An Integrated Wind-Water Desalination Demonstration Plant for an Inland Municipality

Final Report

Submitted to

Texas Department of Agriculture
Att: Travis Brown
PO Box 12847
Austin, TX 78711
Contract No. 728082

Texas Water Development Board
Att: Sanjeev Kalaswad
PO Box 13231
Austin, TX 78711-3231
Contract No. 0804830832

Submitted by

Ken Rainwater[1], Lianfa Song[1], Tom Lehman[2], and John Schroeder[3]
[1]Water Resources Center, [2]Department of Geosciences,
[3]Wind Science and Engineering Center (now National Wind Institute)
Texas Tech University, Lubbock, TX

Submitted for

City of Seminole
Tommy Phillips, City Administrator
302 South Main Street
Seminole, Texas 79360

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List of Abbreviations

Abbreviation	Term Definition
ac	Acre
bgs	Below ground surface
CGST	Center for Geospatial Technology
d	Day
Q_{avg}	Average daily flow
ft	Foot
FTIR	Fourier Transform Infrared Spectroscopy
gpm	Gallons per minute
g/L	Gram per liter
Hz	Hertz
hp	Horsepower
hr	Hour
in	Inch
kW	Kilowatt
kWh	Kilowatt-hour
LEUWCD	Llano Estacado Underground Water Conservation District
LOI	Loss on ignition
μS/cm	Microsiemens per centimeter
mph	Miles per hour
mg/L	Milligram per liter
MGD	Million gallons per day
min	Minute
NWI	National Wind Institute
NMED	New Mexico Environmental Department
PSC	Parkhill Smith & Cooper, Inc.
pCi/L	Picocuries per liter
lb	Pounds
psi	Pounds per square inch
PWT	Professional Water Technologies
RO	Reverse osmosis
rpm	Revolutions per minute
SEM	Scanning electron microscopy
SHP	Southern High Plains
su	Standard units
SECO	State Energy Conservation Office
T-EDXA	Targeted-Energy Dispersive X-Ray Analysis
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
THP	Texas High Plains
TTU	Texas Tech University
TWDB	Texas Water Development Board
TDS	Total dissolved solids
VFD	Variable frequency drive
WRC	Water Resources Center
WTC	West Texas Consultants
WTWWS	West Texas Water Well Service
WiSE	Wind Science and Engineering
yr	Year

Executive Summary

Researchers from the Texas Tech University (TTU) National Wind Institute (NWI) and Water Resources Center (WRC) recently completed a field demonstration project to explore the potential for connecting locally owned renewable wind energy systems with the electrical needs for pumping and treating locally available brackish groundwater. The project took place at the City of Seminole, Texas, a town of 6,430 residents with a declining well field in the Ogallala Aquifer that is also impacted by arsenic and fluoride. The city officials were interested in drilling deeper wells into the Dockum formation to tap local brackish water for future water supply. The NWI and WRC research team worked with the City to develop and deploy a field-scale demonstration project with funding from several local, state, and federal sources. The project objectives included installation of an 1800-ft deep well in the Dockum Aquifer, an appropriate reverse osmosis (RO) system, a 50-kW wind turbine, and other related infrastructure to collect and report useful data from the demonstration project. Operation began in April 2013 and ended in August 2014. The results provide operational experience and data for planning of larger-scale systems.

In general, RO systems tend to work well, with proper maintenance, no matter the source of electricity. Wind turbines can generate electricity when the winds are strong enough and the turbines are in good working condition. The technical elements of this project have been proven successful on their own previously, and this project basically brought the technologies together in an unusual combination. The biggest challenge as the project began was the uncertainty in the hydrogeologic, hydraulic, and water quality characteristics of the local Dockum Aquifer. The project team brought together TTU researchers with local engineering and geological consultants to cover the required technical and regulatory aspects. The TTU team also worked with the City of Seminole and their grant consultant to build the necessary funding from several local, state, and federal sources. The time and effort necessary caused to project to take several years from conception to completion, but the effort was valuable to the City and other municipalities considering developing local brackish groundwater supplies. The following specific conclusions were noted.

- The local conditions in the Dockum Aquifer can be projected through study of existing well log databases, but site-specific well conditions must be found through careful drilling and geophysical testing practices.
- The water quality in the Dockum Aquifer appears to become much more saline with depth, and targeting the upper portions of the aquifer may be appropriate if the hydraulic capacity is sufficient.
- The well construction technique used in this project did provide a productive well, but it should be noted that production of aquifer sediments with the pumped water significantly impacts the choices of pretreatment methods upstream of the desalination process.
- When funding allows, it is preferable to have more than one wind turbine so that the renewable energy is still available when one turbine goes down. Preventive maintenance visits are also important to prevent problems.
- The City of Seminole staff were very cooperative in this project and shouldered the majority of the work and costs for regular operation of the system. Day-to-day management of an RO system is challenging and difficult for a small municipal utility to

run without additional staff. There is a significant opportunity for third-party companies to provide maintenance and operation services.

- The unplanned fouling of the membrane elements, followed by the autopsy analyses, provided additional information about the nature of the inorganic foulants in this brackish water.
- The RO and wind turbine service providers often commented that the first year of operation of their systems normally has unexpected challenges that provide insight for adjustments to the mechanisms and operating procedures. Our experience was similar, and we stretched the demonstration period as long as we could for that same reason. The additional challenges of the well motor failure, nearby lightning strike impacting the electrical systems, and loss of access to the RO system manufacturer lead to unexpected shutdowns.
- The total time of operation of the well and RO system was 250 day-equivalents, with total well production of 20,115,900 gal at an average flow rate of 56 gpm. The average permeate flow was 41 gpm with average concentrate flow of 15 gpm, for an average volumetric recovery of 73 percent. The average TDS values were 7980, 520, and 20,600 mg/L for the feed, permeate, and concentrate flows, respectively. The permeate values from the laboratory analyses of a grab sample for arsenic, fluoride, and TDS were <0.01, <0.5, and 436 mg/L, respectively. The permeate could be potable water after disinfection, and could also be blended with the local Ogallala water to lower arsenic, fluoride, and TDS levels.
- During the demonstration project, the permeate was not permitted for addition to the Seminole distribution system. The permeate and concentrate flows were blended and discharge to a lift station for pressurized flow into the Seminole wastewater collection system. The small flow did not impact the operation of the City's wastewater treatment plant.
- The EW50 wind turbine generated 37,054 kWh in 4276 hr of operation. The well and RO system demand during their operation was approximately 78,000 kWh. The cost of energy per volume of permeate produced at the average of 41 gpm was about $0.33/1000 gal at the average $0.062/kWh charged locally by Xcel Energy. The amount of energy generated by the wind turbine was 47 percent of the demand of the well and RO system. Unfortunately, the exact times of operation for the turbine and well and RO system did not always coincide. Still, the amount of energy generated was significant and encouraging as a renewable energy source alongside the energy from the grid.
- A total of approximately $1.63 million was assembled from several local, state, and federal sources to design, construct, and operate this demonstration project. The types of grants that were used to make this project happen were very helpful, but typically the available amounts of money were limited so that no single source of funds could have covered the entire budget. These limitations are also experienced by other rural municipalities and have slowed their adoption of new technologies. Consideration of bonds or state loan programs, such as those managed by the TCEQ, are warranted. Water rates will only go up, whether the actions take place sooner or later.
- This demonstration project did not lend itself to scalable economic analyses for several reasons. First, most of the funds came from grants, so no capital costs were covered by amortizable debt. Second, the sizes of the well pump, RO system, and wind turbine were set by grant funding limitations, and as such their costs per unit of production were

relatively high compared to full-scale, larger capacity systems. Third, concentrate management, which is usually a large fraction of the overall costs, was done by simply combining the permeate and concentrate flows for disposal through the city's sanitary sewer system, a choice that would not likely be recommended for a full-scale system. Fourth, the costs of providing drinking water from this conceptual combination of wind-assisted brackish water desalination must be greater than the current City of Seminole water costs based on treatment and distribution of chlorinated groundwater, so we are not promoting savings relative to current practice. Finally, we did estimate the value of the wind-generated electricity at $0.33/1000 gal of permeate. As the wind turbine was purchased with grant funds, the water pumped and treated when the electricity came from the wind essentially cost $0.33/1000 gal less than similar water pumped and treated when the electricity came from the grid.

As this field demonstration project came a close, the TTU team began discussions with BW Primoris, a company that has entered into a long-term contract with the City of Seminole to provide potable water supply to the City's existing distribution infrastructure. At the time of this report, BW Primoris had completed a successful pilot test of treatment processes to reduce the arsenic, fluoride, and TDS levels in the water produced from the City's existing Ogallala well fields, and has constructed three full-scale plants, including one near our research facility on the south side of Seminole. They are also exploring the potential of their own Dockum wells to support the City's needs. Due to the limited pumping capacities likely in local Dockum wells, they are very interested in our existing Dockum well, as well as the existing RO system and building that was designed for expansion with additional treatment skids, that can be of great value to both BW Primoris and the City as they consider their future capacity development. BW Primoris is currently planning a packer test at our Dockum well to separate the water quality and production capacities for the three perforated zone. It is possible that the shallowest producing zone may have the most attractive combination of water quality and flow capacity. BW Primoris has also contacted the TTU team to provide a third-party evaluation of the concentrate management practices available at Seminole, and we will also encourage the use of renewable energy through wind and solar power generation. For example, a properly managed solar pond can serve both to accept concentrate as make-up water for evaporation losses and provide electricity or heat for desalination or pumping demands. The TTU team provided draft copies of this report and all pertinent information from this project to BW Primoris as we explore the positive interaction. The TDA grant funds used by the City for this project encourage the City to make the best possible use of the new infrastructure to serve its citizens. In addition, the TTU team watching the U.S. Bureau of Reclamation's Desalination Program to propose using their funds for additional research in better operation of the RO treatment system through improvements in pretreatment, adjustments in antiscalant and pH management, and manipulation of recycle and flush scheduling.

Acknowledgments

The TTU WRC and NWI research team are grateful to the following people whose cooperation and support were necessary to the successful completion of this demonstration project. Mayor Mike Carter of the City first approached the TTU team about the project, and City Administrator Tommy Phillips represented the City in planning and management of the project with the TTU team. Director of Public Works Gary Duncan, and Foreman Tommy

Williams provided input during design and construction, and were primarily responsible for routine operation and maintenance of the system after construction. Kay Howard and the staff of AJ Howco Services, Inc., provided their experience and efforts in preparation of grant proposals and contracts, as well as management of the contracts during the project. Travis Brown of the Texas Department of Agriculture was instrumental with guidance toward grant programs that contributed the funding for the site construction and portions of the well and wind turbine costs. Sanjeev Kalaswad of the Texas Water Development Board administered his agency's contract that contribute most of the costs of the brackish groundwater well construction. Pamela Groce of the State Energy Conservation Office oversaw a grant to TTU that funded most of the wind turbine costs. Lori Barnes, manager of the Llano Estacado Underground Water Conservation District, and her staff provided insight into local groundwater conditions, and the District also contributed funds toward the well construction. Dr. Judy Reeves of Cirrus Associates, LLC, evaluating previous deep well logs near the site, projected the potential well depth required, and logged the well during drilling. Zane Edwards, Leonard Nail, Daniel Albus, John Kelley, and Greg Collins of Parkhill Smith & Cooper, Inc., provided engineering services for the well permit, procurement, and construction, as well as for the procurement and installation of the RO system. Chad Tompkins and John Link of West Texas Consultants, Inc., performed engineering design, procurement, and management of the site infrastructure. Jim Heath of Entegrity Wind provided the wind turbine and cooperated with West Texas Consultants and Lamesa Irrigation for its construction. West Texas Water Well Service drilled and completed the Dockum well under the supervision of Gil Gillespie. Tejas Partners Construction prepared the demonstration site and building. David Anderson of Anderson Welding & Machine Services replaced the well motor and provided expertise on modifications to the well and produced sediment controls. Earl Young of Worth Hydrochem and his colleague David Reed were most helpful in getting the RO system operating smoothly after the lightning strike.

1 Introduction

1.1 Problem Statement and Objectives

Municipalities in the Texas High Plains (THP) face ongoing challenges as they plan for long-term water supply for their citizens. All of these municipalities depend on the relatively shallow and typically fresh Ogallala Aquifer for all or part of their potable water. The recent extended drought has greatly diminished surface water supplies in Lake Meredith, White River Lake, and Lake Mackenzie, which held 5.2, 6.3, and 7.5 percent of their capacities as of the date of this document (TWDB, 2014). These three lakes normally contribute to the water supplies of 19 cities, increasing their current groundwater use. In addition, long-term irrigation withdrawals in excess of recharge in the THP have led to steady depletion of the Ogallala Aquifer. Based on local trends in saturated thickness declines observed from 1990 to 2004, researchers at the Texas Tech University Center for Geospatial Technology (CGST) used geographic information system tools to estimate and map the time until the local saturated thicknesses get too thin (< 30 ft) to allow sufficient pumping rates to supply center pivot systems (CGST, 2006). For much of the Southern High Plains (SHP) of Texas, south of Amarillo, only 30 to 50 years after 2004 remain for traditional irrigated agriculture, and municipalities may have to expand or relocate their well fields.

More recently, many public water supply systems in the THP have been reminded by the U.S. Environmental Protection Agency and the Texas Commission on Environmental Quality (TCEQ) that their groundwater-based supplies are out of compliance with federal standards. Typically, Ogallala groundwater supplies have received only disinfection prior to distribution, although homeowners could always consider additional point-of-use treatment. In the SHP, many local well fields are impacted by fluoride, arsenic, total dissolved solids (TDS), and other drinking water constituents above primary or secondary maximum contaminant levels (MCLs). In a project funded by the U.S. Bureau of Reclamation, we collected information from the TCEQ for 37 Texas municipalities and from the New Mexico Environment Department (NMED) for three nearby New Mexico cities (Elida, Floyd, Vaughn) to see if any had exceedances in at least their worst water supply well (Swift et al., 2009). The findings are provided in Table 1, which also includes the reported population and average daily demand, Q_{avg}, in MGD. Exceedances of both primary (bold) and secondary (bold italics) MCLs are noted. Most of these communities use Ogallala water, but some use other local shallow aquifers. Overall, 39 of the 40 cities had one or more exceedances, and Table 2 breaks down the exceedances by parameter. These results indicated that, even with their existing groundwater supplies, these municipalities are likely to require more involved treatment processes beyond disinfection or blending with less impacted well water to reduce the target constituents below the MCLs. Added treatment capability will require new infrastructure and operation and maintenance costs, including electricity.

