Bench-scale Treatment Study of Produced Water from the Southern San Juan Basin New Mexico

Kanalis Group

December 1, 2022

Volume 1

Prepared for:

NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

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March 10, 2023

Kanalis Group
Attn: Nyle Khan
19925 Stevens Creek Blvd., Suite 100
Cupertino, CA 95014

RE: Approval of Technical Report - Bench-scale Treatment Study of Produced Water from the Southern San Juan Basin New Mexico

Dear Mr. Khan,

The New Mexico Produced Water Research Consortium (Consortium) is a government-university-industry partnership operated by New Mexico State University in collaboration with the New Mexico Environment Department. One of our roles is to coordinate and evaluate the testing of innovative produced water treatment technologies with the potential to safely and cost-effectively treat produced water to support fit-for-purpose uses outside the oil and gas sector.

The Consortium established a project review team composed of technical members from the Consortium that included industry, academia, and non-government agency representatives to review your testing plan, coordinate and observe testing operations at the Brackish Groundwater National Desalination Research Facility, and coordinate disposal of the produced water used for testing with Consortium-member SWD operators in the Permian Basin.

Our evaluation team has reviewed and provided comments on both your preliminary and draft final reports. Based on those reviews and interactions, we found that the data and information provided in your final report accurately represents the overall results, performance, and findings of the pilot-testing conducted in cooperation with the Consortium.

We compliment you and your team on a successfully executed pilot-test and a well documented and thorough technical and analytical pilot-testing effort. If we can be of any further assistance, please feel free to contact me at 505-859-1563 or by email at mmhightower@q.com.

Sincerely,

Mike Hightower

Mike Hightower, Director
New Mexico Produced Water Research Consortium

This report describes the timeline and testing of produced water from the Eagle Springs Field in the southern San Juan Basin of New Mexico. The site is operated by HPOC, LLC, and is approximately 30 miles southwest of Cuba, New Mexico, and near the Ojo Encino Chapter House of the Navajo Nation.

For this study, produced water, a by-product of oil and natural gas production, was taken from the Eagle Springs Field to the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico, where it was treated in a bench-scale study (Project) with both brackish water reverse osmosis (BWRO) and salt water reverse osmosis (SWRO) membranes. The treated produced water was then used to grow rangeland forage grasses in greenhouses at New Mexico State University.

The testing and evaluation were conducted in collaboration with the New Mexico Produced Water Research Consortium (Consortium). The Consortium provided support including support in coordination of treatment testing with BGNDRF, excess produced water disposal, preliminary water analysis, coordination with agricultural testing organizations at NMSU, and provided a technical review team to evaluate and provide comments on the overall desalination and rangeland forage grass testing and performance data and evaluation.

The project and this report were developed, conducted, and prepared following the Consortium's Guidance on Bench-scale and Pilot-scale Testing and Evaluation. This report was prepared for and in cooperation with the Consortium.

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1. Executive Summary

This report describes the timeline and testing of produced water from the Eagle Springs Field in the San Juan Basin; operated by HPOC, LLC, (HPOC), and provides information on the use of the treated produced water in greenhouses at New Mexico State to grow forage grasses. The intent of this bench-scale testing and evaluation effort was the first step in a process to evaluate the potential for using treated produced water to ultimately support rangeland reclamation, greenhouse agriculture, and economic development opportunities near the Eagle Springs Field.

The produced water from the Eagle Springs Field is relatively low salinity, approximately 10,000 ppm TDS, and has very little organics. Based on literature reviews of desalination of water of this quality, it was expected that the water from conventional production would be relatively cost-effective to treat using standard reverse osmosis treatment technology. Previous studies (Pica et al.; 2017; Echchelh et al.; 2020) using treated produced water for rangeland grass irrigation have been shown to be relatively successful. The remoteness of the oil and gas production area, the local climate, and land use suggested that the use of treated produced water for grass land reclamation could be economically and culturally beneficial and at very low risk to public and environmental health and safety.

