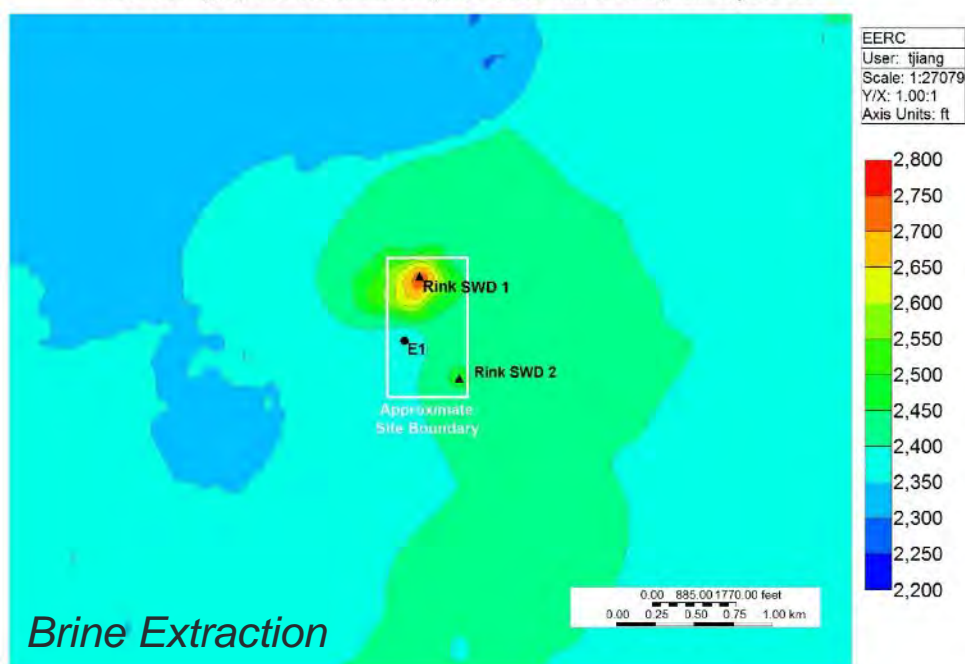
BROOM CREEK CORE TESTS



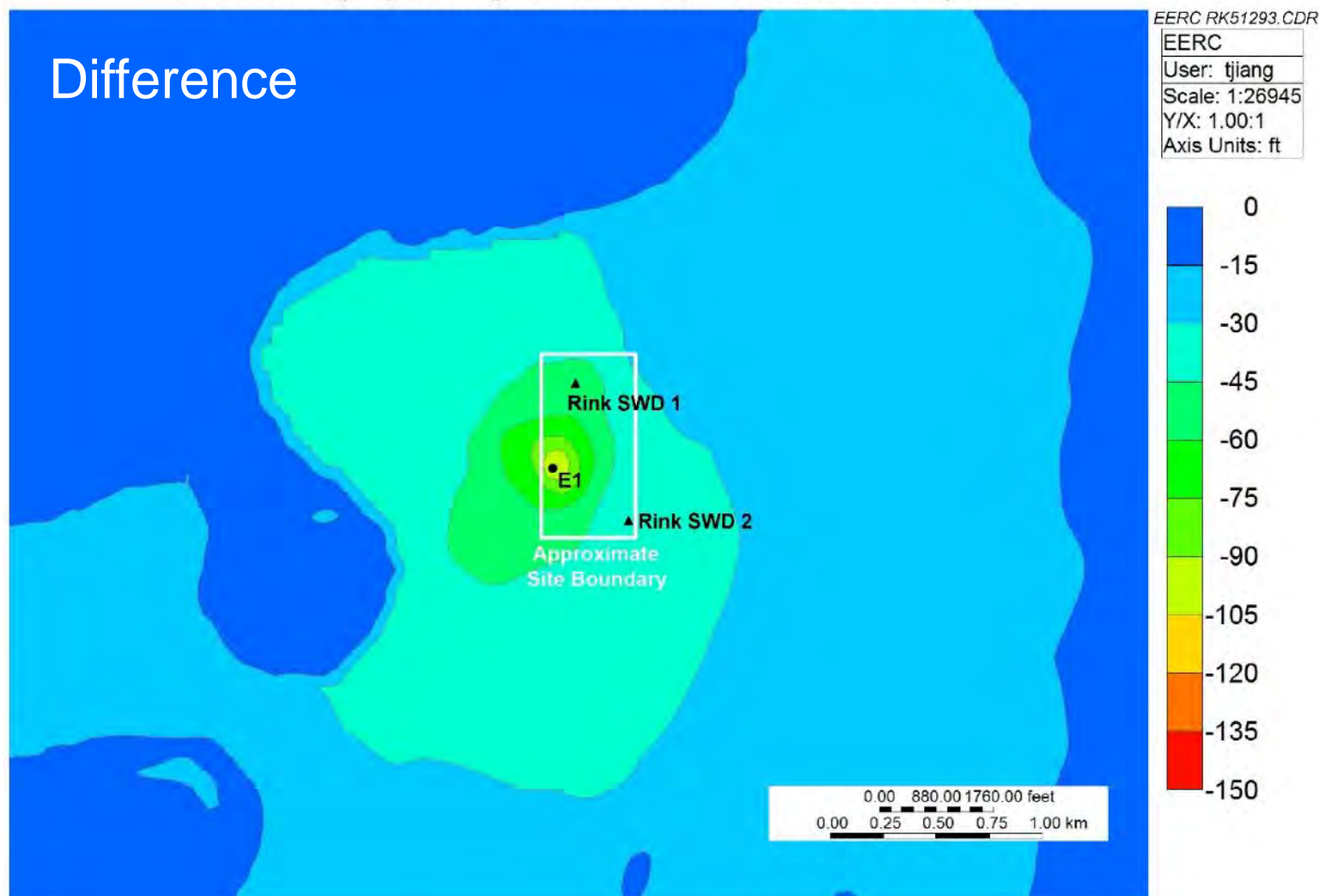
Pressure (psi) Plume at 2020 (no brine extraction) K Layer: 21



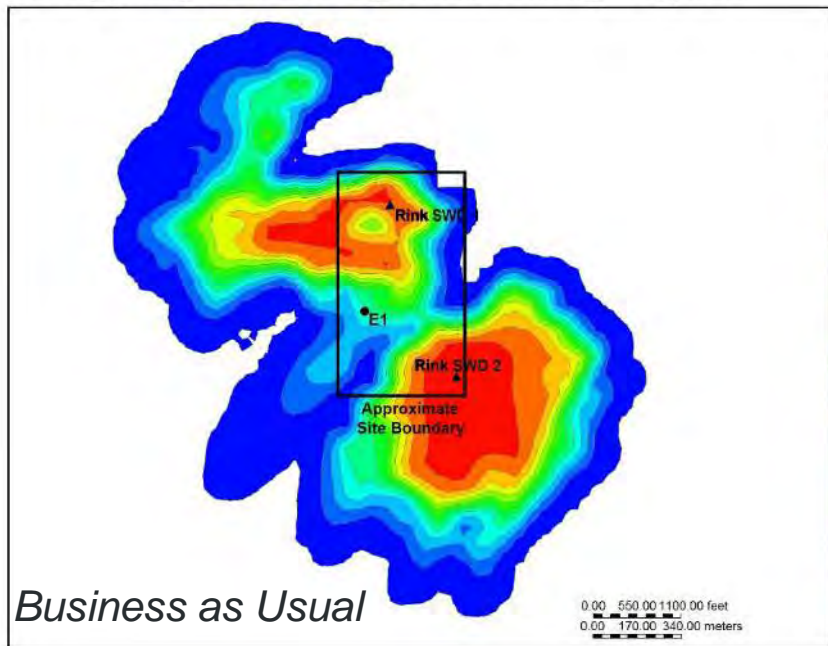
Pressure (psi) Plume at 2020 (with brine extraction) K Layer: 21