As these issues of decreasing freshwater supply and water quality compliance became known, the Texas Water Development Board (TWDB) started the Brackish Groundwater Desalination Initiative in 2004 to facilitate use of brackish groundwater across the state, such as the Dockum Aquifer beneath the Ogallala in the THP (Arroyo, 2011). The TWDB's Innovative Water Technologies program carries out that mission, and its interests often are in cooperation with the U.S. Bureau of Reclamation's Desalination and Water Purification Program, which was originally authorized by the Water Desalination Act of 1996. In 2005, researchers from the

Table 1. Communities with Primary (***bold italics***) and Secondary (**bold**) Exceedances (worst well reported, na = not available, Swift et al. [2009])

City	County	Population	Q_{avg} MGD	TDS mg/L **500**	As mg/L ***0.01***	Cl mg/L **250**	F mg/L ***4***, **2**	SO_4 mg/L **250**	NO_3 mg/L ***10***	Fe mg/L **0.3**	Gross α pCi/L ***15***
Hereford	Deaf Smith	14400	2.750	**1150**	0.003	210	***4.2***	209	5.5	0.05	***18.7***
Levelland	Hockley	12866	1.448	**714**	0.008	87	***4.4***	202	2.6	0.12	13.5
Lamesa	Dawson	9942	1.570	**1150**	***0.018***	**315**	**2.2**	**327**	5.3	0.00	7.2
Andrews	Andrews	9652	2.388	**660**	***0.038***	157	***4.4***	116	2.2	0.00	3.4
Seminole	Gaines	5910	1.847	**531**	***0.017***	116	***4.1***	99	3.4	0.15	5.4
Tulia	Swisher	5200	0.795	**2020**	0.003	**389**	***5.3***	**436**	0.4	0.13	7.1
Denver City	Yoakum	3985	0.852	**948**	***0.014***	**316**	**2.3**	169	2.6	0.00	4.5
Crane	Crane	3191	1.053	464	***0.013***	59	1.5	147	2.2	0.00	4.8
Tahoka	Lynn	2910	0.405	**1020**	0.003	**321**	1.0	225	1.0	0.01	4.8
Stanton	Martin	2900	0.329	**1111**	***0.020***	**302**	**2.4**	**425**	***10.1***	0.00	2.0
Wolfforth	Lubbock	2710	0.442	**652**	***0.015***	76	***5.8***	131	2.2	0.00	10.7
Seagraves	Gaines	2334	0.328	**788**	***0.049***	120	***4.7***	223	***10.9***	0.00	6.7
Shallowater	Lubbock	2300	0.380	**725**	***0.012***	67	**2.9**	177	7.6	0.09	***47.3***
Morton	Cochran	2245	0.379	**1050**	***0.015***	217	**3.6**	**342**	5.1	**1.00**	6.4
Lorenzo	Crosby	1372	0.172	351	***0.016***	24	**2.5**	32	1.5	0.00	9.8
Plains	Yoakum	1350	0.931	**1124**	***0.015***	184	***4.3***	**446**	3.2	0.01	6.3
Booker	Lipscomb	1200	0.282	**785**	0.005	239	1.4	105	2.6	0.21	9.6
O'Donnell	Lynn	1011	0.100	**1262**	0.003	**352**	1.0	**348**	0.0	0.00	na
Silverton	Briscoe	780	0.111	358	***0.012***	19	**3.5**	19	1.1	0.02	na
Meadow	Terry	750	0.110	**930**	***0.028***	164	***4.8***	**274**	6.8	0.01	***17.9***
Lefors	Gray	560	0.093	**3666**	0.010	**1926**	0.2	4	1.5	0.07	0.0
Vaughn	Guadalupe	540	0.198	na	0.009	na	**3.2**	na	na	na	***50.1***
Wilson	Lynn	532	0.045	**1336**	0.009	**275**	**4.0**	**350**	***11.0***	0.00	***16.9***
Turkey	Hall	500	0.065	**1237**	0.005	157	1.5	**437**	***17.1***	0.01	10.8
Smyer	Hockley	480	0.053	**1000**	***0.012***	92	***5.2***	176	3.0	0.01	***23.6***
Quitaque	Briscoe	463	0.105	**1124**	0.004	231	1.9	**286**	***14.6***	0.01	na
Wickett	Ward	455	0.118	**586**	0.006	83	1.9	169	1.3	0.02	6.7
New Home	Lynn	440	0.047	**859**	***0.026***	135	***5.0***	171	5.0	0.00	10.0
Texhoma	Sherman	371	0.100	330	0.004	12	2.0	72	2.1	0.01	13.8
Welch	Dawson	354	0.049	**1295**	***0.027***	**298**	***4.6***	**408**	***17.2***	**4.08**	14.6
Floyd	Roosevelt	350	na	**657**	***0.012***	135	***4.2***	**290**	4.5	0.00	na
Loop	Gaines	300	0.031	**654**	***0.031***	27	***4.9***	197	7.0	0.00	na
Goldsmith	Ector	250	0.079	494	***0.017***	72	**3.2**	83	2.6	0.03	na
Wellman	Terry	225	0.038	**823**	***0.037***	108	***5.7***	241	5.3	0.01	8.8
Elida	Roosevelt	189	0.022	**897**	***0.012***	na	**2.3**	na	na	na	na
Opdyke West	Hockley	180	0.050	**628**	***0.014***	53	***5.9***	127	6.7	0.11	8.1
Whitharral	Hockley	175	0.054	**1040**	0.007	107	***4.4***	**395**	***11.0***	0.16	***17.0***
Dodson	Collingsworth	120	0.030	335	0.002	9	0.7	40	***13.8***	0.02	2.9
Grassland	Lynn	75	na	**1732**	***0.020***	**659**	***5.0***	**332**	***13.0***	0.00	***16.6***
Flomot	Motley	40	na	**749**	0.007	131	2.0	168	***19.0***	0.00	4.6

Table 2. Summary of Municipal Supply Exceedances

Parameter	Number of Cities
TDS	33
Fluoride	29
Arsenic	24
Sulfate	14
Chloride	10
Nitrate	10
Gross α	8
Iron	2

Texas Tech University (TTU) Wind Science and Engineering (WiSE, known as the National Wind Institute [NWI] since December 2012) Center and Water Resources Center (WRC) began to explore the potential for connecting locally owned renewable wind energy systems with the electrical needs for pumping and treating brackish groundwater. Electricity can be 30 to 50 percent of the life-cycle cost of RO treatment systems, and renewable wind energy is readily accessible in the THP, so the NWI and WRC researchers began to investigate the potential for combining locally owned community wind systems with smaller municipalities' water production, treatment, and distribution infrastructure requirements. The intent was for behind-the-meter application of the renewable energy to reduce the community's grid electricity needs when the wind is sufficient, with the possibility of shifting a significant portion of the electrical needs associated with drinking water delivery to that same time window, essentially storing lower cost energy in the produced water. Figure 1 provides a conceptual sketch of the addition of a brackish water production and treatment system to an existing municipal water system. Concentrate management is another significant issue with any RO or desalination system, especially at inland sites that cannot just discharge to the ocean.

Through public outreach workshops, the research team was approached by Mayor Mike Carter and other officials of Seminole, Texas, a town of about 6,340 residents with a declining Ogallala well field impacted by arsenic and fluoride. Seminole is the county seat of Gaines County, which is known for its irrigated and dryland agriculture as well as oil and gas production, so the city officials were comfortable with the possibility of drilling deeper wells into the Dockum formation to tap the water in the interbedded sandstones and gravels, known to some locally as the Santa Rosa aquifer. The depth(s) to the producing zone(s), water quality, and potential well flow rates were not well known locally, but recent expansions of wind turbine installations in the region were encouraging. The NWI and WRC research team agreed to work with the City to develop and deploy a field-scale demonstration project. The primary purpose of this report is to document those efforts. The project objectives included obtaining funding from various agencies and grants, planning and installation of a new well in the Dockum Aquifer, selection and installation of an appropriate RO system, selection and installation of a 50-kW wind turbine, design and construction of other site infrastructure, and operation of the system to observe and report useful data from the demonstration project.

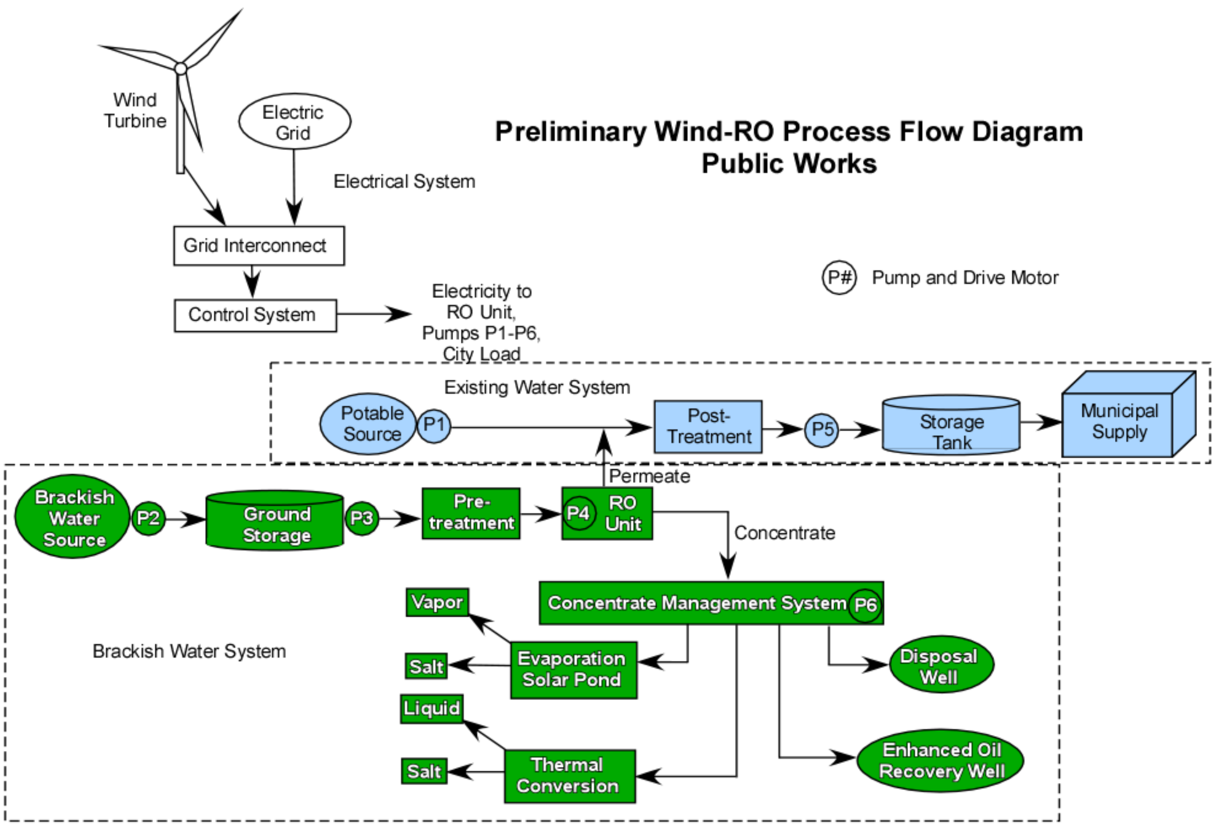


Figure 1. Integrated wind-RO layout for an inland municipality (Swift et al., 2009)

1.2 Funding Sources

As with many demonstration projects, it is often necessary to leverage multiple sources of funds, and municipalities in Texas have access to some federal pass-through funds and state funds through different state agencies. The City of Seminole is mentioned first, as their local funds, managed by City Administrator Tommy Phillips, purchased the project site, provided the electrical connection to the grid, and other infrastructure development. The City will retain the infrastructure at the site and was responsible for its day-to-day operation. The Renewable Energy Demonstration Pilot Program in the Texas Department of Agriculture (TDA) provided a large portion of the project funding as Seminole's demographic characteristics qualified for low- and moderate-income incentives. The TWDB provided most of the funds for the Dockum well, with the balance coming from the TDA grant and the Llano Estacado Underground Water Conservation District (LEUWCD). The State Energy Conservation Office (SECO) within the office of the Texas Comptroller provided part of the funds for the wind turbine purchase through a grant to TTU, which was combined with TDA funds. The NWI and WRC contributed funds from a multi-year Department of Energy project that were primarily used for geologic and engineering consultant services, the RO system, and engineering and project management services. A grant consulting firm, AJ Howco Services, provided overall coordination for contractual and financial requirements. The funding levels from the different sources as reported by AJ Howco Services were as follows.