For the bench-scale study, 1000 gallons of the Eagle springs produced water was taken to the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico, where it was treated in mid April 2021 using a brackish water reverse osmosis (BWRO) membrane. An additional 1000 gallons was taken to BGNDRF in March 2022 and was filtered using seawater reverse osmosis (SWRO) membrane. The treated water quality of both the BWRO was around 200-300 ppm TDS and SWRO processing was around 30 – 50 ppm TDS; meeting relevant EPA, WQCC, and NMPWRC agricultural irrigation standards. The treated water analysis also showed that the SWRO membranes reduced boron levels to below WQCC NMAC 20.6.2.3103 thresholds. The treated water quality also met Federal Primary and Secondary Drinking water standards which were used as general measure of overall water quality.

HPOC partnered with Kanalis Group, LLC to manage all research activities with the Consortium and NMSU. Kanalis engaged NMSU Las Cruces (Dr. Manoj Shukla) and USDA (NRCS) to conduct a greenhouse test of forage grasses using Eagle Springs soil and the RO treated produced water from BGNDRF. The greenhouse tests began in late May 2021. Seed selection, soil baseline testing, seed germination, and growth monitoring were conducted. NMSU tested the growth characteristics and mineral uptake of five forage grasses irrigated with water ranging from tap water, treated, and non-treated produced water. In all cases, plants using treated produced water performed equal to or better than plants using tap of untreated produced water.

2. Site Location

The Eagle Springs Field is a conventional oil field (no hydraulic fracking) and produces about 2,500 barrels of water daily. As shown in Figure 1, the site is in the San Juan Basin of northwestern New Mexico, about 80 miles southeast of Farmington. The field is on federal land in the Checkerboard area of northwestern New Mexico.

Eagle Springs Locator Map

Figure 1. **Eagle Springs Production Location.**

The oil is separated from the water and sold while the produced water is currently reinjected into the Eagle Springs 9 Federal SWD #001 (API well # 30-043-21065, Lat. 35.897 Long. 107.271) disposal well which is about a mile away and due east as shown in Figure 2.

Eagle Springs
Production and Disposal Facilities

Figure 2. Eagle Springs production and disposal facilities.

Figure 3 shows the location of the Permian Basin in southeastern New Mexico and the San Juan Basin in northwestern New Mexico.

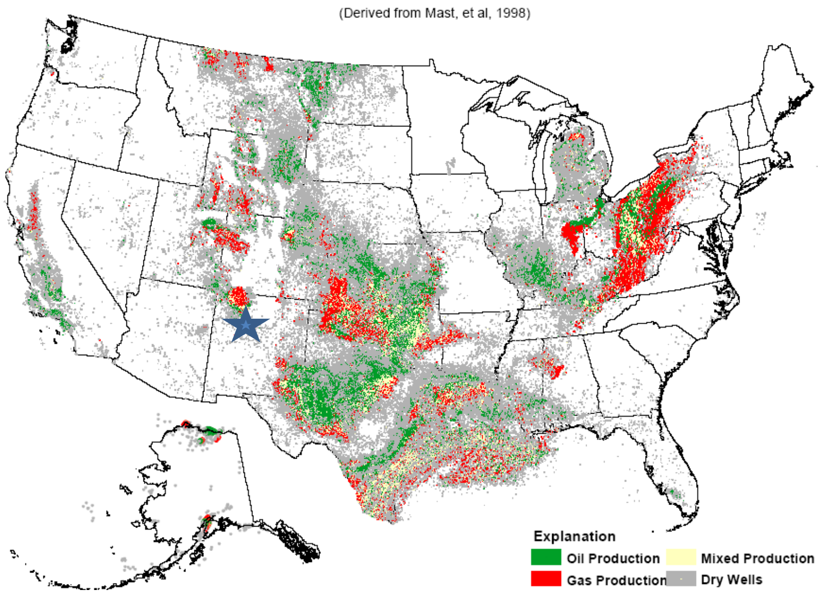

Figure 3. Oil and Gas production areas.

In general, the San Juan Basin in northwestern New Mexico has much lower salinity produced water than the Permian Basin in southeastern New Mexico. San Juan produced waters often vary between 10,000 ppm and 30,000 ppm total dissolved solids (TDS). This type of water quality is commonly treated with either brackish or sea water reverse osmosis (RO) membranes. Permian Basin produced water is generally much higher in organics and TDS and can vary from 30,000 to 150,000 ppm TDS. Produced waters of over 40,000 to 50,000 ppm currently require the use of thermal treatment technologies, which makes produced water treatment generally six to ten times more expensive.