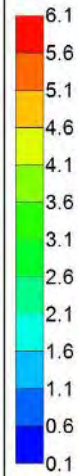
Pressure (psi) Change from Brine Extraction K Layer: 21



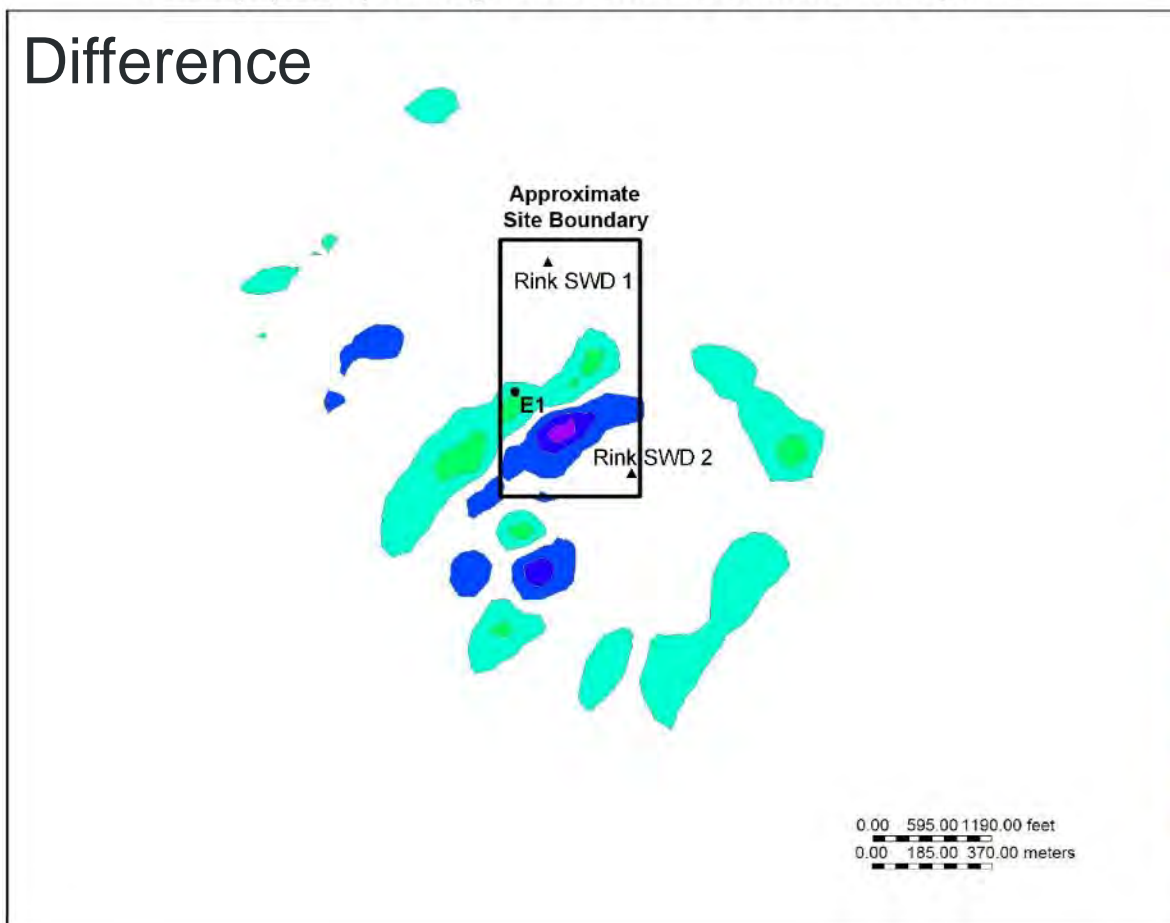
Salinity (molar) Plume at 2020 (no brine extraction) K Layer: 21



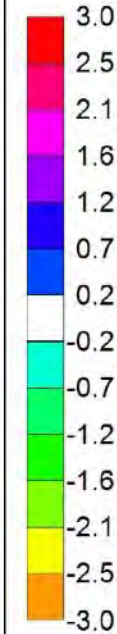
EERC RK51294.C
EERC
User: tjiang
Scale: 1:16859
Y/X: 1.00:1
Axis Units: ft



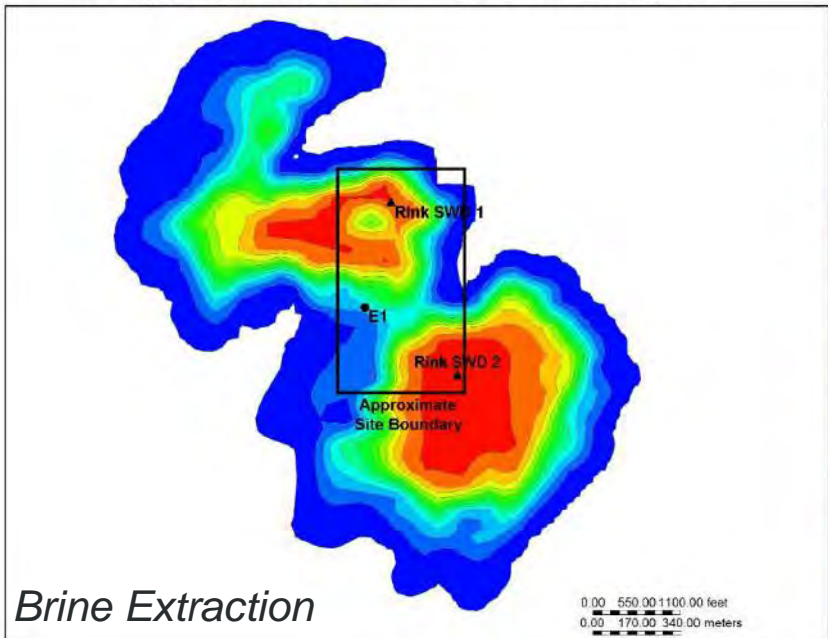
Salinity (molar) Change from Brine Extraction K Layer: 21