- City of Seminole $235,461.24
- Texas Department of Agriculture $724,624.76
- Texas Water Development Board $300,000.00
- Texas Tech University
  - State Energy Conservation Office grant $162,000.00
  - Department of Energy grant $167,362.85
- Llano Estacado Underground Water Conservation District $40,000.00
- Total Capital Expenses $1,629,448.85

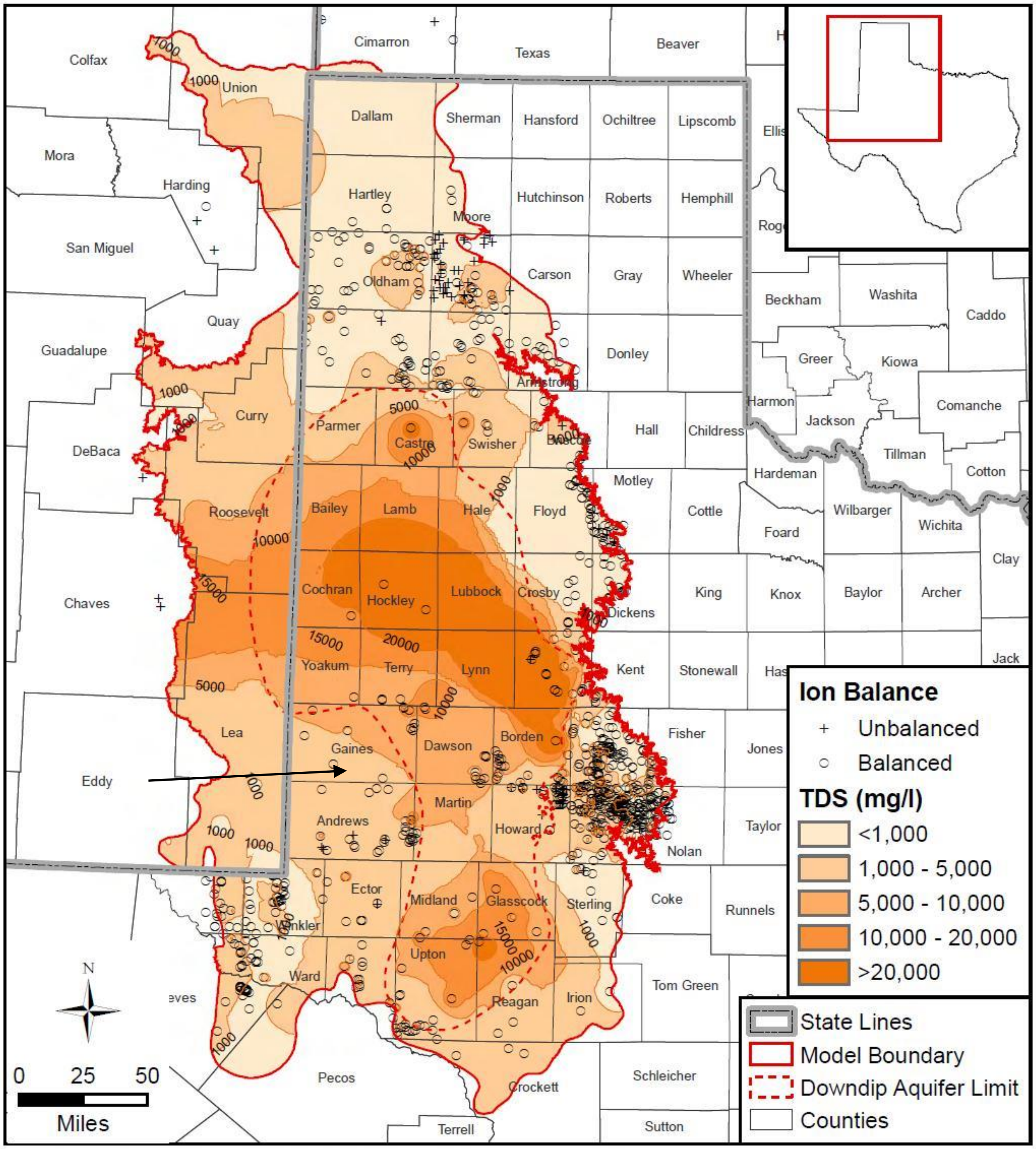
The City of Seminole also contributed directly through its funding of the time and effort of its staff members that operated the demonstration project, the grid electricity, and repair visits by the RO service company. The TTU WRC and NWI shared some of the operational costs for antiscalant, water leveling monitoring equipment, data acquisition, and repair visits by the RO service company.

2 System Components

2.1 Brackish Groundwater Well

At the inception of the project in 2005, the primary reference describing the Dockum Aquifer was by Bradley and Kalaswad (2003), who had collected all the previous reports and data held by the TWDB and others. Later, Ewing et al. (2008) built on the work of Bradley and Kalaswad (2003) and others during development of a groundwater availability model intended to simulate hydraulic conditions within the aquifer. Figure 2 (Ewing et al., 2008) shows the extent of the Dockum Aquifer in Texas and nearby New Mexico and Oklahoma, as well as estimated contours of TDS. The plus and circle symbols identify the locations of wells with available major ion water quality data. It is clear that most of the available wells were drilled in the zones with lower TDS values, making large areas of the contour map uncertain. Of course, when and where the fresher Ogallala Aquifer, which overlies the Dockum, was available, the local landowners and industrial water consumers had no reason to tap the lower aquifer, so much less was known about the Dockum Aquifer, affecting the detail available to the research team and others interested in the local conditions. An arrow was added in Figure 2 to show the site location at Seminole, near the 5000 mg/L TDS contour. It is obvious that there were few historical data points near the project site from the water-based literature. The state database also had little lithological information to go with the historical water samples, so the number and position of water-bearing zones in the Dockum were unclear. Anecdotal information from local well drillers indicated that at least two different water-bearing layers might be encountered, one at less than 1000 ft of depth below ground surface and a second near the bottom of the Dockum about 2000 ft below ground surface (bgs).

The location for the brackish groundwater well, referred to as SR-1, was set at latitude 32º 41’ 06.415”N, longitude 102º 40’ 0.727”W, at the local elevation of approximately 3300 ft above mean sea level, as shown in Figure 3 (Figure 1 from Cirrus [2011] in Appendix A). This site is located within 510 ac on the south side of Seminole that the City had recently purchased for installation of additional Ogallala water supply wells. Spacing of 300 ft from any other water well was required by the LEUWCD. Cirrus Associates LLC (Cirrus 2009) evaluated available nearby geophysical logs and constructed north-south and east-west cross sections to describe the



Source: TWDB, Panhandle GCD; USGS/New Mexico; Hart and others (1976)

Figure 2. Extent and TDS contour map of the Dockum Aquifer (Ewing et al., 2008)

subsurface conditions and project potentially productive zones in the Dockum Aquifer prior to the procurement of the drilling contract. Cirrus (2009) identified two possible productive zones, from 450 to 580 ft bgs in the upper Dockum (Trujillo Formation) and from 1440 to 1840 ft bgs in the lower Dockum (thought to be the Santa Rosa horizon).

Figure 3. Seminole brackish groundwater well site (Cirrus 2011)

The research team used TTU DOE funds to contract with Parkhill, Smith & Cooper, Inc. (PSC) for the design, permitting, and procurement of the brackish water well. PSC designed the well to meet TCEQ permit requirements for a drinking water well with 12.75-in diameter casing in combination with mill slot screen and gravel pack in the target producing zones, and the TCEQ provided conditional permission for construction in March, 2010. As the PSC staff pursued the procurement of the well, only two vendors bid on the brackish well drilling and construction, and they requested the flexibility to propose alternative well completion techniques that had been previously approved by the TCEQ for deep municipal water wells. West Texas Water Well Service (WTWWS) submitted the successful bid at $419,720, with the following included items as stated in their bid documents.

- Mobilize to location and set-up
- Ream 17.5-in to 350 ft for 12.75-in surface casing
    - The 350-ft bid is an arbitrary amount, as the actual amount of surface required will be determined during the drilling process and may vary from this amount
- Set and pressure cement 350 ft of 12.75-in surface casing
- Drill 11-in hole from below surface casing to 1800 ft
- Set and pressure cement to surface 1800 ft of 7-in threaded and coupled casing
- Geophysical logging
    - Proposed logging gamma and neutron porosity logs through cemented casing
- Perforate (shoot) up to 300 ft, 2 shots per ft, of casing based on geophysical logging
- Furnish, install, and remove test pump
- Test pump for 36 hours
- Wellhead completion
- Labor to install
- Equipment rentals

The drilling was completed during June 21 to July 7, 2011. Figure 4 is a photograph of the drill rig and crew on site. To protect the shallow Ogallala Aquifer, 12.25-in steel surface casing was placed and cemented in a 17.5-in hole to a depth of approximately 274 ft, terminating about 100 ft below the base of the Ogallala and the underlying Cretaceous layer. An 11-in hole was advanced below to a total depth of 1808 ft, and a 7-in steel casing was installed and cemented. Cirrus (2011) collected samples for the geologic log. The driller's log (State of Texas Tracking #259331) is provided in Appendix B. Cirrus (2011) provided a detailed geologic log based on the field observations of Dr. Judy Reeves, as well as the geophysical gamma and neutron porosity logs were run by E-P Wireline/Schlumberger. The logs were interpreted by Dr. Judy Reeves of Cirrus and Dr. Dennis Powers, another geologist who consulted with WTWWS on deep wells. Based on the cuttings and the geophysical logs, the most promising zones were noted from 540-650 ft (in the lower Cooper Canyon Formation with claystones interbedded with sands and gravels), 890-920 ft (in the lower Trujillo Formation with silts and siltstones interbedded with clays), and 1610-1770 ft (interpreted as within the Santa Rosa Formation based on sandstone and siltstone interbedded with clays). These three zones were perforated with two shots per ft. Figure 5 shows the completed well site.

Figure 4. WTWWS drill rig and crew during drilling event

Figure 5. Complete well and plumbing

Dr. Tom Lehman, an expert on the Dockum Formation in Texas and New Mexico (Lehman et al. 1992, Lehman 1994a, 1994b), also generated a simplified geologic log from his analyses of the cuttings samples provided by Cirrus. Dr. Lehman noted that his analyses of cuttings could have been affected by caving within the well during drilling. Figure 6 summarizes his descriptive log, and his verbal descriptions are included in Appendix A. His analyses indicated thin intermittent sand units from about 200 ft to 600 ft in the Cooper Canyon Formation in the upper Dockum, less likely to be productive. The Trujillo Sandstone in the middle Dockum appeared to have more coarse-grained and conglomeratic materials at 625 ft to 660 ft, which may be productive. He described the Tecovas Formation in the lower Dockum as having virtually no sand above the 1700 ft depth, and the sandy intervals below were lithic sands, not the quartzarenite and chert conglomerates that are typically associated with the Santa Rosa Sandstone. While the sandy intervals can provide water, the zone is not technically the Santa Rosa. He concluded that either the Santa Rosa was not present or the well was not deep enough to penetrate that sandstone. The well was terminated within the Dockum, so it is probably best that we refer to our well as a Dockum well, and be pleased that we have producible water. As noted by Bradley and Kalaswad (2003), the productive part of the Dockum is often referred to locally as Santa Rosa without consideration of the sand materials.

WTWWS performed well development and pump testing in early August 2011. The initial depth to water on August 4 was 743 ft in the 1800-ft deep well with its 7-in casing. The pump test began on August 4 at 8:00 a.m, with the pump intake set at 1600 ft. Figure 7 shows the records of pumping rate and drawdown in the pumping well vs. time for the next 36 hr. The pumping rate was 175 gpm for 4 min, then 160 gpm for 8 min, and then stabilized at 150 gpm for the next 35 hr and 48 min. The drawdown stabilized at approximately 180 ft in less than 30 min and remained at that value for the duration of the test. After 36 hr of pumping, the pump was turned off, and the well recovered to a stable depth to water of approximately 746 ft within 30 min. These results were very encouraging, as the stable pumping rate of 150 gpm was three times the target of 50 gpm planned for the demonstration project. The position of the water column in the well allowed selection of a pump with its intake less than 1000 ft from the ground surface, which fell within the range of commercially available water well pumps. The original budget for the well included a 50-gpm pump with its intake planned near the well bottom, at a nominal 1800-ft depth, which would have required a more expensive and unique pump. The pump selected was a Grundfos Model 85S200-18, 20 hp pump to deliver 50 gpm at 900 ft of total dynamic head. The pump was set with its intake at approximately 894 ft bgs.

A field grab water sample taken by WTWWS during the pump test was found to have TDS of 7130 mg/L, and it was unclear how waters from one or more producing zones might be mixing. Project funding did not allow for a packer test to separate and sample the water from the perforated zones. An Aqua Troll® from In-Situ, Inc., was installed downhole just above the pump (approximately 889 ft bgs) to monitor water level, temperature, and TDS over time.