The lower TDS of the Eagle Springs water suggests the potential for cost-effective treatment and reuse of this water for a number of potential applications many water-short and water-stressed locations in northwestern New Mexico.

3. Project Test Plan

This section discusses the project bench-scale testing goals, objectives, testing and evaluation key performance indicators that were used in evaluating initial bench-scale viability to move forward to a bench-scale application. As noted in Section 3, the project objectives and key data that needed to be collected included:

1. Preliminary produced water quality analysis -
    a. Conducted water quality analysis to determine source produced water quality values of importance to agriculture applications, especially TDS, sodium adsorption ratio, and boron
    b. Utilized water quality data to determine if RO membrane treatment is appropriate and expected permeate recovery percentage
    c. Used initial source water quality data to identify best membrane and appropriate recovery pressure to use to get appropriate treatment quality for ag applications
2. Produced water treatment and testing -
    a. Based on preliminary source water quality analysis, determine whether BWRO and SWRO membranes could provide the best performance to get appropriate boron removal, permeate ratio, and lowest energy use
    b. Included purchase of and testing of SWRO membranes to improve boron removal efficiency, and
    c. Conducted single and double pass treatment studies to assess permeate recovery percentage vs pressure and energy demand for most efficient operations
3. Forage grass growth testing -
    a. Conducted forage grass growth using several species of grasses and forage crops identified by NMSU agricultural research and NCRS
    b. Selected five grasses compatible with north west New Mexico climate and soil types
    c. Utilized four set of water quality, including fresh water and source produced water to see growth variation
    d. Used fresh water irrigation in small site plot to identify the types of native grasses that will grow locally and compare to NCRS selected grass seed recommended to compare if suitable for local habitat
4. Detailed treated water analytical testing -
    a. Conducted detailed water quality analysis to see what types of potential applications the treated produced water could be used for.
5. Use collected data to determine potential for expansion to a pilot-scale
    a. Determined what water qualities can be reached and what applications might be feasible
    b. Estimated treatment and application costs and determine if treatment and reuse is cost-effective for a range of options and applications - range land restoration, and use in green houses for high-value crops

c. Based on the economics and expected health and safety impacts, determine if a pilot-demonstration of one of the applications noted above is appropriate to pursue.

4. General Project Schedule

This section describes the timeline and schedule for the project testing and evaluation including preliminary analyses, the produced water treatment and testing, the forage grass growth testing, and treated water analytical testing. While the produced water treatment testing only took a few months for planning and execution, the plant treatment studies and analytical testing took several months each.

- February 2021

  HPOC joined the NMPWRC and submitted a proposal to test its produced water for possible agricultural uses. Samples of Eagle Springs pre-treated produced water (having undergone an oil and grease filtering step and called pretreated source water), were collected in accordance with the NMPWRC protocol; "Guidance for Treated and Untreated Produced Water Sampling Procedure" draft of October 10, 2020. Hall Environmental Analysis Laboratory (HALL) tested the samples and reported findings in HALL Report 1 – Pre-Treated Source Water (see Volume 2).

- March 2021

  HPOC partnered with Kanalis Group, LLC to manage all water activities with the NMPWRC. Kanalis engaged NMSU Las Cruces (Dr. Manoj Shukla) to conduct a greenhouse test of forage grasses using Eagle springs soil and RO treated produced water. Kanalis partnered with NMSU Los Lunas and the NRCS for a rangeland/grassland forage study in the NMSU greenhouse, and potentially a field scale pilot in the future on the Eagle Springs wellsite.

- April 2021

  1000 gallons of source water and several buckets of soil from the Eagle Springs well pad was delivered to BGNDRF. 100 gallons of source water were reserved as a baseline. 900 gallons were filtered using Toray 710 brackish water membranes - yielding approximately 315 gallons of permeate and 585 gallons of concentrate. The permeate and soil were given to NMSU and the concentrate was disposed by the NMPWRC. Separately, NMSU Los Lunas and NRCS took soil samples from several sites at Eagle Springs for soil testing.

- <u>May 2021</u>

  The greenhouse tests, designed in collaboration with NMSU, Los Lunas, and Kanalis began on May 22nd. Seed selection, soil baseline testing, seed germination, and growth monitoring were conducted.

- <u>June 2021 – Sept 2021</u>

  First run growth in greenhouse. Plants cut back 9/20/21.