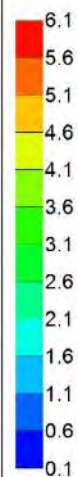
EERC RK51296.CDR
EERC
User: tjiang
Scale: 1:18163
Y/X: 1.00:1
Axis Units: ft



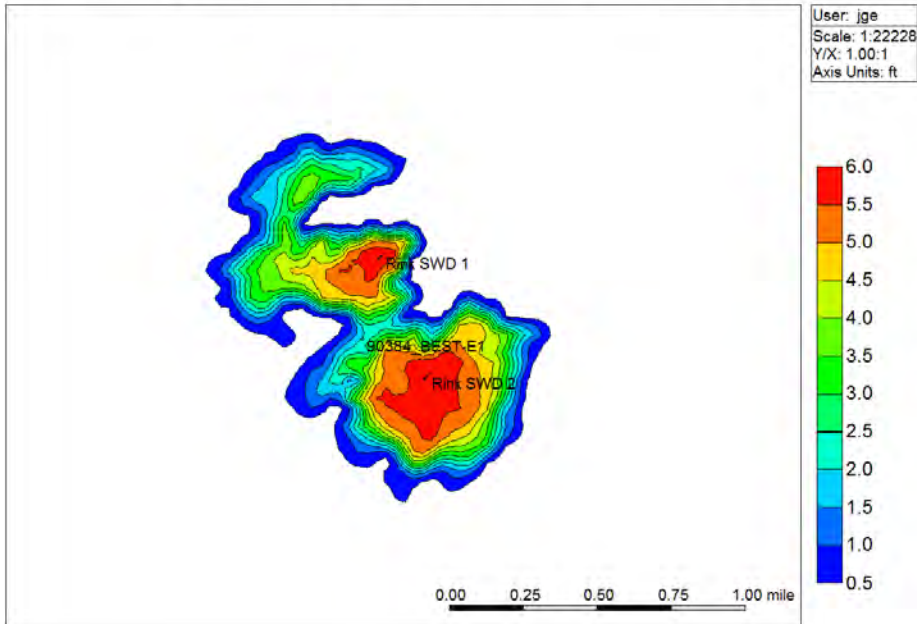
Salinity (molar) Plume after Brine Extraction K Layer: 21



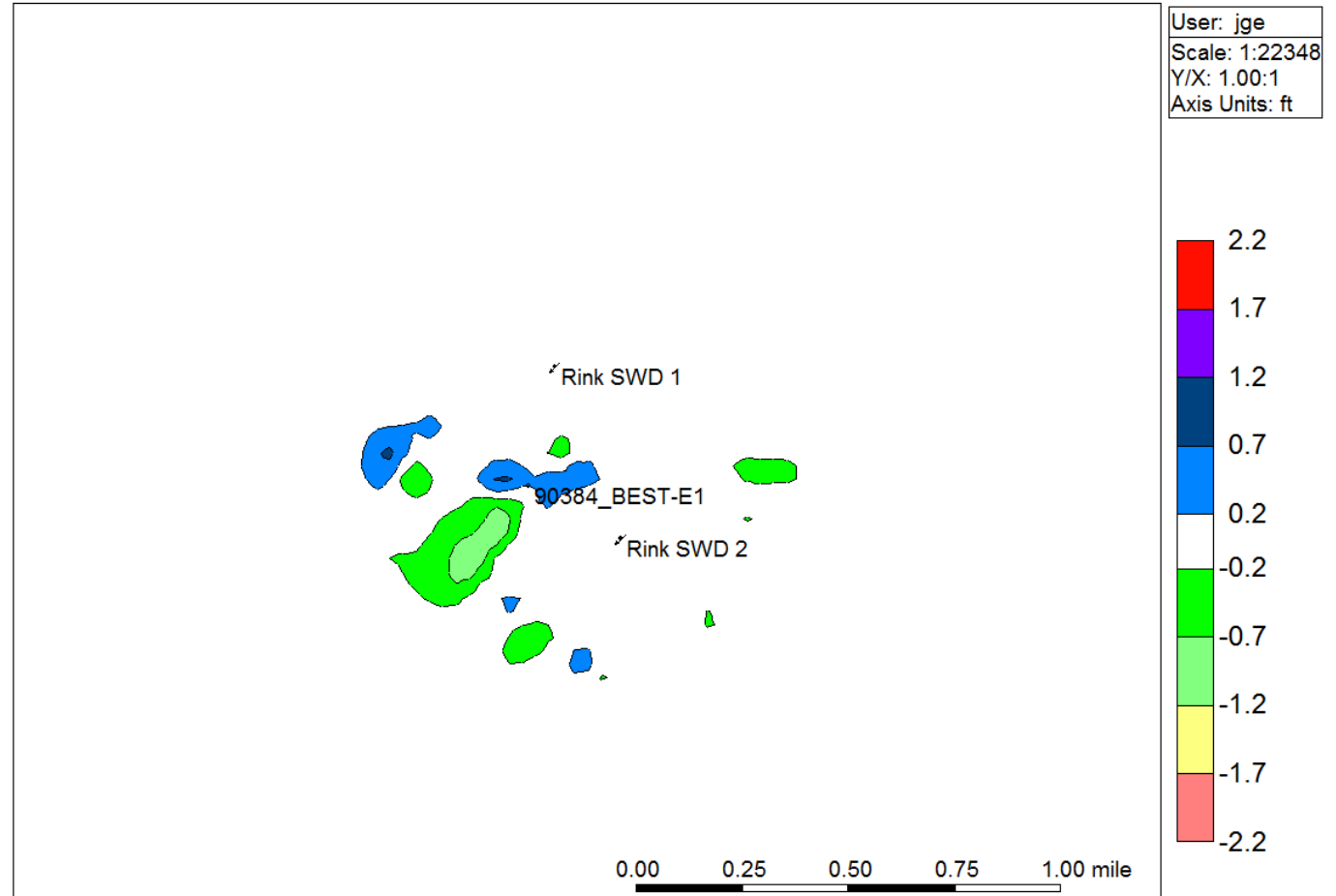
EERC
User: tjiang
Scale: 1:16858
Y/X: 1.00:1
Axis Units: ft