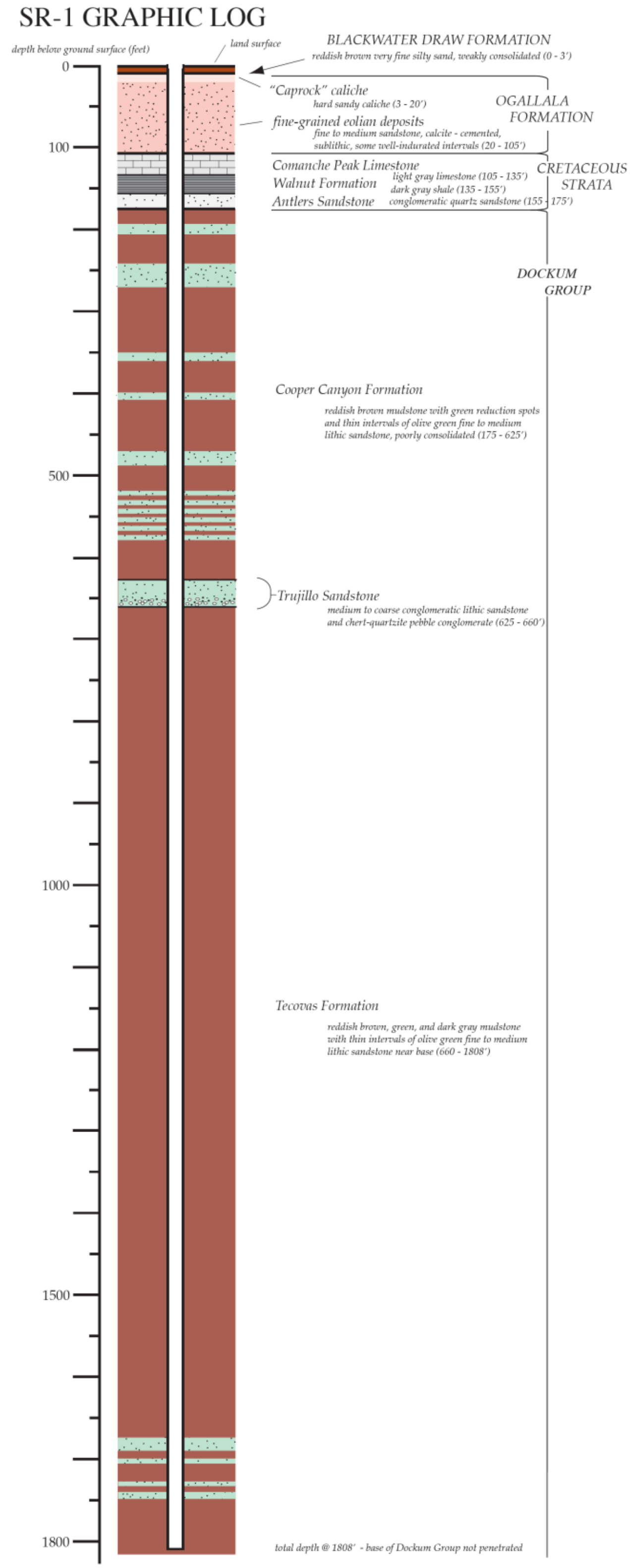


Figure 6. Simplified geologic log by Dr. Tom Lehman

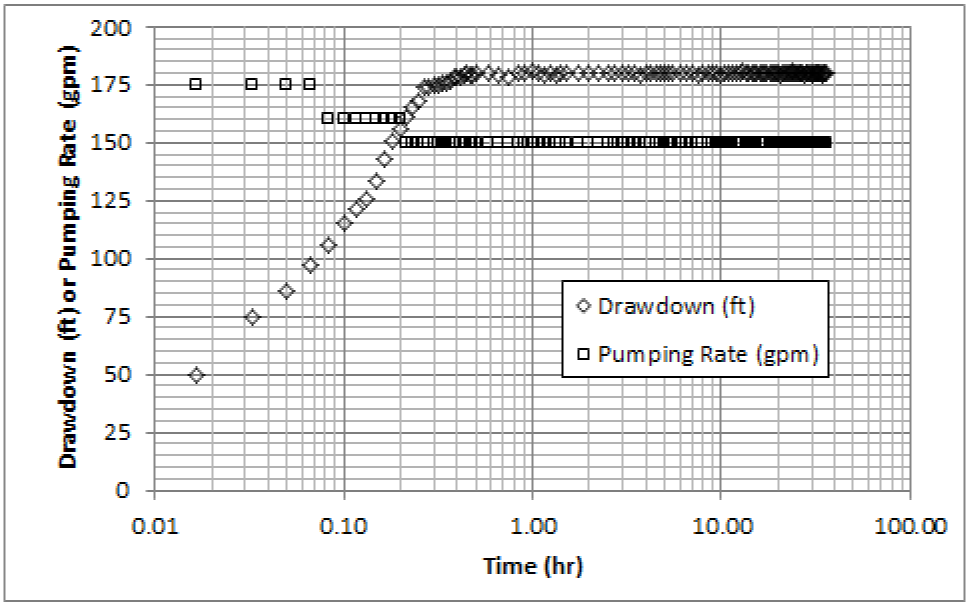


Figure 7. Drawdown and pumping rate during the 36-hr pumping test on August 4-5, 2011

2.2 RO Treatment System

PSC staff engineers assisted with the procurement of the RO system for the demonstration project based on their previous experience with similar treatment projects and TCEQ regulatory requirements. The general goal of the specification was a complete operational skid-mounted RO system to treat an inflow of at least 50 gpm of brackish water to meet the TCEQ's primary drinking water standards, with pretreatment capability for cartridge filtration, pH adjustment, and antiscalant addition. The target recovery factor was at least 70 percent with a salt rejection rate of 95 percent and minimum membrane life of two years. The RO system was purchased from Crane Environmental of Venice, Florida, in December 2010 with TTU DOE funds for $85,169 plus $5,500 for spare parts. The RO system model was an EPRO 12x840 with clean-in-place capability and two chemical dosing systems for antiscalant and pH adjustment. The Dow Filmtec LE RO membranes were 8-in diameter by 40-in long elements in a two-stage configuration with the first array containing two sets of four elements and the second array holding one set of four elements. A variable frequency drive (VFD) controlled the high pressure pump. A touch-screen monitor provided access to the electronic controls for data outputs, alarm settings, recycle flow settings, and flush scheduling. Various flow, temperature, pH, and conductivity meters collected the displayed data. One of the few manual valves was used to control the concentrate recycle flow. The antiscalant was CC 4200, a polymer-based chelating agent input through one of the two chemical dosing system. Acid could be added to the antiscalant tank, or input from the second chemical dosing system. A Myron-L test meter, with associated stock standard solutions, allowed direct measurement of pH, conductivity, and TDS from grab water samples from the various ports on the system. Figure 8 shows the RO skid inside the RO building. The two lower white pipes each held four elements and make up the first array, while the upper white pipe held the four elements of the second array.

Figure 8. RO skid in place at the demonstration site

Figure 9. RO building, wind turbine, and well site

Concentrate management is an important aspect of any desalination system. Alternatives considered included an evaporation pond, additional RO for the concentrate flow, and discharge into the City's wastewater collection system. After discussion with PSC and the City staff, the choice for this demonstration project was to simply blend the permeate and concentrate flows in a lift station and pump the mixture into the City's wastewater collection system. This alternative required the least attention from the City staff, and the flow rate was small enough to easily dilute into the City's wastewater flow without impacting the wastewater treatment plant. The lift station and associated sewer line were designed by West Texas Consultants (WTC) and constructed in 2012.

A 30 ft by 30 ft metal building was constructed at the site to contain the RO system. The building and the infrastructure between the well and the RO system were also designed by WTC and constructed in 2012. Electricity from the local Xcel Energy grid connection was also included, so that the demonstration of the well and RO system operation could be continuous, not just when sufficient wind energy was available. Figure 9 shows an external view, looking northwest, of the building, wind turbine, and well site after construction was completed. Figure 10 provides a simple process diagram for the well and RO system.

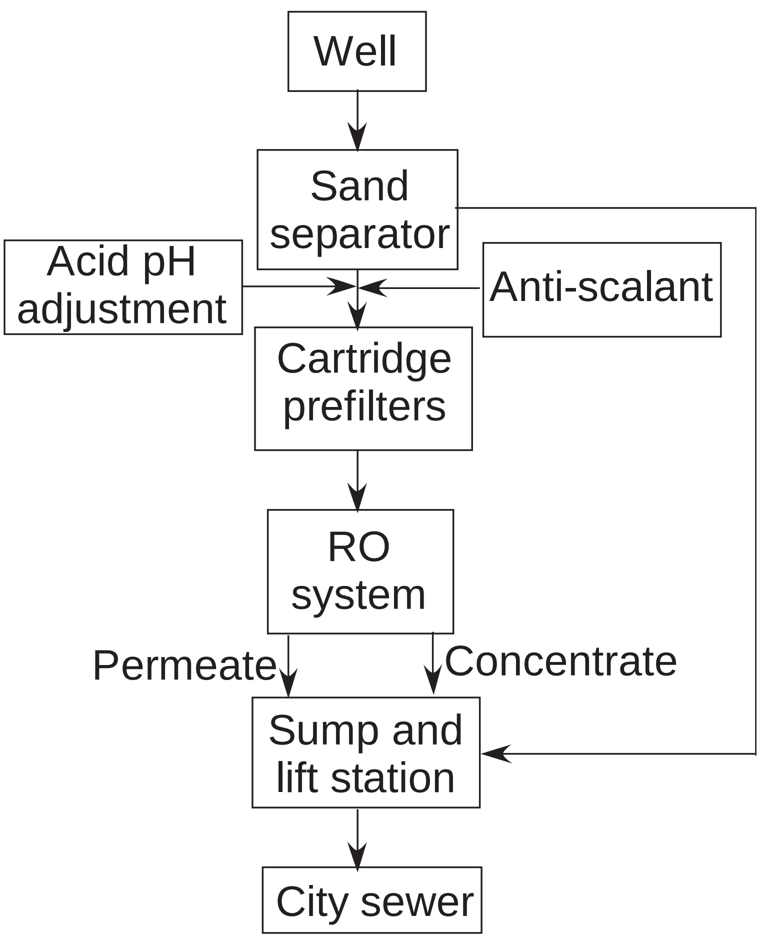


Figure 10. Process flow schematic

2.3 Wind Turbine

The 50-kW wind turbine was purchased from Entegrity Wind LLC for $250,000, which included the turbine and tower, site engineering, foundation, wind turbine assembly and start up, and a five-year warranty. The funding comprised a TTU grant of $162,000 from the State Energy Conservation Office (SECO) and $88,000 from the TDA. Entegrity partnered with WTC for the site engineering and local construction contractors Lamesa Irrigation for the installation. The turbine's nacelle and blades are supported by a 100-ft galvanized steel lattice tower at a centerline hub height of 102 ft. Figure 11 shows the installation of the nacelle at the top of the lattice tower. Other technical specifications for the wind turbine are listed below.

- **Performance Parameters**
  - Rated Electrical Power
    - 50 kW @ 25.3 mph
  - Wind Speed Ratings
    - Cut-in: 8.9 mph (4.0 m/sec)
    - Shut-down: 56 mph (25 m/sec)
    - Design Speed: 133 mph (59 m/sec)
  - Average Annual Output at Sea Level:
    - Class 2 wind speed: 115,000 kWh
    - Class 3 wind speed: 149,000 kWh
    - Class 4 wind speed: 177,000 kWh
- **Rotor**
  - Type of Hub: Fixed Pitch
  - Rotor Diameter: 49.2 ft
  - Swept Area: 1902 ft^2
  - Number of Blades: 3
  - Rotor Solidity: 0.077
  - Rotor Speed @ 50 kW: 65 rpm
  - Location Relative to Tower: Downwind
  - Cone Angle: 6 degrees
  - Tilt angle: 0 degrees
  - Rotor Tip Speed: 114 mph @ 60 Hz
- **Blades (3)**
  - Length: 23.7 ft
  - Material: Epoxy/glass fiber
  - Blade Weight: 330 lb (approx.)
- **Generator**
  - Type 3 phase/4 pole asynchronous
  - Frequency: 60 Hz
  - Voltage: 3 phase @ 50/60 Hz, 415-600
  - kW @ Rated Wind Speed: 50 kW
  - kW @ Peak Continuous: 66 kW
  - Insulation: Class F
  - Enclosure: Totally Enclosed Air Cover

Figure 11. Assembly of the 50-kW wind turbine

The nominal maximum height of the turbine was 127 ft, and a Federal Aviation Administration (FAA) determination of no hazard to air navigation was required because of the proximity of the turbine to the Gaines County Airport. PSC engineers prepared the successful application for the FAA site approval. Both the wind turbine and the local electrical grid were connected to the RO building with a two-meter set up so that the contributions of both sources could be separated. During the demonstration period, the well and RO system were run continuously using renewable wind energy when available and grid electricity otherwise. The control box at the base of the tower displayed current operational data as well as the accumulated run time and energy generation in kWh. The wind turbine became completely operational on March 6, 2013, and began generating electricity on that date.

3 Demonstration Observations

3.1 Well Behavior

After the well was completed in August 2011, it was rarely pumped because the RO system was not commissioned until October 2012. Occasional access to the pressure transducer datalogger showed that the "static" depth to water decreased from the initial 746 ft in August 2011 to less than 100 ft in the spring of 2012. The RO system was commissioned in October 2012 while running only on grid power before the wind turbine became operational in March 2013. The City staff subsequently turned on the well and RO system for an hour or so several times a week to keep the membranes in working condition. The depth to water and TDS data under these conditions showed interesting behaviors, as shown in Figures 12 and 13. The TDS felt by the sensor under static conditions was typically 2.0 to 2.3 g/L, and remained in that range for the one hour of pumping, which could cause over 200 ft of drawdown at the well. After the well pump was shut off, the TDS felt by the sensor rose markedly, showing values as high as 10 to 16 g/L in Figure 12, and even exceeding 30 g/L in at times in Figure 13. These results indicated that significant mixing took place in the well as the water level recovered quickly and deeper water rushed upward. The variation of TDS values from 2 to 34 g/L demonstrated differences in TDS between the shallow water, which resided at the transducer under static and pumping conditions, and the deeper water, near the bottom of the well. As is discussed in Section 3.2, under long term pumping conditions, the feed water received at the RO system had intermediate TDS levels closer to 8 g/L.

The other effect of the higher water level in the well was a large increase on the pressure on the intake side of the pump. The initial design and construction of the RO system installation included an intermediate 5-hp booster pump with a VFD to manage potential pressure variations from the well pump. With the higher intake pressure on the well pump, the well pump delivered too much pressure to the booster pump. The eventual solution was to remove the booster pump and put a VFD on the well pump, allowing the well pump to run at approximately 45 Hz instead of the original 60 Hz by controlling the pressure delivered to the RO system. This improvement was accompanied by the addition of a sand separator tank to assist the prefilters. Further description of the well performance is combined with the RO system results in the next section.