- <u>June 2021</u>

  Dr Pei Xu took permeate and concentrate water samples from the April 2021 Toray 710 treatment test for analysis.

- <u>Sept 2021 – Dec 2021</u>

  Second run growth. Plants cut back 12/15/21.

- <u>Oct 2021</u>

  A qualitative growth study was conducted on a small 10 ft x 20 ft plot on the Eagle Springs well-pad to evaluate potential native grass seed varieties. Local area drinking water was used for irrigation. The study yielded very good growth results despite a late growing season start, suggesting general soil fertility available to support range grass reestablishment with appropriately managed irrigation.

- <u>Dec 2021 – Feb 2022</u>

  Third run growth. Third and final cut occurred 2/27/22. Plant cuttings and soil were sent for analysis by NMSU.

- <u>Feb 2022</u>

  Due to the positive greenhouse test and NMPWRC water analysis, the permeate from the April 2021 RO filtered water was sent to HALL for EPA Primary & Secondary Drinking Water and WQCC Part 34 Discharge Standards testing. These results are detailed in the HALL Report 2 - Pre-Treated Toray 710 RO Filtered Water (see Volume 2).

- March 2022

Water test results in HALL Report 2 met all Primary and Secondary Drinking water standards. However, boron levels exceeded WQCC Discharge Standards as outlined in NMAC 20.6.2. Simulations with brackish water and seawater RO membranes were conducted by Toray and BGNDRF. Results suggested use of a Toray 810 Seawater Membrane would yield better boron rejection. Kanalis purchased the 810 membranes and filtered ES source water at BGNDRF. Approximately 450 gallons of source water were filtered. These results are detailed in HALL Report 3 - Pre-Treated Toray 810 RO Filtered Single/Double Pass Filtered Water. To be provided in Volume 2.

5. Treatment System Overview

This section provides and overview of the reverse osmosis (RO) brackish water treatment system utilized at BGNDRF to treat the source water from the HPOC Eagle Springs site. As noted, the produced water was pre-treated using a 5-micron filter on site to remove the small concentrations of oils seen in the raw produced water. This is standard procedure for reinjection into a salt water disposal well. Figure 4 below shows the BGNDRF RO system used to treat the Eagle Springs source water. The system was operated by BGNDRF staff in support of this bench-scale test. The system can operate at about 10 gallons per minutes. Once the system was checked out and all systems were tested and verified ready for operation, the 900 gallons of source water was treated in about 90 minutes to two hours.

Figure 4. Reverse osmosis treatment system at BGNDRF.

The system uses spiral-wound membranes that are inserted into the tubes shown on the picture on the right. Under pressure, the water is separated from the salts by the membranes and the clean water (called permeate) is collected in one line, and the rejected salty water (called concentrate) is collected in a second line. The permeate is the treated water that is low in TDS and is used for a number of applications. The concentrate is usually collected on disposed of through injection or evaporation.

Grab samples of the source water and treated water are often collected during testing operations to assess and check operational performance. This is often done using hand-held analytical monitors in bench testing or with automated electronic conductivity monitors for pilot-testing or full-scale operational treatment. These values are compared to the calculated performance of the membranes used for the testing or operations. In this bench-scale test, grab samples were taken (shown in Figure 5) to compare the expected Toray membrane performance relative to the calculated performance identified based on the source produced water quality data measured in the Hall Environmental analysis.

The expectation was a water quality of approximately 300-400 ppm TDS. A picture of the source produced water and the treated produced water compared to local BGNDRF fresh water is shown below in Figure 5.

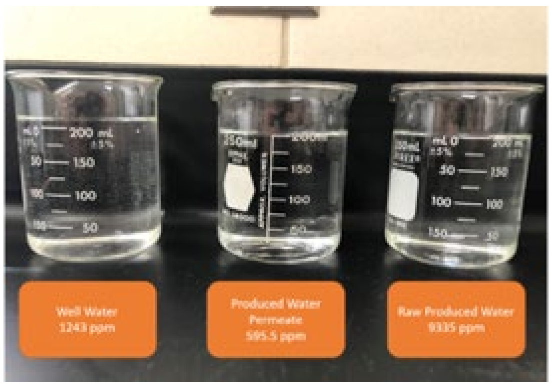

Figure 5. Example of produced water treatment results.