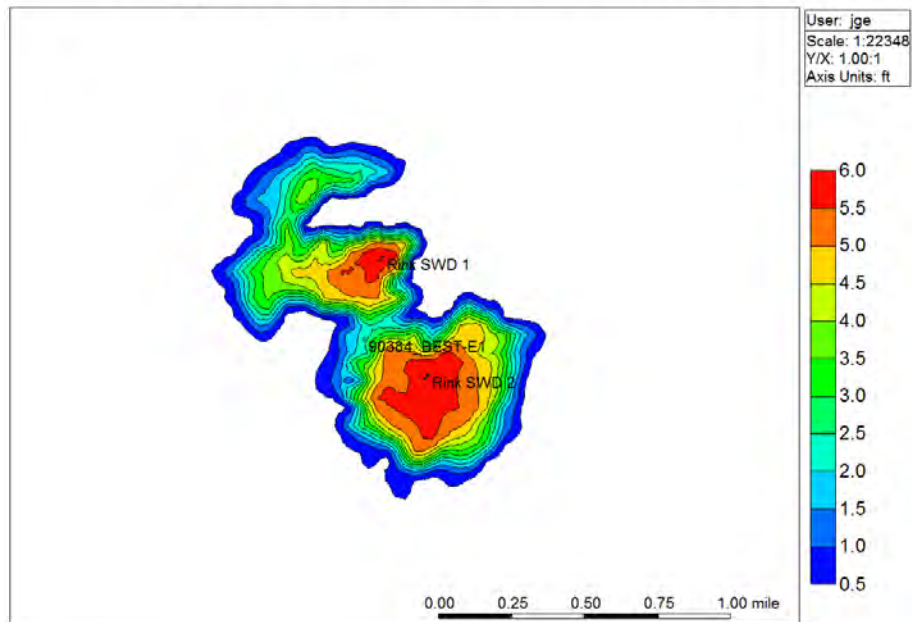
Salinity (molar) Plume without Brine Extraction 2020-08-01 K layer: 21



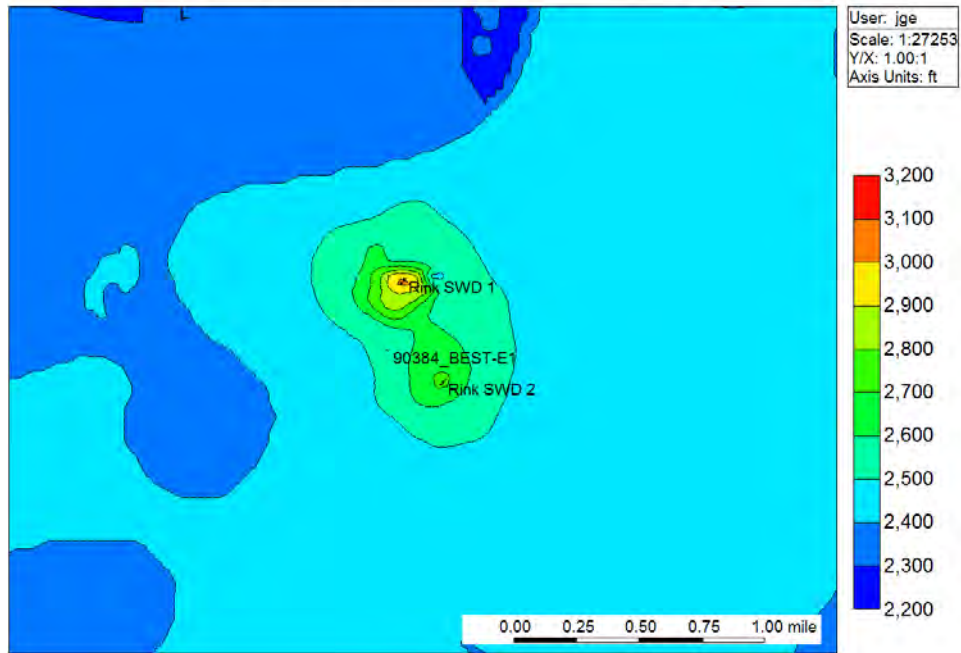
Salinity (molar) Change from Brine Extraction 2020-08-01 K layer: 21



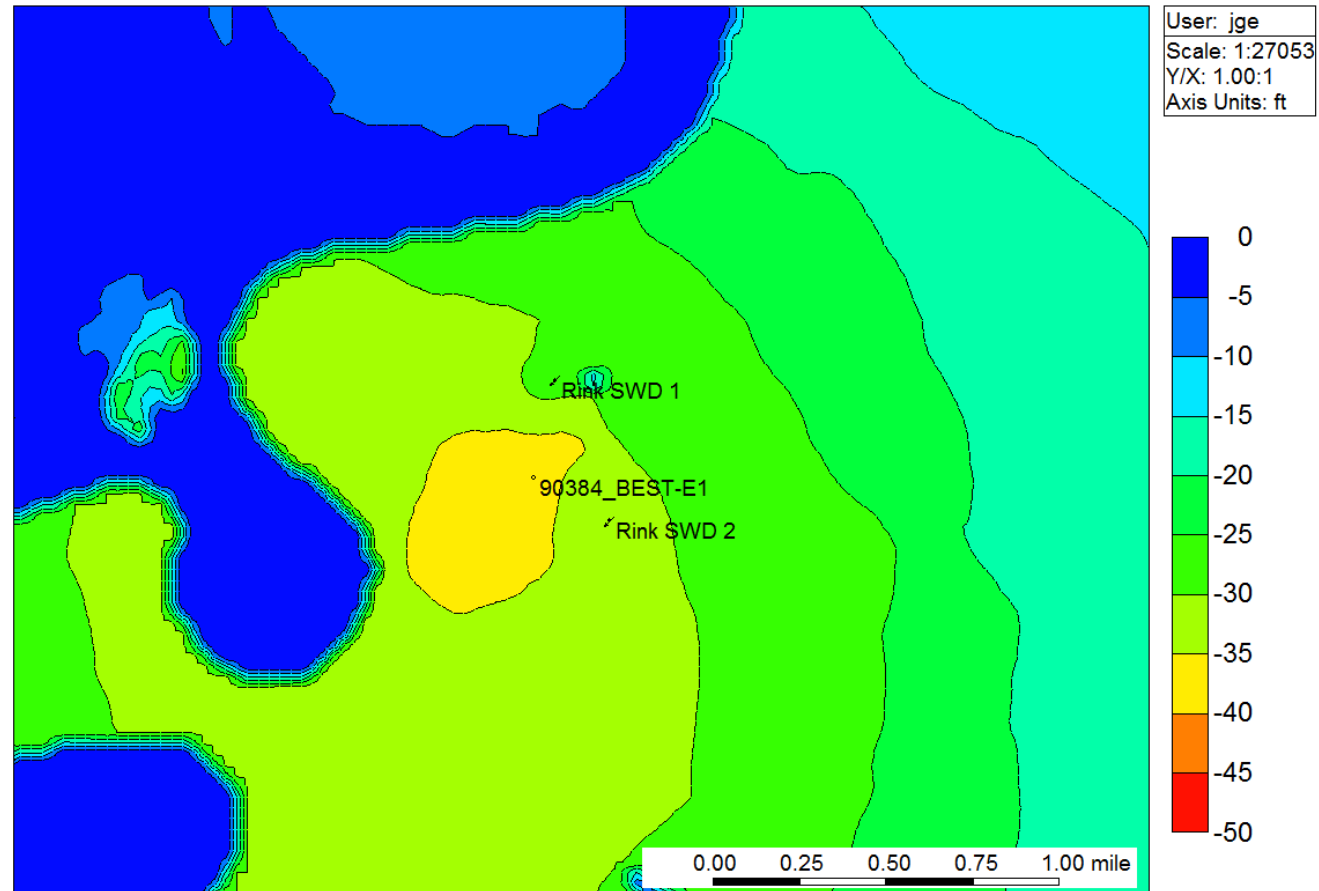
Salinity (molar) Plume with Brine Extraction 2020-08-01 K layer: 21