Continuous operation of the well, RO system, and wind turbine began on April 18, 2013. The typical flow rate from the well was approximately 55 gpm. Unfortunately, the well motor

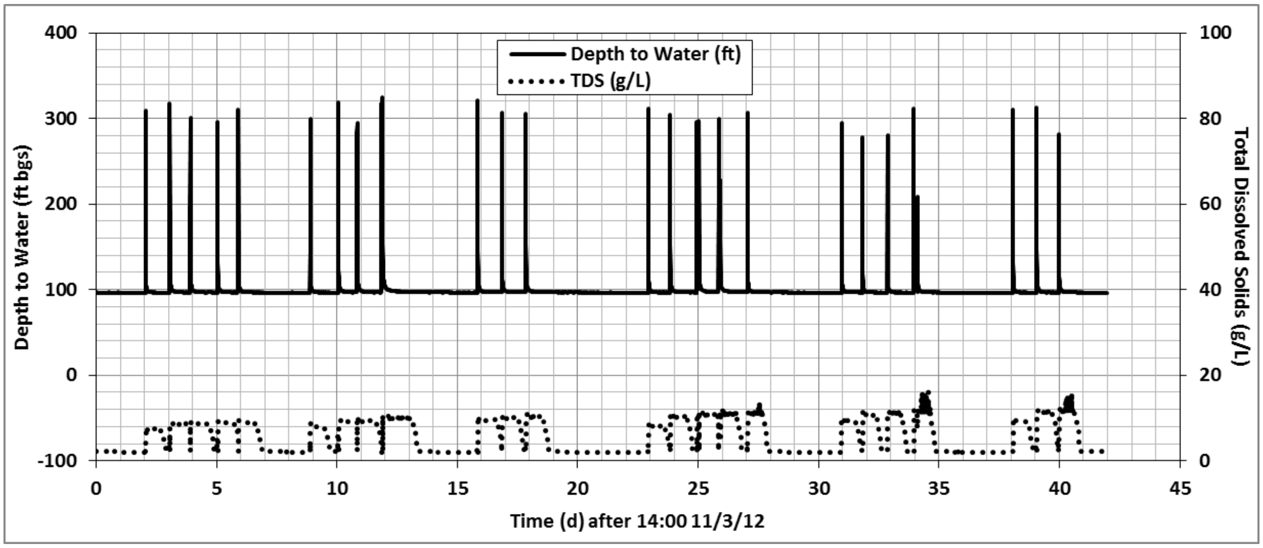


Figure 12. Depth to water and TDS from Aqua Troll for November 3 to December 15, 2012

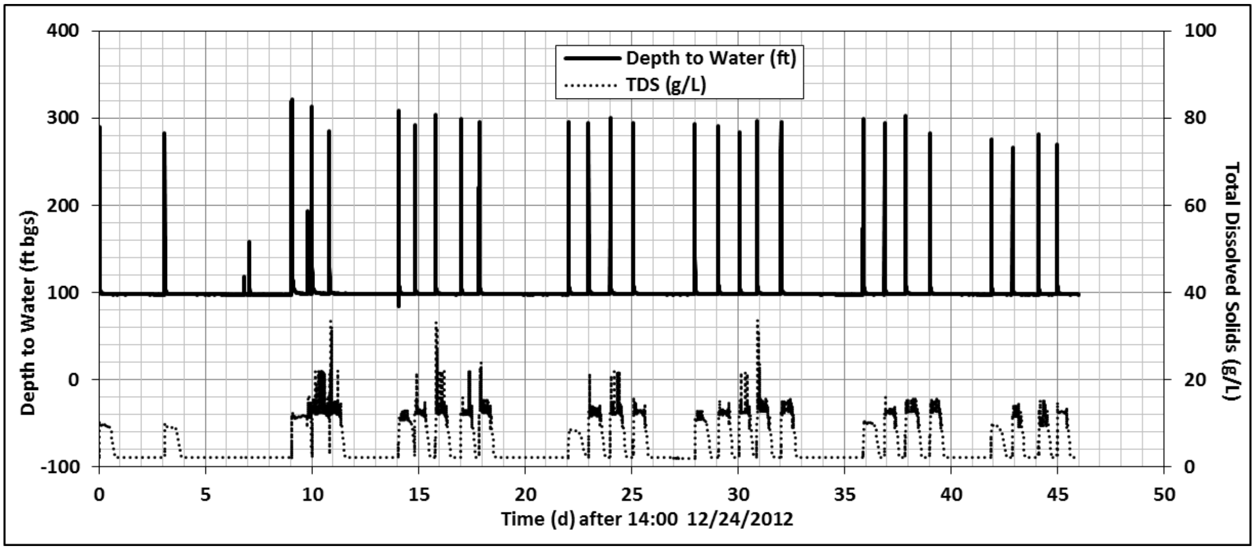


Figure 13. Depth to water and TDS from Aqua Troll for December 24, 2012 to February 10, 2013

stopped with a ground fault on May 2, 2013, after 13 days of operation. The well pump and motor were pulled, and the motor was replaced. The Aqua Troll cable was damaged as it was removed. The well became operational again on June 17, 2013, and ran almost continuously for 42 days until August 7, 2013, when a nearby lightning strike disabled most of the site devices. The power surge affected the control system for the RO system, which required eventual service, but the complete system was operated from August 12, 2013 until October 12, 2013, when chronic shutdowns became more common. The Aqua Troll was repaired by the manufacturer by removing the damaged section near the upper end, leaving 905 ft of cable. The sensor was put back in the well at a depth of approximately 879 ft on September 26, 2013. The well was turned off from mid-November 2013 until a second service call got the system back up on January 13,

2014. The transducer failed again in mid-February 2014 due to another cable problem. After two service events, the transducer had to be replaced, and the cable was shortened to 598 ft. The Aqua Troll was put back in the well on July 10, 2014, and recorded steadily after that date.

Based on the cumulative flow volume recorded by the flow meter at the well head, approximately 20,155,900 gal of water were delivered from the well through August 31, 2014. At an average flow rate of 56 gpm (based on flow data from the RO system), the cumulative operational time of the well was 250 day-equivalents (as opposed to calendar days). Figures 14 to 21 show the depth to water measurements for a total of 275 days between February 28, 2013 and September 21, 2014. It is interesting to note the changes in the pumping and non-pumping depths to water over time. Prior to April 2013, the static depth to water was typically 95 to 100 ft, and the depth to water increased by 80 to over 300 ft during the short 1-hr intermittent pumping intervals for short-term RO system operation. The static water level recovered quickly after the short pumping intervals. After April 2013, the pumping depths to water ranged from 340 to almost 500 ft for pumping rates of 55 to 65 gpm, as is detailed in the next section. During extended down time, such as December 2013, the depth to water had time to recover back to about 122 ft, about 25 ft below the earlier static depth. It is apparent that the recovery time was much longer after long pumping periods. After December 2013, the non-pumping depths to water were often greater than 200 ft. Figure 21 shows September 2014 depths to water, and that the well continued to run until September 10. The Aqua Troll has been left recording in the well to track final recovery of static water level over the next few months beyond the project end date. As several months were required for the initial decrease in the depth to water from 740 ft to 96 ft, it may take several months for the water level to equilibrate again.

3.2 RO System

3.2.1 Operational Results

After the RO system was installed in the RO building and grid electricity became available, initial startup of the RO system was scheduled in the fall of 2012 with representatives of Crane Environmental, even though the wind turbine had not yet been commissioned. As previously noted, the static water level slowly rose from its temporarily stable 740 ft bgs after drilling in July 2011 and development to about 96 ft bgs in the spring of 2012 and persisted for several months. The certified cementing of the surface casing must prevent any inflow to this Dockum well from the shallower Ogallala Aquifer, so the higher water level was caused by the pressure in one or more of the three perforated zones. In anticipation of the startup event, a water sample was collected in August 2012 by PSC from the Dockum well after one hour of continuous pumping for laboratory analyses at TraceAnalysis, Inc., in Lubbock. Table 3 summarizes the results of those analyses and compares them to the water quality reported for the City of Seminole’s nearby new Ogallala well 43. The TDS level of 2330 mg/L was well below the 7130 mg/L reported in the grab sample in July 2011, which was collected with a temporary pump set at 1600 ft bgs, indicating that the August 2012 sample was mostly from the shallower fresher water produced by the permanent pump set at 894 ft bgs. The 2330 mg/L was a little higher than the typical TDS value of 1950 to 2100 mg/L from the Aqua Troll that was exposed to the upper, fresher water after the cable was shortened. It is apparent that some mixing between

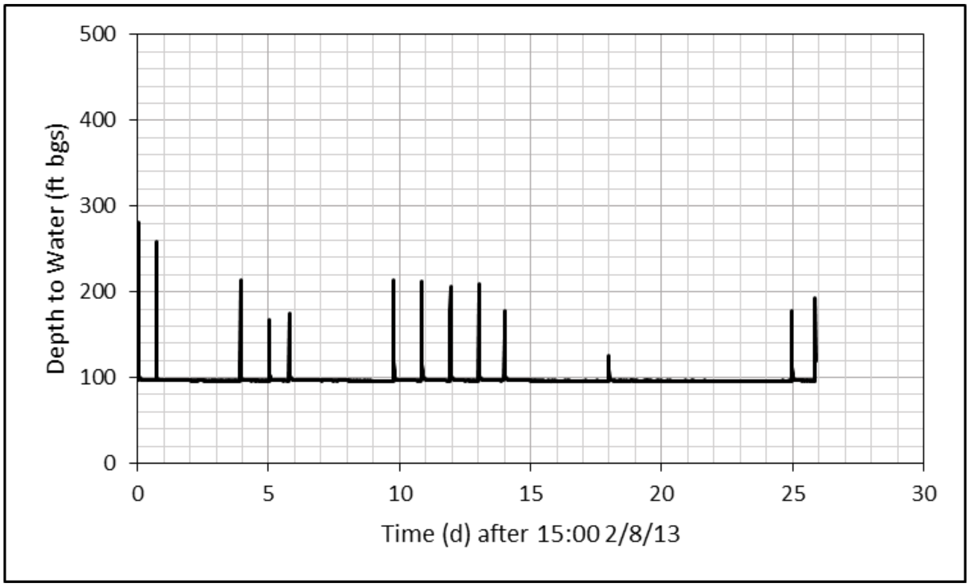


Figure 14. Depths to water for February 8 to March 6, 2013

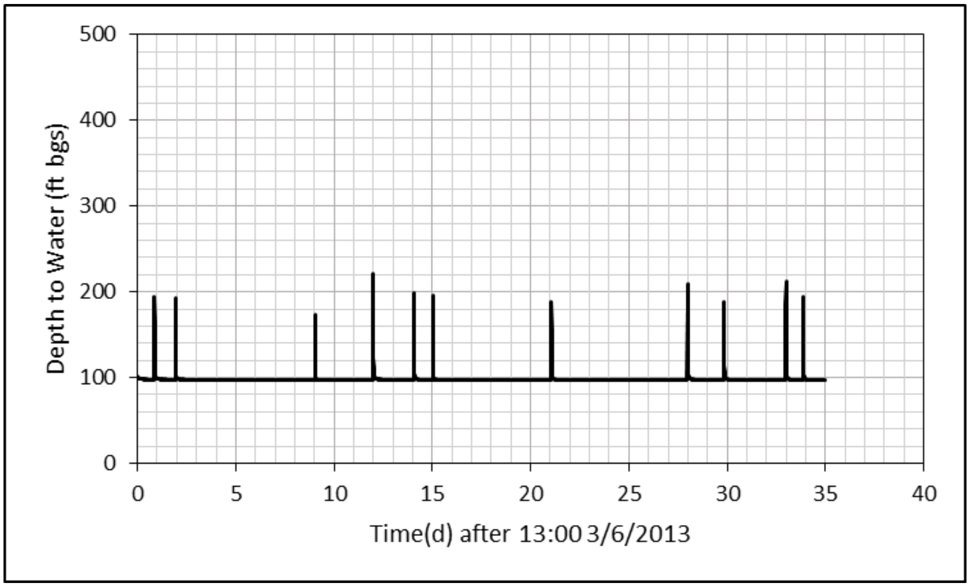


Figure 15. Depths to water for March 6 to April 10, 2013

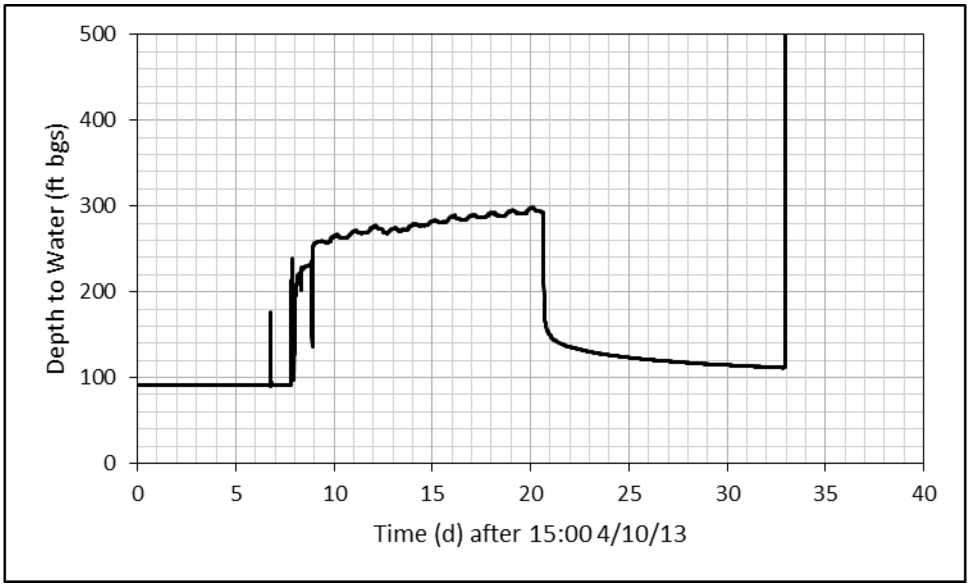


Figure 16. Depths to water for April 10 to May 13, 2013 (well motor failed on May 1, transducer removed May 13)