The grab sample results showed a general source produced water quality of around 9,000 ppm TDS and a general permeate quality of around 500-600 ppm TDS. This is in the range of drinking water and Class 1 agricultural water quality. The bench-scale results suggest that the treatment of water of this quality from the San Juan Basin is promising for potential treatment and fit-for-purpose applications and should continue to be investigated in more detail and at larger scale.

6. Project Test Results

As noted above in Section 5, the RO treatment system performed closely to the calculated performance, providing treated produced water meeting current relevant EPA, NMAC, and NMPWRC agricultural and irrigation discharge standards. The permeate was then used to irrigate selected forage grasses in an NMSU green house. The sections below discuss both the water quality obtained from the analytical analyses as well as the crop forage studies.

SUMMARY ANALYSES OF TREATED WATER QUALITY

Hall Environmental Analysis Laboratory (Hall) performed three separate detailed evaluations of Eagle Springs produced water. Each of these water sample tests were analyzed according to EPA procedures or equivalent as directed by the Consortium. Kanalis sought to treat the Eagle Springs produced water to comply with standards appropriate for rangeland and agricultural applications, but was also interested if the treated produced water would meet federal primary and secondary drinking water standards as a simple, overall method of describing test results to non-experts. Those different analytical analysis efforts are summarized below and discussed in detail.

Table 1. Hall Environmental Water Quality Analyses

Exceptions to Reporting Standards			Hall	Hall	Hall	Hall
EPA National Primary Drinking Water Regulations			**Mar 2021**	**Feb 2022**	**Mar 2022**	**Mar 2022 v2**
		Standard			**One RO Pass**	**Two Passes**
Contaminant		Limit (mg/L)	**Exceptions**			
Arsenic		0.0100	**0.0150**	0.0021	No further test	
Ethylbenzene		0.7000	**1.6000**	Not Detected	No further test	
Radium 226/228	**(pCi/L)**	5.0000	**7.0900**	4.4980	No further test	
Toluene		1.0000	**2.2000**	Not Detected	No further test	
EPA Secondary Drinking Water Regulations						
Chloride		250.0000	**890.0000**	29.0000	7.1000	Not Detected
Fluoride		2.0000	**3.2000**	0.1700	Not Detected	Not Detected
Iron		0.3000	**1.2000**	Not Detected	No further test	
Manganese		0.0500	**0.0740**	Not Detected	No further test	
Sulfate		250.0000	**6,400.0000**	82.0000	7.1000	Not Detected
Total Dissolved Solids		500.0000	**10,200.0000**	224.0000	35.0000	Not Detected
WQCC Irrigation Water Regulations						
Boron		0.7500	**3.5000**	**2.0000**	**0.8500**	**0.3400**
Hall Environmental Analysis Laboratory Evaluations - Eagle Springs						

All values in Table 1 are listed in mg/L

Hall Report 1 (March 2021) – This first report analyzed pre-treated produced water quality from Eagle Springs and will be provided in Volume 2. At Eagle Springs, upon delivery from the produced water storage tank, the produced water is treated with a five-micron filter and then pumped through a treated charcoal filter prior to reinjection. Therefore, this first sample of produced water given to Hall for analysis included the above pre-treatment. In all subsequent produced water testing, the produced water used was also collected after the above pre-treatment filtration.

The raw produced water quality results from Eagle springs showed that arsenic, ethylbenzene, radium 226/228 (combined), and toluene levels exceeded primary drinking water standards. Chloride, fluoride, iron, manganese, sulfate, and the TDS levels exceeded secondary drinking water standards, and boron exceeded irrigation water standards. This is not surprising for a raw produced water. Surprising, many common constituents in the Eagle Springs produced water were actually below current discharge standards, highlighting the general good quality of the Eagle Springs produced water.

Hall Report 2 (February 2022) - In this analysis, the permeate of the treated produced water using a Toray 710 RO membrane, was collected and analyzed. The analysis data will be provided in Volume 2. This second round of analytical results found that the RO treated produced water passed all primary and secondary drinking water standards. Unfortunately, the boron levels, though passing Class 2 agricultural standards of < 2 ppm boron, still exceeded New Mexico NMAC surface discharge standards, measuring at 2.0.