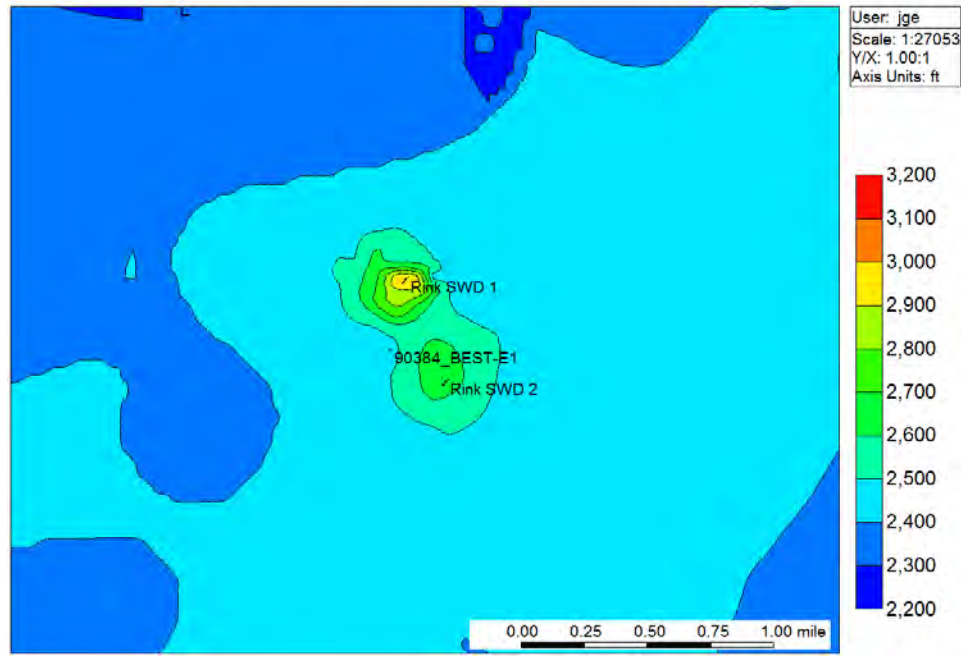
Pressure (psi) Plume without Brine Extraction 2020-08-01 K layer: 21



Pressure (psi) Change from Brine Extraction 2020-08-01 K layer: 21



Pressure (psi) Plume with Brine Extraction 2020-08-01 K layer: 21



TREATMENT TECHNOLOGY SELECTION PROTOCOL

- Screening criteria
 - Ability to produce a beneficial use effluent or product at reasonable operating costs based on target influent water quality
 - Enable successful operation of other technologies (i.e., pretreatment)
 - Provide a relatively high yield of treated water or product
 - Significantly reduce the volume of fluids requiring disposal
 - Not produce hazardous by-products
- Ranking factors
 - Treatment costs (40%)
 - Readiness level (30%)
 - Safety considerations (20%)
 - Waste generation (10%)



SOLICITING BRINE TREATMENT TECHNOLOGIES

- NETL, EPRI, and the EERC are coordinating efforts to define water treatment goals and solicit technologies for pilot testing.
 - Cooperatively developed vendor questionnaire and selection criteria
- The North Dakota and Florida facilities will provide unique water treatment scenarios but will have similar operational capabilities.
- North Dakota test bed is anticipated to be operational by fall 2018.
- Site access agreements will be negotiated between host site operator, EERC, and brine treatment technology provider.
- Knowledge-sharing workshop tentatively scheduled for fall 2018.

WILLISTON BASIN WATER TREATMENT TECHNOLOGY TEST BED



WE SEEK TO PILOT-TEST TECHNOLOGIES CAPABLE OF TREATING HIGH-TDS WATER.

TREATMENT AND HANDLING of high-TDS (total dissolved solids) waters associated with energy production are challenging and not readily or economically accomplished using conventional water treatment techniques. Geologic injection is often required to effectively manage fluids associated with electrical power generation, oil and gas production, and active reservoir management for geologic CO₂ storage.

As part of a public-private collaboration, a facility is being constructed in western North Dakota to pilot-test high-TDS water treatment technologies that can:

- Produce alternate sources of water for industrial or domestic use.
- Produce salable products.
- Meaningfully reduce brine disposal volumes.

Pilot testing provides critical understanding of technology performance under field operating conditions. This understanding enables the advancement and commercial adoption of viable technologies capable of treating these challenging waters for beneficial use.

The Energy & Environmental Research Center (EERC) is seeking companies interested in pilot-testing water treatment technologies at the facility. This is a collaborative effort with Nuverra Environmental Solutions (Nuverra) and the U.S. Department of Energy (DOE) National Energy Technology Laboratory.



The extracted water treatment test bed facility is located approximately 13 miles east of Watford City, North Dakota, immediately adjacent to North Dakota Highway 23 on the Johnsons Corner site, a Nuverra-operated commercial saltwater disposal (SWD) facility.

The test bed will feature the ability to blend extracted and produced waters in order to generate tailored brine compositions ranging from ~4500 to ~300,000 mg/L TDS. The facility is anticipated to be operational by summer 2018.

EERC engineering staff will be on-site during all demonstration activities to assist with connections to the test bed facility and to monitor and gather process performance data. Technology developers are expected to provide their own operations staff. During steady-state operation, EERC engineering staff will conduct energy and material balances (power consumption, process flows, and influent and effluent quality analyses).

A report summarizing demonstration activities and detailing performance data and technology capabilities will be prepared and submitted to DOE. Nondisclosure and site access agreements between the EERC, Nuverra, and technology developers will be negotiated prior to demonstration.

Currently, no guarantee is offered that DOE or other funding will be available to assist interested treatment technology developers. However, the field site and facilities for water treatment demonstrations, including potential cost offsets for power, cooling water, and effluent disposal, may be made available at no or reduced cost to selected demonstrations.



Conceptual extracted water treatment flow diagram.

EMERGING BRINE TREATMENT TECHNOLOGIES

- Treatment technologies for high-salinity brines continue to evolve, but few have been tested at the commercial scale.
- Most technologies fall into several main categories:
 - Evaporation/distillation (mechanical vapor recompression)
 - Evaporation/crystallization (low- pressure, low-temperature evaporation)
 - Membrane treatment (reverse osmosis, forward osmosis, membrane distillation)
 - Freezing-based treatment



BRINE TREATMENT TEST BED OPERATIONS

- Shakedown testing of all pretreatment equipment prior to pilot tests.
- Selected technologies connected to the test bed facility – electric, propane, cooling water (EERC assistance to ensure safety requirements are satisfied).
- Technology vendors to provide operations staff, with assistance by EERC staff.
- During steady-state operation, EERC staff will conduct energy and material balances (power consumption, process flows, influent and effluent quality analyses).
- Extended operating periods (60+ days) to identify maintenance requirements and any operational issues.
- Operations will be scheduled to coincide with preferable operational windows (weather, ARM test program, etc.) where possible.