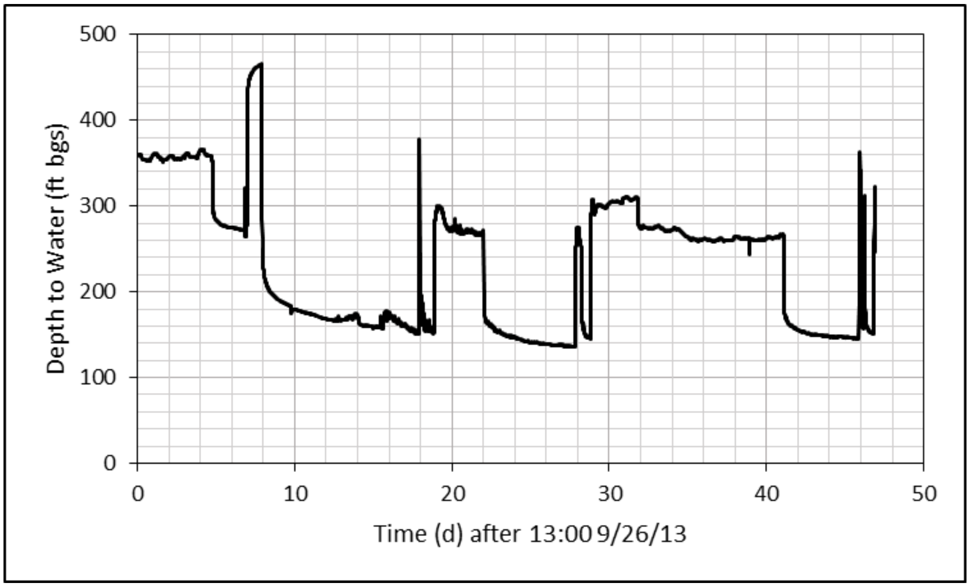


Figure 17. Depths to water for September 26 to November 12, 2013

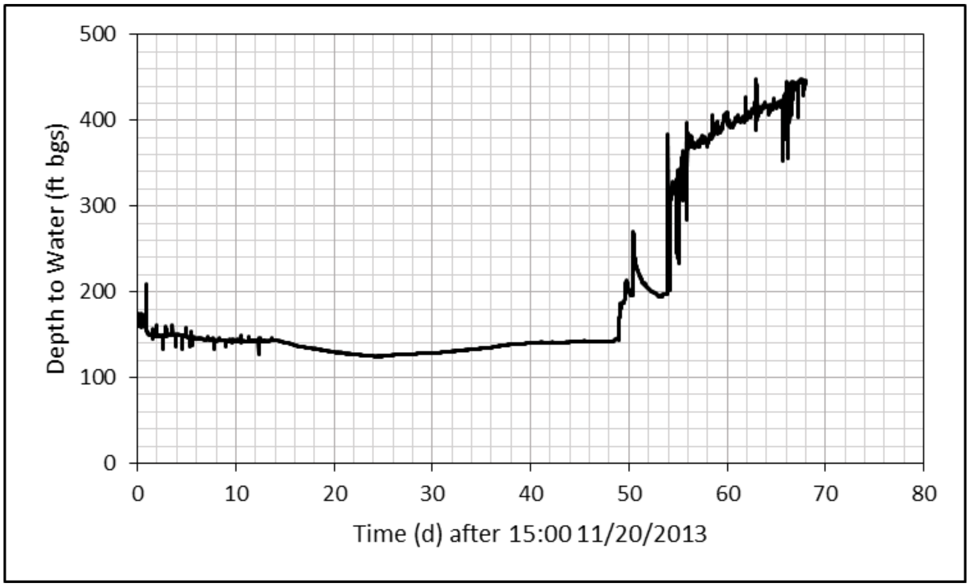


Figure 18. Depths to water for November 20, 2013 to January 27, 2014

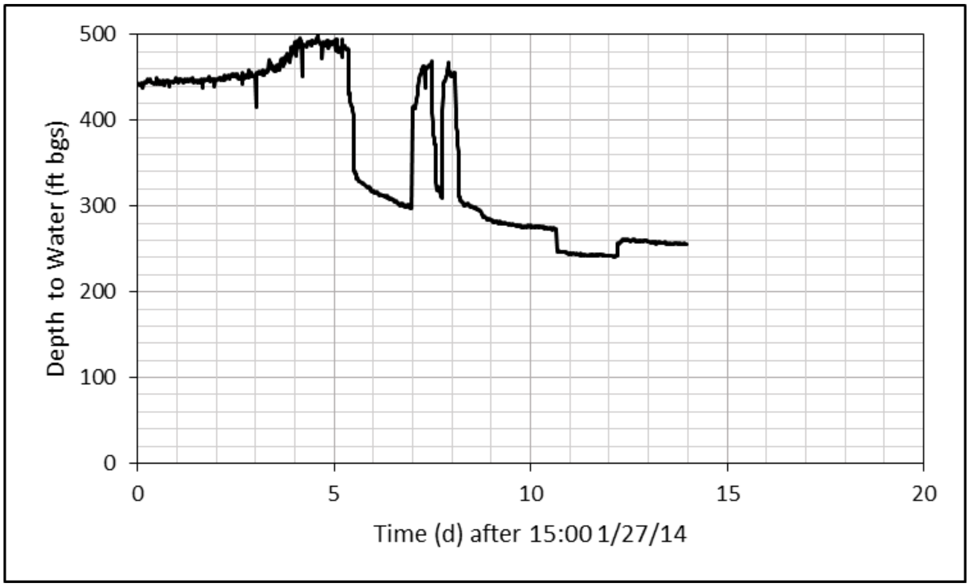


Figure 19. Depths to water for January 27 to February 10, 2014 (well flow set at 65 gpm prior to February 2, then reduced to 55 gpm, followed by down time; transducer failed on February 14)

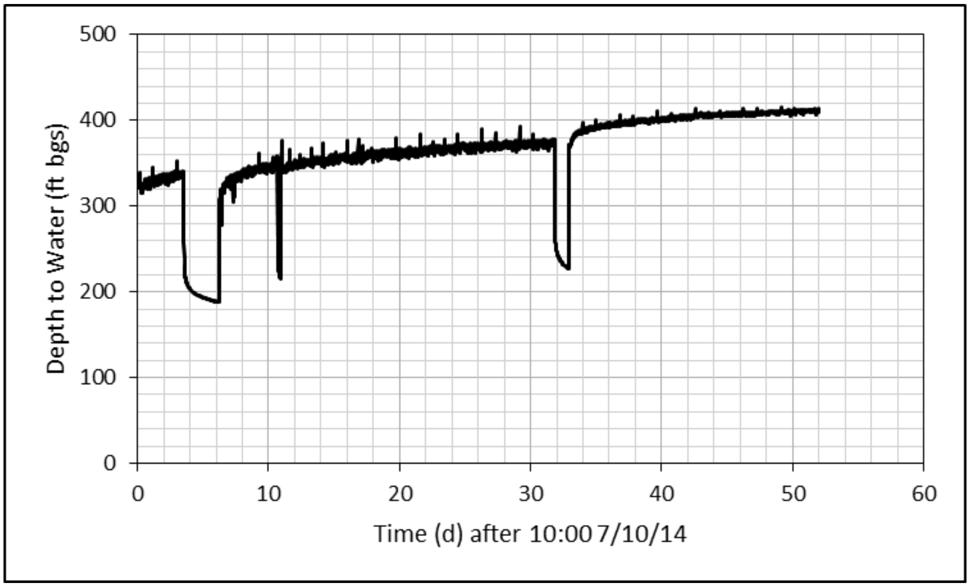


Figure 20. Depths to water for July 10 to August 31, 2014

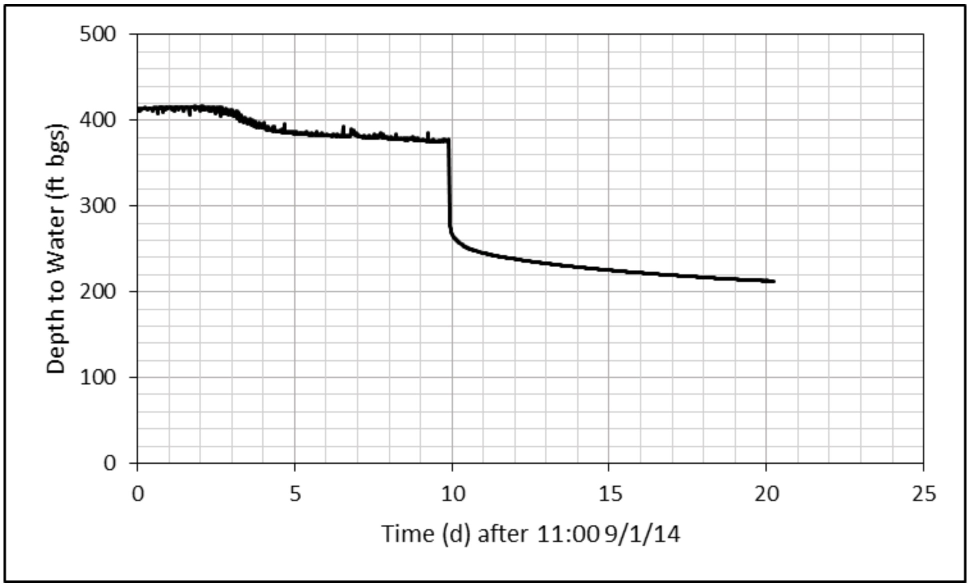


Figure 21. Depths to water for September 1 to 20, 2014

Table 3. Comparison of Dockum (8/12/12) and Ogallala water quality samples (concentrations in mg/L, except for pH in standard units)

Parameter	Dockum	Ogallala
pH	8.8	7.5
Calcium	7.85	94.9
Potassium	19.5	na
Magnesium	8.31	81.1
Sodium	829	95
Total Iron	1.01	0.01
Fluoride	<2.50	4.09
Chloride	424	243
Sulfate	747	213
Nitrate	0	6.75
Carbonate	19	0
Bicarbonate	210	148
Total Dissolved Solids	2330	891
Total Arsenic	<0.01	0.0189
Total Barium	<0.01	0.144
Total Cadmium	<0.01	<0.001
Total Chromium	<0.01	<0.01
Total Mercury	<0.0002	<0.0004
Total Lead	<0.01	<0.001
Total Selenium	<0.02	0.0229
Total Silver	<0.005	<0.01

two or more of the perforated zones must have occurred in the well, and that mixing process was obviously influenced by running the pump.

Commissioning and startup of the RO system with Crane Environmental, City of Seminole staff, and PSC took place on October 2-5, 2012, using grid-based power. According to the Crane technician, the RO system could easily reduce the TDS in the brackish water from over 2000 ppm to less than 100 ppm. Several City of Seminole water staff members were trained on the operation of the RO system, and they began running the well and RO system three to five days per week for 30 min to 1 hr to prevent deterioration of the membranes and other parts of the system. This intermittent procedure was followed until the wind turbine became operational on March 6, 2013. The Crane technician planned to return to Seminole for a 24-hr test run at that time to insure that the system was tuned and ready for continuous operation. During the period of intermittent operation, the City staff noted that the prefilters were clogging quickly due to build-up of sediments from the aquifer, and there were pressure problems between the well pump and the intermediate booster pump. With the assistance of PSC, the issues were resolved by installing a sand separator tank in the feed water line, removal of the intermediate booster pump, and addition of a VFD to control the speed of the well pump motor, as described in Section 3.1.

The wind turbine was commissioned on March 6, 2013, and the earliest date for the Crane technician's return to Seminole was April 18, 2013. The 24-hr operational test was successful with the cooperation of the City staff and Dr. Ken Rainwater, who monitored the system overnight. At the end of the test, the operational data in Table 4 were recorded either on the touch-screen data display or taken from the Myron-L test meter. The conductivity readings were converted to TDS as mg/L by multiplying them by 0.65. For example, the feed, permeate, and concentrate TDS levels were 7930, 429, and 21,100 mg/L, respectively.

Table 4. Operational Parameters on April 19, 2013

Source	Parameter	Value
Touch-screen	Feed Conductivity (μS/cm)	12200
	Feed pH	7.7
	Feed Temperature (°F)	72
	Raw Feed (PF in) Pressure (psi)	42
	Prefilter Out Pressure (psi)	40
	HPP Out Pressure (psi)	232
	Interstage Pressure (psi)	226
	Recycle Flow (gpm)	0
	Concentrate Pressure (psi)	222
	Concentrate Flow (gpm)	16
	Permeate Pressure (psi)	13
	Permeate Flow (gpm)	40
	Permeate Conductivity (μS/cm)	660
	Permeate pH	6.4
Myron-L Meter	Permeate Conductivity (μS/cm)	660
	Concentrate Conductivity (μS/cm)	32400
	Bottom Array 1 - Vessel 1 Permeate Conductivity (μS/cm)	526
	Middle Array 1 - Vessel 2 Permeate Conductivity (μS/cm)	352
	Top Array 2 - Vessel 3 Permeate Conductivity (μS/cm)	2285

The RO system did not have internal capability to collect and store operational data, so the City staff were given log sheets to fill out each day they visited the site. The data were available as shown in Table 4. Figures 22 to 28 display the reported data values from April 18, 2013 to August 31, 2014. Blanks in the figures indicate down times, except for June to mid-July 2014, when the system was running but few log sheets were filled out due to staff vacations. Some general issues in the data are mentioned here, while others are clarified in the narrative of the system operation later in this section. Figure 22 provides the permeate and concentrate flow values, with the total feed as the simple addition of those two values. Near-zero values of

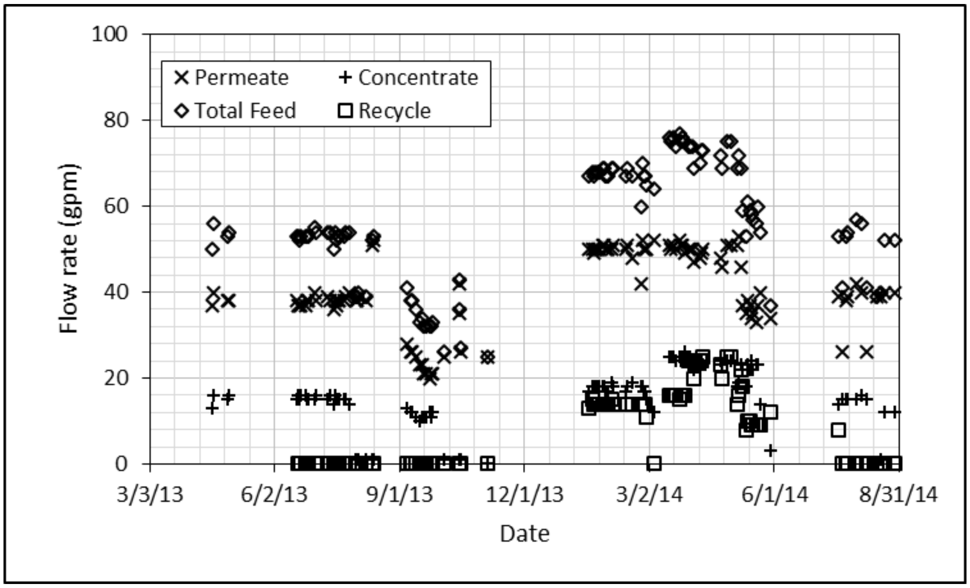


Figure 22. Comparison of permeate, total feed, concentrate, and concentrate recycle flow rates