Hall Report 3 (March 2022) – The produced water desalination permeate from a Toray 810 SWRO membrane was evaluated for both a one-pass and two-pass process. The one-pass process reduced boron levels to near NMAC discharge standards for irrigation water, and the two-pass process further reduced boron levels to below current NMAC discharge standards for irrigation. The additional treatment step, while reducing boron levels, also removed much of the minerals important to plant growth. Therefore, other boron removal approaches might be necessary, or blending with treated or fresh waters may be considered for rangeland applications using the Eagle Springs filtered produced water.

SUMMARY ANALYSIS OF SITE SOIL TESTING

The local soil was tested at the Eagle Springs site to identify soil type, irrigation demand of range crops, and quality of soil for rangeland restoration. The results are presented in Table 2 below. According to the USDA-NRCS, loamy soil is prevalent in the Cabezon area where the Eagles Springs site is located.

Table 2. Eagle Springs Soil Classification

Sample No	H1/40 sec	F1	H2/ 3 H	F2	Sand %	Clay %	Salt %	Soil Type	EC	pH
1	25	71.6	14	69.8	52.56	24.72	22.72	Loam	0.19	6.8
2	26	71.6	14	69.8	50.56	24.72	24.72	Loam	0.25	6.9
3	25	69.8	13	69.8	53.28	22.72	24.00	Loam	0.21	6.7
4	25	69.8	14	68.9	53.28	24.36	22.36	Loam	0.29	6.8

SUMMARY ANALYSIS OF PLANT GROWTH

NMSU tested the growth characteristics and mineral uptake of five forage grasses irrigated with four waters:

- Eagle Springs produced water treated through conventional RO,
- diluted untreated Eagle Springs produced water,
- conventional city tap water, and
- Pre-treated, raw, Eagle Springs produced water.

The respective total dissolved solids (TDS) content in parts per million (ppm) for the four water types were 231 ppm for the treated produced water, 427 ppm for the city tap water, 1400 ppm for the diluted produced water, and 8610 ppm for the produced water.

Measurements were made of growth height, chlorophyll content, temperature, and minerals uptake for five forage grasses "broadly adapted to grow in the colder climates of northern New Mexico (Ben Ali, Shukla, Marsalis, Khan, 2020).

- Western wheatgrass, "Pascopyrum smithii"
- Alfalfa, "Medicago sativa"
- Meadow bromegrass, "Bromus biebersteinii"
- Russian wildrye, and "Psathyrostachys junceus"
- Tall fescue "Schedenorous arundinaceus"

While all the data collected is presented in Volume 2, Table 3 below summarizes the general growth information for each forage grass evaluated. These parameters are indicative of plant health and stress relative to fresh city tap water as a comparison.

Table 3. Forage grass growth and chlorophyll content

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Western Wheatgrass				
Height (CM)	21.00	27.25	29.00	NA
Chlorophyll Content	23.68	24.83	28.95	NA
Temperature C°	26.08	25.38	25.05	NA
Alfalfa				
Height (CM)	18.75	26.50	17.00	NA
Chlorophyll Content	41.98	49.78	30.83	NA
Temperature C°	21.63	21.60	24.05	NA
Meadow Bromegrass				
Height (CM)	14.00	17.00	16.25	NA
Chlorophyll Content	11.23	19.70	19.20	NA
Temperature C°	22.70	23.50	25.08	NA
Russian Wildrye				
Height (CM)	16.50	21.75	24.50	NA
Chlorophyll Content	25.03	21.50	33.45	NA
Temperature C°	25.43	25.83	25.48	NA
Tall Fescue				
Height (CM)	13.25	13.25	13.50	22.67
Chlorophyll Content	14.88	15.83	11.58	29.00
Temperature C°	24.13	22.23	22.08	24.87

All grasses germinated well with diluted produced water (1400 ppm), conventional city tap water (427 ppm), and RO treated produced water (231 ppm), respectively from left to right in Figure 6 below. Only Tall Fescue germinated with produced water (8610 ppm). This is highlighted in

Figure 6 below. SAR scores by species by water type are detailed in Volume 2. KPIs were not part of the study, nor was carbon sequestration.

Figure 6. Forage grass growth performance using different waters.

Forage grass mineral uptake was also analyzed and was determined by NCRS to be in line with normal agricultural uptake expectations for these forage grasses. But boron levels observed as noted in Tables 4 through 13 below were on the high side per NMSU Los Lunas review. These boron levels will be studied in subsequent studies.