Top-ranked technologies may receive operating cost offsets.

OPERATIONS

- Shakedown testing of all pretreatment equipment prior to pilot tests.
- Selection and scheduling of treatment technology, negotiate site access agreements.
- Mobilize technology demonstration to site.
- Treatment technology connected to the test bed facility – electric, propane, cooling water, influent/effluent water, etc.
 - EERC assistance to ensure health, safety, environmental and operability.
- Treatment technology demonstration providers will operate their treatment equipment; the EERC will operate the treatment test bed facility in coordination with the treatment technology demonstrator.
- During steady-state operation, EERC staff will conduct energy and material balances (power consumption, process flows, influent and effluent quality analyses).
- Extended operating periods (60+ days) to identify maintenance requirements and any operational issues.
- Operations will be preferentially scheduled to coincide with optimal operational windows (weather, ARM test program, etc.) when possible.
- Effluent and treated water will be blended and reinjected where possible; waste streams unable to be reinjected will be disposed of at an authorized facility.

Top-ranked technologies may benefit from cost offsets.

BRINE TREATMENT TEST BED – POTENTIAL SYNERGY

- Technology providers are indicating limited resources and incentives for technology development and for CCUS and oil and gas brine treatment demonstrations.
- Facility could be readily adapted for use with alternate fluid compositions or treatment processes.
 - Alternate water sources trucked and offloaded at site
 - Blending of alternate fluid chemistries for demonstration of water or chemical treatment processes
 - Test beds for other fluid conditioning or treatment processes
- Flexibility of the system makes it ideal for demonstrating a wide variety of technologies.
 - Oil and gas fluid conditioning (e.g., emulsion breaking, corrosion, scale inhibitors, fluid compatibility testing, etc.) and produced water treatment
 - Electric power generation wastewater treatment
 - Industrial and municipal waste and water treatment
 - Mineral resource recovery
 - Agricultural water treatment
 - Geologic conditioning and homogenization as a means of water pretreatment
 - Synergistic opportunities with other federal, state, or industry groups
 - Benchmarking the economic and technical limits of water treatment technologies (e.g., MVR)



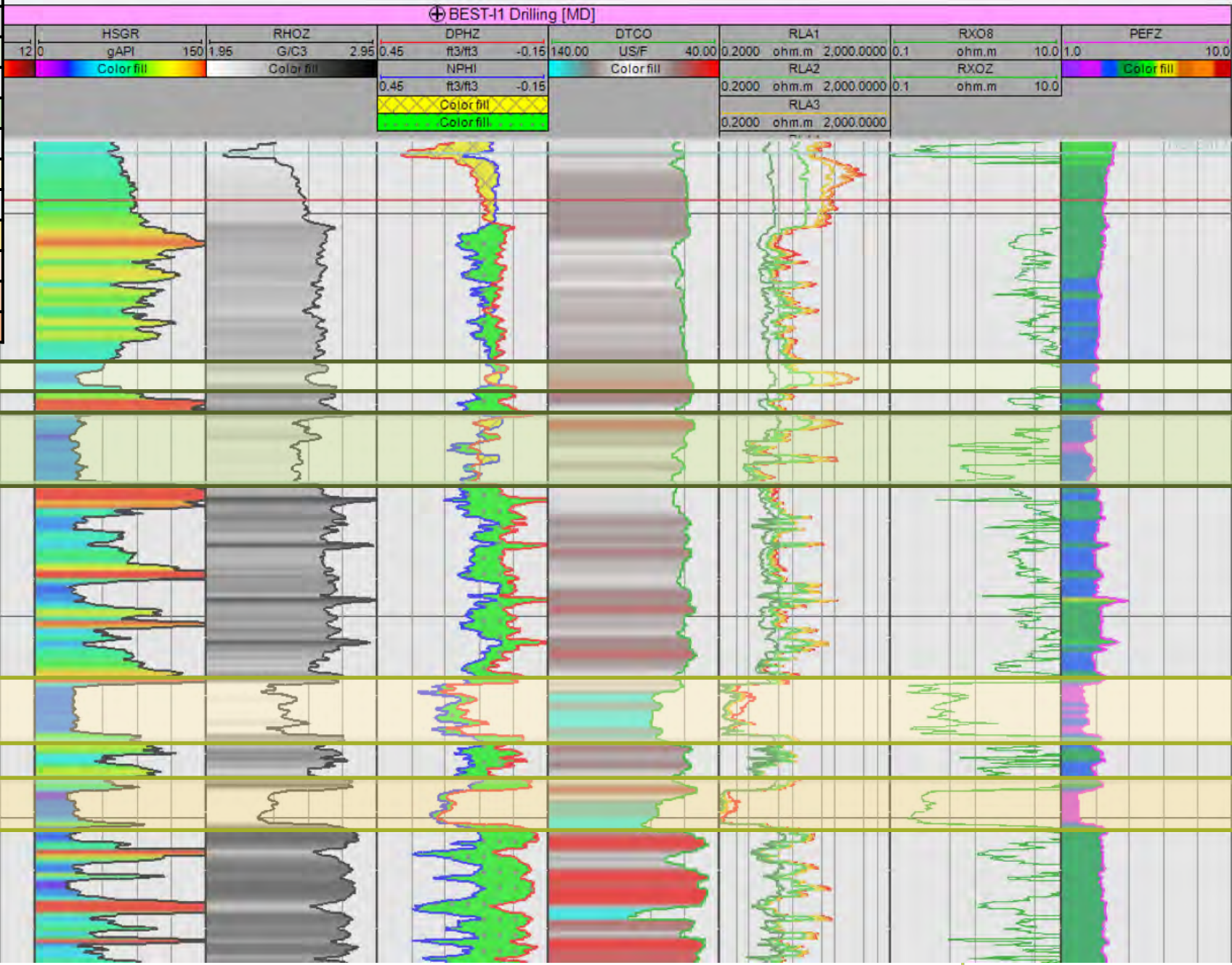
PROJECT SUMMARY

- The EERC is finalizing construction of all infrastructure for the BEST program.
 - Wells drilled, pipeline installed, electrical service installed, test bed building constructed.
 - ◆ Complete wells and initiate MVA program
 - ◆ Pretreatment system being assembled; building is being outfitted.
 - ◆ Plumbing of ARM and treatment systems.
 - ARM infrastructure and treatment technology test bed are anticipated to be fully operational by fall 2018.
 - Continue engagement with technology providers.