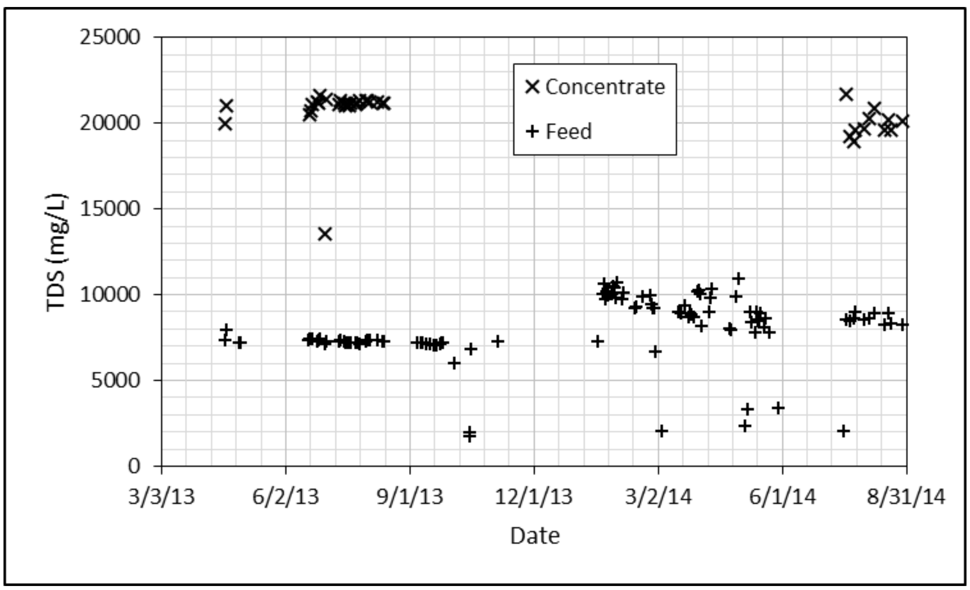


Figure 23. Comparison of feed and concentrate TDS levels

concentrate flow indicated malfunctioning of the concentrate flow meter, which the City staff could repair by removing, cleaning, and replacing the flow meter. Recycle flow refers to concentrate recycle that was added to the total feed to manage the water flux across the membranes. The zero values toward the end of the demonstration period were likely due to sensor failure. Figure 23 displays the TDS levels in the feed water and the concentrate produced by the RO system. The permeate TDS values are shown separately in Figure 23 as a different flow rate scale was necessary. In Figure 24, there were some dates on which values of permeate TDS were recorded both the RO system sensor and the Myron-L meter. In the early months of

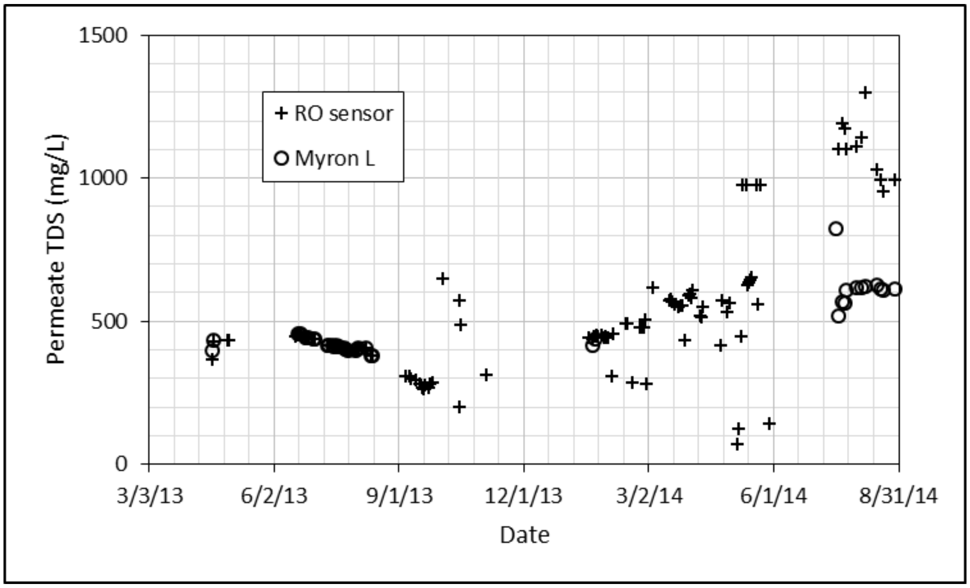


Figure 24. Comparison of permeate TDS from RO system sensor and Myron-L meter

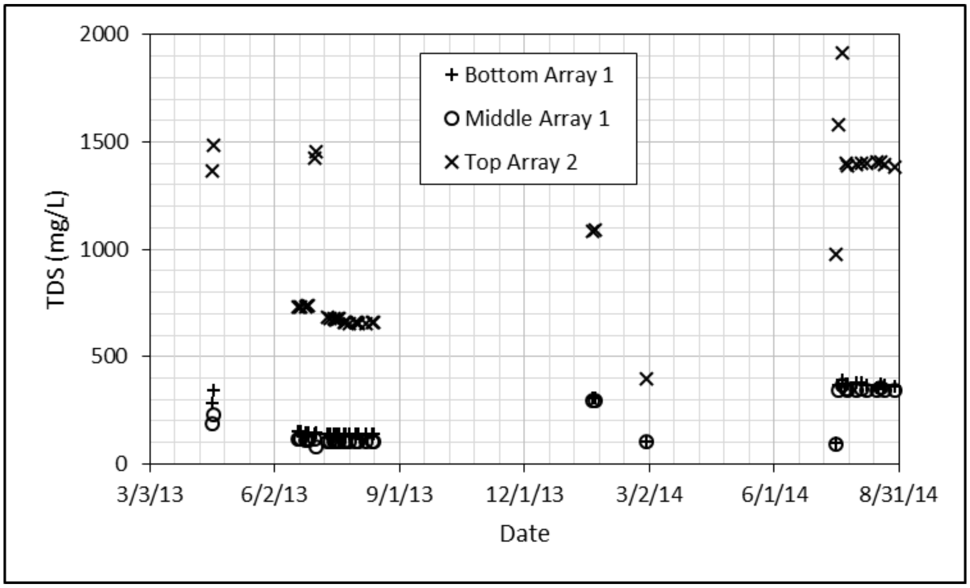


Figure 25. Comparison of TDS levels in the permeate from the three membrane vessels

continuous operation, the two readings were identical, and only the red marker can be seen because it lies on top of the blue marker. Toward the end of the demonstration period, the RO system TDS sensor began to give erratic high readings, well above those from the Myron-L meter, which was easy to calibrate and thus trustworthy. Figure 25 provides TDS values from the Myron-L meter for grab samples from the output of the three membrane vessels. The two vessels in Array 1 were expected to have similar values, and Array 2's output TDS was expected to be greater than the Array 1 values as it received the concentrate from Array 1. The incoming and exiting pressures across the prefilters are shown in Figure 26. High pressure values indicated the need to replace the prefilters. Figure 27 shows how the pressure dropped across the

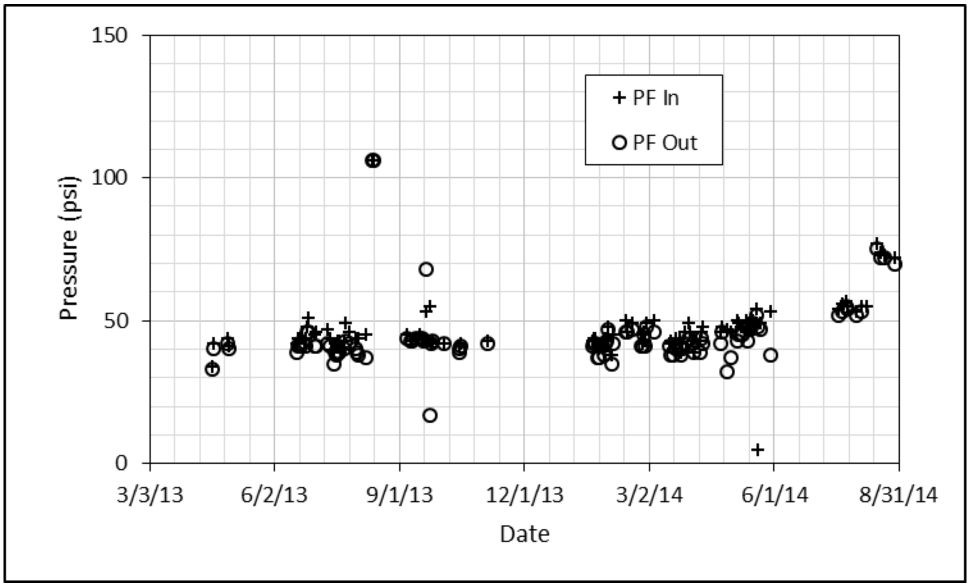


Figure 26. Comparison of pressure upstream (PF in) and downstream of prefilters (PF Out)

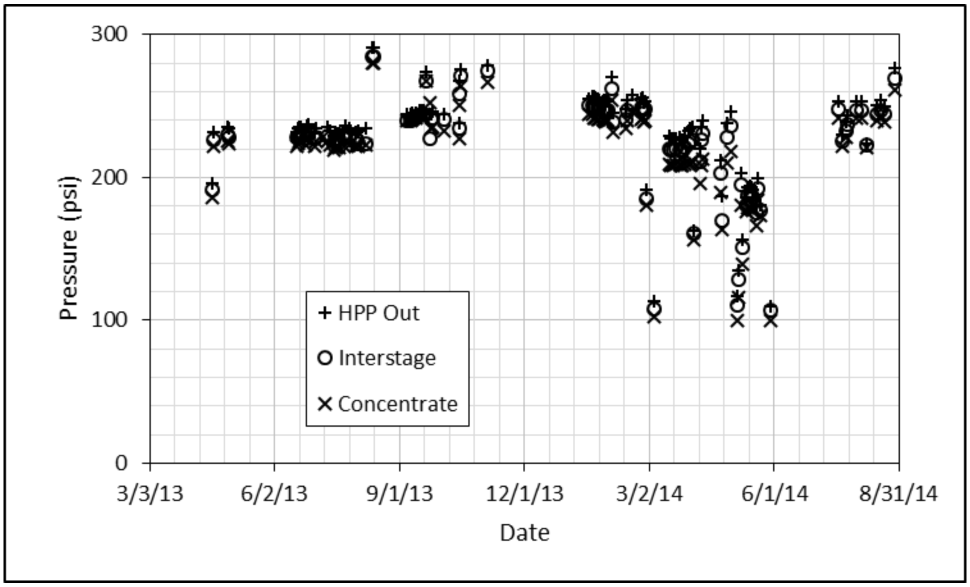


Figure 27. Comparison of pressure after the high pressure pump (HPP Out), interstage (between membrane arrays), and after the membrane arrays (Concentrate)

two membrane arrays. The pH levels recorded by the RO system sensors for the feed and permeate waters are shown in Figure 28. Erratic and high values of pH indicated the need for maintenance of these probes.

The well and RO system worked continuously until May 2, 2013, when the well pump shut down with a ground fault in its motor. The well pump and motor were pulled, the motor was replaced, and the well and motor were put back in place and restarted on June 17, 2013. The

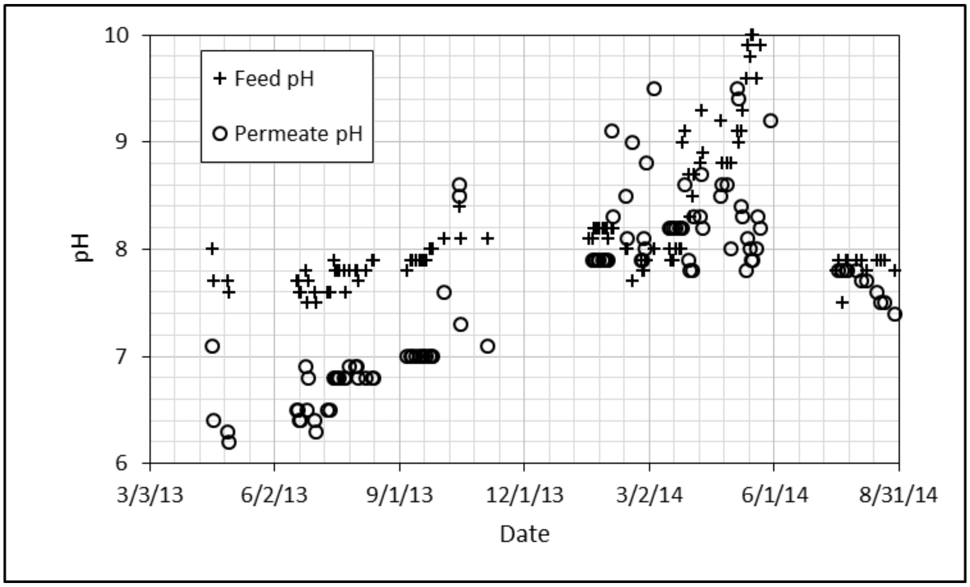


Figure 28. Comparison of feed and permeate pH levels

RO system and well then ran relatively continuously, with occasional shutdowns primarily due to maintenance of the antiscalant tank and dosing system plumbing, until August 7, 2013, when a nearby lightning strike caused local power surges. The City staff inspected all the electronic systems and made the adjustments that they could, and the well and RO system were restarted on August 12, 2013. As shown in Figure 22, the permeate and concentrate flows fell off markedly, and the pressures across the membranes were erratic and high. The research team and City staff concluded that the lightning strike had caused problems in the electrical controls and sensors for the RO system, so we reached out to Crane Environmental for a service call to check the electrical, mechanical, and programming aspects of the RO system. We learned that Crane Environmental no longer had sales or technical employees in Texas, and it took several weeks for them to find a service company in Texas to assist in Seminole. Eventually, Crane directed us to Noble Water Technologies from Dallas. Noble sent a two-person team to Seminole for November 11-12, and this team recalibrated sensors and flow meters successfully, but they were unfamiliar with the control programming and had more questions than answers about the Crane configurations. They did say that it was likely that the membranes were fouled, but they did not examine the membranes directly. Their repair visit costs were covered by the prepaid service agreement with Crane Environmental. After the departure of the Noble team, the system could only run for less than 1 hr, so the research team had to identify another service organization. Based on recent experience, PSC recommended Worth Hydrochem from Norman, Oklahoma.