Table 4. Western Wheatgrass mineral uptake (First Harvest)

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Western Wheatgrass		mg/l	First Harvest	
Nitrogen	11.18	10.87	10.55	NA
Phosphorous	1.54	1.92	1.38	NA
Potassium	13.80	14.50	10.60	NA
Magnesium	1.97	2.57	1.73	NA
Calcium	4.70	3.97	2.63	NA
Zinc	161.00	50.78	31.45	NA
Manganese	79.64	75.61	113.90	NA
Iron	367.85	48.70	28.38	NA
Boron	237.35	14.99	19.19	NA
Aluminum	214.00	17.15	11.71	NA
Sulfur	3.40	2.57	5.73	NA
Sodium	7.38	7.15	11.50	NA

Table 5. Alfalfa mineral uptake (First Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Alfalfa		mg/l	First Harvest	
Nitrogen	21.77	21.03	20.40	NA
Phosphorous	1.04	1.07	1.27	NA
Potassium	14.20	13.40	7.87	NA
Magnesium	2.77	3.87	2.97	NA
Calcium	20.23	22.37	15.47	NA
Zinc	70.35	21.14	27.37	NA
Manganese	217.95	65.31	142.60	NA
Iron	103.45	76.62	87.33	NA
Boron	369.19	80.86	125.84	NA
Aluminum	45.67	36.23	31.49	NA
Sulfur	7.50	5.97	22.73	NA
Sodium	11.70	7.11	42.70	NA

Table 6. Russian wildrye mineral uptake (First Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Russian Wildrye		mg/l	First Harvest	
Nitrogen	16.83	29.10	17.20	NA
Phosphorous	1.94	2.02	1.66	NA
Potassium	21.90	19.30	15.90	NA
Magnesium	3.20	4.20	3.23	NA
Calcium	8.13	6.30	4.97	NA
Zinc	77.91	42.89	42.52	NA
Manganese	119.97	64.35	130.40	NA
Iron	129.78	49.40	66.35	NA
Boron	413.17	22.45	53.47	NA
Aluminum	94.26	31.56	44.04	NA
Sulfur	5.97	3.43	13.57	NA
Sodium	16.16	8.20	33.62	NA

Table 7. Tall fescue mineral uptake (First Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Tall Fescue		mg/l	First Harvest	
Nitrogen	11.37	12.14	9.39	13.73
Phosphorous	2.42	2.41	1.55	1.17
Potassium	11.70	15.10	9.17	8.73
Magnesium	7.03	7.17	4.53	5.17
Calcium	8.60	9.70	6.57	17.10
Zinc	47.27	41.12	29.16	68.70
Manganese	336.14	326.84	552.80	136.33
Iron	96.03	75.34	80.68	138.46
Boron	306.95	35.89	77.76	159.95
Aluminum	75.09	60.10	48.48	94.00
Sulfur	9.03	5.33	17.33	45.20
Sodium	24.27	15.95	35.61	70.20

Table 8. Meadow bromegrass mineral uptake (First Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Meadow Bromegrass		mg/l	First Harvest	
Nitrogen	11.60	11.61	11.20	NA
Phosphorous	1.95	1.72	1.49	NA
Potassium	18.00	19.60	18.70	NA
Magnesium	3.17	4.40	3.47	NA
Calcium	14.17	9.40	7.20	NA
Zinc	47.82	21.36	31.24	NA
Manganese	186.50	134.22	166.98	NA
Iron	81.08	61.76	60.12	NA
Boron	737.82	35.93	101.09	NA
Aluminum	55.87	45.15	44.08	NA
Sulfur	8.70	5.93	20.83	NA
Sodium	16.08	13.43	44.96	NA

Table 9. Western Wheatgrass bromegrass mineral uptake (Second Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Western Wheatgrass		mg/l	Second Harvest	
Nitrogen	7.30	8.79	8.43	NA
Phosphorous	1.17	1.53	1.23	NA
Potassium	9.50	12.00	9.27	NA
Magnesium	1.83	2.20	2.03	NA
Calcium	5.03	4.80	3.77	NA
Zinc	24.32	22.86	18.30	NA
Manganese	83.01	61.56	131.55	NA
Iron	105.07	40.56	43.05	NA
Boron	391.68	15.96	42.31	NA
Aluminum	79.06	21.66	24.74	NA
Sulfur	1.77	2.57	4.00	NA
Sodium	3.06	4.84	10.70	NA