BEST-I1 Recommended Completion Intervals

BEST-I1 Completion			
Interval	Top Depth (ft)	Bottom Depth (ft)	Thickness (ft)
Upper Broom Creek	7478	7487	9
Interburden	7487	7499	12
Lower Broom Creek	7499	7534	35
Interburden	7534	7633	99
Amsden 1	7633	7659	26
Interburden	7659	7686	27
Amsden 2	7686	7703	17
Gross Thickness (All Units)			225
Net Thickness (Broom Creek Sands Only)			44
Net Thickness (Broom Creek + Amsden Sands)			87



APPENDIX REQUESTED SLIDES

PRESENTATION OUTLINE

- Technical Status
 - Overview
 - Active Reservoir Management (ARM) Installations
 - Brine Treatment Test Bed Installations
- Major Accomplishments
- Future Activities
- Lessons Learned
- Synergistic Opportunities
- Summary

BENEFIT TO THE PROGRAM

This project is expected to result in the development of engineering strategies/approaches to quantitatively affect changes in differential formation pressure and to monitor, predict, and manage differential pressure plume movement in the subsurface for future CO₂ saline storage projects. Additionally, the brine treatment technology evaluation is expected to provide valuable information on the ability to produce water for beneficial use. The results derived from implementation of the project will provide a significant contribution to the U.S. Department of Energy's (DOE's) Carbon Storage Program goals. Specifically, this project will support **Goals 1 and 2** by validating technologies that will improve reservoir storage efficiency, ensure containment effectiveness, and/or ensure storage permanence by controlling injected fluid plumes in a representative CO₂ storage target. Geologic characterization of the target horizons will provide fundamental data to improve storage coefficients related to the respective depositional environments investigated, directly contributing to **Goal 3**. In addition, this project will support **Goal 4** by producing information that will be useful for inclusion in DOE best practices manuals.

PROJECT OVERVIEW

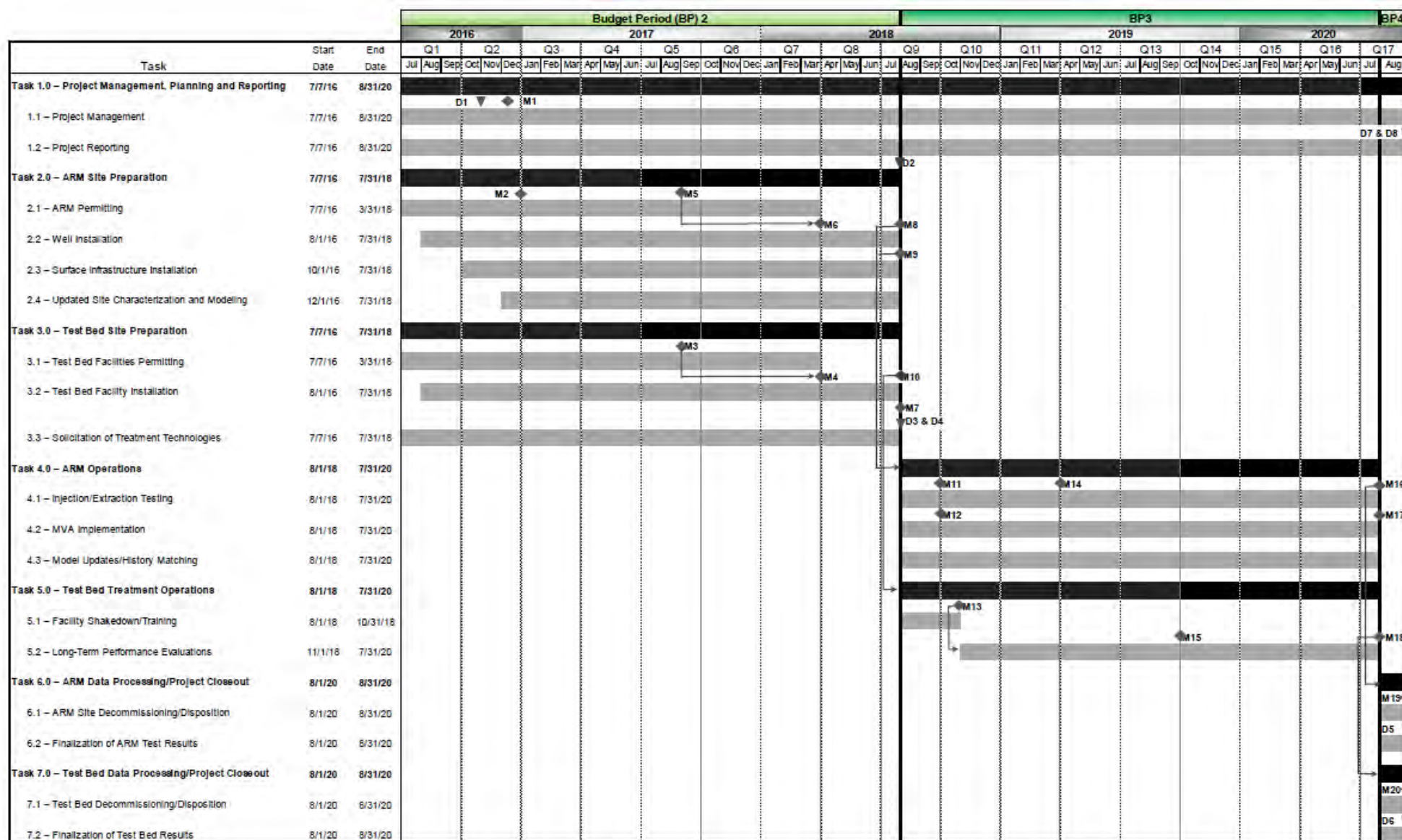
GOALS AND OBJECTIVES

- Confirm efficacy of the ARM approaches developed during Phase I
 - Formation pressure
 - Predicting and monitoring plume movement
 - Validating pressure and brine plume model predictions
- Implement and operate a test bed facility for the evaluation of selected brine treatment technologies applicable to ARM for CCUS

Three development stages over 48 months

1. Site preparation and construction
2. Site operations including ARM and extracted brine treatment technology testing and demonstration
3. Project closeout/decommissioning and data processing/reporting