Table 10. Alfalfa mineral uptake (Second Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Alfalfa		mg/l	Second Harvest	
Nitrogen	31.27	29.53	35.53	NA
Phosphorous	0.95	0.88	1.94	NA
Potassium	10.20	10.70	10.30	NA
Magnesium	2.63	5.03	2.30	NA
Calcium	19.47	30.07	12.70	NA
Zinc	19.10	18.28	30.04	NA
Manganese	195.14	80.89	64.00	NA
Iron	173.73	131.98	150.08	NA
Boron	520.86	132.20	140.57	NA
Aluminum	44.99	77.74	69.41	NA
Sulfur	3.87	5.20	12.17	NA
Sodium	8.43	5.82	24.79	NA

Table 11. Russian wildrye mineral uptake (Second Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Russian Wildrye		mg/l	Second Harvest	
Nitrogen	11.99	12.57	14.43	NA
Phosphorous	2.04	1.81	1.74	NA
Potassium	16.97	17.83	16.37	NA
Magnesium	3.70	5.10	3.73	NA
Calcium	8.00	9.03	7.27	NA
Zinc	16.02	16.43	17.79	NA
Manganese	66.23	45.78	122.08	NA
Iron	87.98	65.82	72.74	NA
Boron	388.53	22.17	59.65	NA
Aluminum	42.04	48.11	35.90	NA
Sulfur	4.40	4.50	7.50	NA
Sodium	11.02	11.36	18.06	NA

Table 12. Tall fescue mineral uptake (Second Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Tall Fescue		mg/l	Second Harvest	
Nitrogen	10.45	10.39	15.67	15.13
Phosphorous	2.07	1.74	1.96	1.96
Potassium	12.87	12.90	12.33	14.80
Magnesium	4.43	4.30	3.40	1.47
Calcium	8.90	9.07	6.93	4.10
Zinc	20.73	19.05	21.74	13.45
Manganese	232.86	228.77	616.45	225.01
Iron	70.18	72.29	74.80	75.05
Boron	686.45	31.79	93.72	207.58
Aluminum	39.80	49.40	38.50	30.52
Sulfur	5.63	4.17	7.80	12.60
Sodium	10.83	8.22	16.55	33.62

Table 13. Meadow bromegrass mineral uptake (Second Harvest).

Water Category	RO Treated	City Tap	Diluted Lease	Pretreated Lease
TDS - ppm	231	427	1400	8610
Meadow Bromegrass		mg/l	Second Harvest	
Nitrogen	11.70	12.50	13.90	NA
Phosphorous	2.93	2.21	2.46	NA
Potassium	20.97	19.40	18.10	NA
Magnesium	3.27	4.87	3.33	NA
Calcium	12.30	13.40	13.37	NA
Zinc	19.30	16.24	16.69	NA
Manganese	96.10	78.53	90.38	NA
Iron	148.65	98.33	92.64	NA
Boron	791.16	33.37	92.53	NA
Aluminum	102.14	92.13	48.86	NA
Sulfur	4.97	7.10	14.57	NA
Sodium	7.72	13.43	27.78	NA

7. Bench Scale Project Summary

This report summarizes these initial bench-scale results of treating Eagle springs produced water for fit-for-purpose reuse outside the oil and gas sector for rangeland restoration. The purpose of the bench-scale efforts was to;

1) determine the relative performance of membrane treatment of this low TDS produced water,
2) collect general operational performance of membrane systems applicable for this produced water quality,
3) assess the viability and safety of using the treated produced water for rangeland reclamation applications, and
4) if the results were promising, use the data collected to design a larger-scale pilot testing system to conduct a larger-scale and longer field operation to better asses the long-term feasibility and viability of this type of produced water treatment and reuse application in northwestern New Mexico.

The data presented suggest that the Eagle Springs water is relatively easy to treat using reverse osmosis and the resulting permeate can be used to support forage grass growth. The boron in the Eagle springs produced water was not easily removed, so additional post-treatment or blending may be required in future efforts. But overall, the results suggest that agricultural used of the treated produced water could be successful and pilot and field operations should be considered to identify final system cost-effectiveness and reliability.

Appendix A-1

SEE VOLUME 2

Appendix A-2

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Appendix A-3

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Appendix B

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