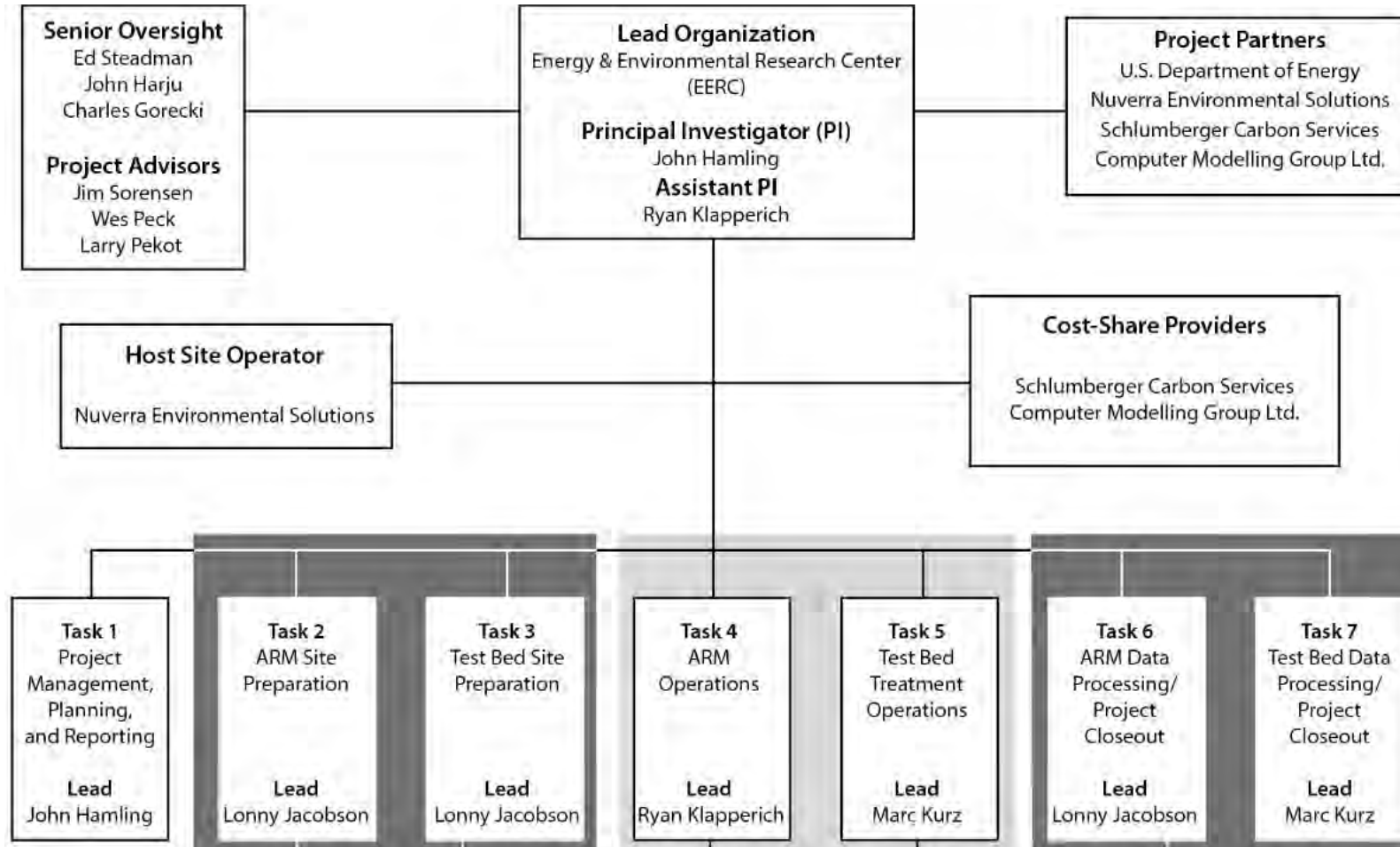
Gantt Chart, Deliverables, and Milestones



Note: The contract modification for Phase II was fully executed on September 9, 2016.

Deliverables ▼	Key for Milestones (M) ◆
D1 – Updated PMP	M1 – Project Kickoff Meeting
D2 – Field Implementation Plan (FIP) Finalized	M2 – Permit to Drill Submitted
D3 – Water Treatment Technology Selection Process Summary	M3 – Water Treatment Test Bed Permit Received
D4 – Preliminary Schedule of Technologies	M4 – Start Water Treatment Facilities Construction
D5 – Vol. 1 – ARM Engineering and Evaluation Summary	M5 – Permit to Drill Received
D6 – Vol. 2 – Technology Evaluation Report	M6 – Start Site Preparation
D7 – Data Submission to EDX	M7 – First Treatment Technology Selected
D8 – Lessons Learned Document	M8 – Well Installation Complete
	M9 – Surface Installation Complete
	M10 – Water Treatment Facilities Complete
	M11 – Initiate Stage 1 of Experimental Scenario
	M12 – Initiate Collection of Operational Data
	M13 – Water Treatment Test Bed Fully Operational
	M14 – Initiate Stage 2 of Experimental Scenario
	M15 – First Treatment Technology Evaluated
	M16 – Completion of ARM Operations
	M17 – Conduct Repeat BSEM Survey
	M18 – Completion of Water Treatment Technology Demonstration
	M19 – ARM Site Decommissioning/Disposition Completed
	M20 – Water Treatment Test Bed Decommissioning/Disposition Completed

ORGANIZATION CHART



BIBLIOGRAPHY

- Ge, J., Pekot, L.J., and Hamling, J.A., 2016, BEST Phase I simulation: Webinar presentation for U.S. Department of Energy National Energy Technology Laboratory personnel, July 25, 2016.
- Hamling, J.A., 2016, Brine extraction and storage test (BEST) Phase II: Presented at the Regional Carbon Sequestration Partnerships RCSP Water Working Group Annual Meeting, Pittsburgh, Pennsylvania, August 17, 2016.
- Hamling, J.A., 2016, Developing and validating reservoir pressure management and plume control strategies in the Williston Basin through a brine extraction and storage test (BEST): Presented at the Brine Extraction and Storage Test (BEST) Program/Planning Meeting, Pittsburgh, Pennsylvania, November 29, 2016.
- Hamling, J.A., 2016, Developing and validating reservoir pressure management and plume control strategies in the Williston Basin through a brine extraction and storage test (BEST): Presented at Mastering the Subsurface Through Technology Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, Pennsylvania, August 16–18, 2016.
- Hamling, J.A., 2017, Brine Extraction and Storage Test (BEST) project briefing: Presented to the North Dakota Industrial Commission, Bismarck, North Dakota, January 9, 2017.
- Hamling, J.A., Klapperich, R.J., Stepan, D.J., and Jacobson, L.L., 2017, Brine Extraction and Storage Test (BEST) Phase II—implementing and validating reservoir pressure management strategies in the Williston Basin [abs.]: Carbon Capture, Utilization & Storage, Chicago, Illinois, April 10–13, 2017.
- Hamling, J.A., Klapperich, R.J., Stepan, D.J., Sorensen, J.A., Pekot, L.J., Peck, W.D., Jacobson, L.L., Bosshart, N.W., Hurley, J.P., Wilson IV, W.I., Kurz, M.D., Burnison, S.A., Salako, O., Musich, M.A., Botnen, B.W., Kalenze, N.S., Ayash, S.C., Ge, J., Jiang, T., Dalkhaa, C., Oster, B.S., Peterson, K.J., Feole, I.K., Gorecki, C.D., and Steadman, E.N., 2016, Field implementation plan for a Williston Basin brine extraction and storage test: Phase I topical report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FE0026160, Grand Forks, North Dakota, Energy & Environmental Research Center, April.
- Hamling, J.A., Klapperich, R.J., and Vettleson, H.M., 2017, U.S. Department of Energy Brine Extraction and Storage Test (BEST) project update: Presented at the mid-year meeting of the Carbon Sequestration Leadership Forum, Abu Dhabi, United Arab Emirates, May 1, 2017.
- Hamling, J.A., 2018, Regional update of CCUS field projects within the Plains CO₂ Reduction (PCOR) Partnership Region, [abs.]: Carbon Capture, Utilization, & Storage Conference, Nashville, Tennessee, March 20, 2018.



EERCSM

UNIVERSITY OF
UND NORTH DAKOTA

Critical Challenges. **Practical Solutions.**