A two-person team from Worth spent three days at the site between January 13 and 15, 2014. The team was well experienced with the mechanical systems and the programming of the system controls. Their control programming specialist reconfigured the programming to better manage the VFD on the feed booster pump and the fast flush and permeate cycles. They also worked with the City staff to adjust the settings on the VFD for the well pump to better handle occasional pressure fluctuations. Finally, they found that the prefilters and membranes were fouled. The system had been idle for two months, and the prefilters and membranes had a hydrogen-sulfide-type odor. Figures 29 and 30 show their photographs of the prefilters and membranes that day. The Worth team recommended autopsies of the most upstream element, one of the most downstream elements, and one of the prefilter cartridges. The results of those analyses are presented in the next subsection.

Figure 29. Prefilters removed on January 13, 2014 (new cartridge on left for comparison)

Figure 30. Membrane elements removed on January 13, 2014 (upper row Array 2, lower row Array 1)

Based on the improvements made by the Worth team, the well and RO system were able to process a feed flow of about 70 gpm, producing 50 gpm of permeate and 20 gpm of concentrate. While this greater production was impressive for the RO system, the total feed flow rate was eventually taxing on the well pump, causing pressure fluctuations that led to occasional shutdowns, after which the system could be restarted. The research team encouraged the City staff to reduce the VFD settings for a target feed flow of about 55 gpm. The lower flow rates in the last two months appeared to contribute to smoother operation with fewer shutdowns. The relatively high pressures across the prefilters at the end of August indicated that the prefilters were in need of replacement. The high pressures at the prefilters then led to relatively high pressures at the membranes.

As stated in the previous section, the total time of operation of the well and RO system was 250 day-equivalents based on total well production of 20,115,900 gal at an average flow rate of 56 gpm. Based on the RO system data, the average permeate flow was 41 gpm (14,727,700 gal total), accompanied by an average concentrate flow of 15 gpm (5,388,200 gal total), for an average volumetric recovery of 73 percent. The average TDS values were 7980, 520, and 20,600 mg/L for the feed, permeate, and concentrate flows, respectively. When running, the system was able to deliver high quality water. Feed and permeate water samples were collected on June 24, 2013, for multiple analyses by TraceAnalysis, Inc. Table 5 summarizes the results. The local Ogallala Aquifer water quality was shown in Table 3, with arsenic, fluoride, and TDS as 0.019, 4.1, and 891 mg/L, respectively. The permeate values from the laboratory analyses of arsenic, fluoride, and TDS were <0.01, <0.5, and 436 mg/L, respectively. It is interesting that the iron concentration was 0.57 mg/L in the feed water and 1.25 mg/L in the permeate. Iron is also of special interest in the following membrane autopsies. Although we were disappointed that the membranes fouled during the demonstration, the added information will be useful to the City and others interested in desalination of this brackish water. We were likely at a disadvantage due to the storage of the new RO skid from December 2010 until its first startup in October 2012. The Crane Environmental staff was concerned that the system was intended to be started up within a relatively short time to encourage better and longer membrane performance.

3.2.2 Prefilter and Membrane Autopsies

Professional Water Technologies (PWT) of Vista, California, was engaged to carry out autopsy analyses for the foulants on the fouled membranes and prefilters. The most upstream and most downstream membranes removed in January 2014 had been stored in open air until they were shipped in July 2014, so they had dried. A recently fouled cartridge filter was obtained on June 16, 2014, and was kept moist until shipping. All three items were treated with a sodium bisulfite solution and wrapped in plastic prior to packing. PWT staff performed several analyses, including Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted-Energy Dispersive X-Ray Analysis (T-EDXA) and Fourier Transform Infrared Spectroscopy (FTIR). In addition, the membrane elements were also wet-tested, and data were normalized to the manufacturer's standard conditions. The complete reports of the autopsies are available as separate pdf files (Wardle 2014a, b, c). The following paragraphs were paraphrased from those reports.

Table 5. Comparison of Feed and Permeate Water Qualities

Analyte	Concentration		Units	Reporting Limit
	Feed Water	Permeate		
Bicarbonate	184	<12.2	mg/L	12.2
Carbonate	<12.0	<12.0	mg/L	12
Chloride	2910	178	mg/L	2.5
Fluoride	<5	<0.5	mg/L	0.5
Nitrite-N	<0.4	<0.04	mg/L	0.04
Nitrate-N	<0.4	0.0718	mg/L	0.04
Sulfate	1780	3.97	mg/L	2.5
Dissolved Calcium	117	<1	mg/L	1
Dissolved Magnesium	49.4	<1	mg/L	1
Dissolved Potassium	14	5.94	mg/L	1
Dissolved Sodium	2830	121	mg/L	1
Total Dissolved Solids	8235	436	mg/L	2.5
pH	7.67	6.35	s.u.	2
Total Silica	8.72	<0.5	mg/L	0.5
Total Aluminum	<0.05	<0.05	mg/L	0.05
Total Arsenic	<0.01	<0.01	mg/L	0.01
Total Copper	<0.005	<0.005	mg/L	0.005
Total Iron	0.571	1.25	mg/L	0.01
Total Manganese	0.402	<0.005	mg/L	0.005
Total Uranium	<0.03	<0.03	mg/L	0.03
Total Zinc	<0.01	<0.01	mg/L	0.01

The cartridge filter was covered in a heavy layer of brown-colored foulant. Brown discoloration was also noted on the interior of the filter. LOI testing indicated the foulant from the cartridge filter was composed of 8.8 percent volatile organic material and 91.2 percent inorganic material. SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant was iron at 71.30 percent. The remaining inorganic constituents were silicon (11.97 percent), calcium (4.57 percent), sulfur (3.70 percent), chlorine (2.95 percent), aluminum (2.70 percent), potassium (2.06 percent), manganese (0.39 percent), titanium (0.28 percent), and magnesium (0.02 percent). FTIR analysis of the foulant removed from the cartridge filter indicated it was mostly alumino-silicate clays, obviously from the Dockum clays, with small amounts of carbohydrates and polysaccharides.

The leading membrane element was subjected to a wet test that showed that the element produced both slightly lower than normal flow (10,658 gpd vs. 11,500 gpd) and rejection (98.3 percent vs. 99.3 percent). The element had good mechanical integrity. Orange deposition was found on the fiberglass wrap of the element. Foulant build-up was found on the feed scroll end of the element. Dissection of the element revealed a coating of orange-colored foulant on the membrane surface. Staining of the membrane backing material was found on several of the leaves. The integrity of the glue lines and channel spacer netting material was good. LOI testing indicated this foulant was 10.5 percent volatile organic material and 89.5 percent inorganic material. SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant was silicon at 41.57 percent. The remaining inorganic constituents included iron (31.19 percent), aluminum (11.56 percent), calcium (7.22 percent), potassium (6.91 percent), titanium (1.23 percent), chlorine (0.14 percent), and magnesium (0.14 percent). FTIR analysis of the foulant indicated mostly alumino-silicate clays with small amounts of carbohydrates and polysaccharides.

The tail membrane element's wet test showed that the element produced significantly lower than normal flow (639 gpd vs. 11,500 gpd) and low rejection (97.1 percent vs. 99.3 percent). The element had good mechanical integrity. Orange deposition was found on the fiberglass wrap and both anti-telescoping devices (ATD) of the element. Dissection of the element revealed a coating of a crystalline foulant and orange discoloration on the membrane surface. The integrity of the glue lines and channel spacer netting material was good. LOI testing indicated the foulant was 1.4 percent volatile organic material and 98.6 percent inorganic material. SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant was calcium at 91.96 percent. The remaining inorganic constituents were manganese (3.16 percent), iron (3.10 percent), sulfur (1.20 percent), and silicon (0.56 percent). FTIR analysis of the foulant removed from element indicated mostly calcium carbonate with small amounts of alumino-silicate clays.

The autopsy analyses showed that the foulants consisted mainly of inorganic minerals. The organic foulants were 10.5 percent and 8.8 percent on the leading membrane elements and the cartridge filter, respectively, while almost negligible (1.4 percent) on the tail membrane element. We can conclude that organic fouling and biofouling were not major concerns in this current study.

Iron and silicon were the two leading constituents in the foulants on both the cartridge filter and the leading membrane element. The cartridge filter was clearly fouled by clay particles produced with this water from the Dockum Aquifer. From the slight decrease in permeate flux and salt rejection, it can be deduced that the fouling on the leading membrane element was also mainly due to the deposition of the particulate materials. The shift of relative importance of the two constituents indicated that the iron minerals had relatively large particle sizes so that they could be more readily intercepted by the cartridge filter. The cartridge filter was not sufficient for fouling control because significant amounts of iron and silicon particulates passed through and reached the RO membrane.

The tail membrane element was seriously fouled, as indicated by the reduction of permeate flux almost by 50 percent. The foulant composition analyses showed the most probable foulant was calcium carbonate. Scale forms when the calcium carbonate becomes supersaturated in the retentate in the RO channels. Calcium carbonate scale forms a dense layer that can significantly reduce the permeability of the RO membrane. Calcium carbonate scale can be readily prevented by acidifying the feed water with strong acid, such as hydrochloric or sulfuric acid. The Worth team noticed permeate pH values of 8.4 and higher when running the system with the fouled membranes. The carbonate scaling indicated insufficient management of the acid dosing system, whether as a separate liquid or mixed with antiscalant. The significant decrease of iron and other constituents in the foulant composition on the tail membrane element can be a result of the relatively fast rate of calcium carbonate scale formation. The relatively low amount of silicon may be due to the higher solubility of silicate minerals at higher pH.

From the autopsy results and analyses, we can conclude that the current cartridge filter was not sufficient to mitigate particulate fouling on the RO membrane. Although a different cartridge filter with smaller pore size can do a better job in particulate removal, it may not economically favorable because of the high fouling rate of the feed water. A microfiltration unit, multimedia filter, greensand filter, or aeration followed by a multimedia filter or settling basin could be alternative choices for particulate fouling control. It is anticipated that the major fouling constituents iron and silicon can be sufficiently reduced by such pretreatment. The calcium carbonate scaling can be effectively controlled through pH management. The initial settings for antiscalant and acid additions were set by the Crane Environmental representative at the first startup in October 2012. The antiscalant dosage was adjusted by the Worth Hydrochem team in January 2014, and pH adjustment was terminated because of difficulties with the acid addition system and pH meters.

3.3 Wind Turbine

The 50-kW EW50 Entegrity wind turbine became operational on March 6, 2013. The research team attempted to set up a data acquisition system with RealTime Automation, a local electronics and communication contractor. The data generated from the wind turbine was supposed to be collected over time for later downloads. Unfortunately, although the company was paid for their services, no real-time data were collected or made available after repeated assurances that the data were being collected and stored. The wind turbine's control box did include a display that allowed the user to see selected current and cumulative data values. Based on the readings at the end of the demonstration period, the wind turbine had generated 37,054 kWh over 4276 hr (178 day-equivalents) of operation. The following analyses were done to evaluate the effectiveness of the wind turbine.

The research team was notified by the City staff that occasionally the wind turbine shut down due to its tip brake control. The City staff assumed that the shutdowns were caused by occasional high wind gusts, which can be common in West Texas. The wind turbine could be easily restarted by the start button, but the amount of down time was not known. In the early spring of 2014, the wind turbine was apparently stopped by a serious tip brake malfunction for a few weeks before the City staff notified the research team. Visits to the site by the research team were often at times of little to no wind, so there were no external indications that the turbine was down. When the research team notified Lamesa Irrigation, the service company, of the problem, the technicians had to wait several weeks to come to the site and scale the turbine tower due to safety concerns about the daytime wind conditions. The technicians accessed the turbine in early May 2014 and found that the tip brake mechanism needed replacement. The parts were covered by the warranty, but the parts had to be obtained from a Canadian supplier. Eventually, the technicians repaired the turbine and started it up on about June 6, 2014. It is possible that the wind turbine was down for four or more months in total, during a typically productive time of the year. As we had to deal with down time for the RO system and the well, the wind turbine also had its share of down time.

The best technical alternative to evaluate the energy produced by the wind turbine was to perform theoretical estimates of potential wind energy generation by combining the wind speed data over time from the West Texas Mesonet (WTM) station at Seminole with the power curve for the EW50 turbine. The WTM station was 4.25 mi north-northeast of the wind turbine, and the data records provided wind speeds at 10-m height at 5-min intervals. The 10-m (z_r) wind speeds (U_r) were scaled up to the wind speed (U) at turbine's hub height (z) of 102 ft (31.1 m) using the 1/7th power conversion as

$$\frac{U}{U_r} = \left(\frac{z}{z_r}\right)^{1/7} \quad (1)$$

The power curve for the turbine was generated by the testing staff at the Department of Energy's National Renewable Energy Laboratory in Golden, Colorado, and published in a report by Smith et al. (2011). The power curve for the Golden site's air density is shown in Figure 30, at the local elevation of 5428 ft (1655 m). It is apparent that the wind speed must exceed 5.54 m/sec (12.4 mph) to start generating power. Based on the cut-in wind speed of 8.9 mph (3.98 m/sec), wind speeds between the cut-in speed and the 5.54 m/sec actually consume small amounts of energy. The power curve values were also provided as scaled to sea level average air density of 1.225 kg/m^3. An intermediate set of power values was interpolated for the estimated average air density for the Seminole elevation of 3313 ft (1010 m) (Hibbeler 2015). The research team then fit a sixth-order polynomial equation to the Seminole elevation power curve to get values of power in kW for each wind speed value in the WTM dataset for March 6, 2013 to August 31, 2014. These power values were then multiplied by the 5-min time intervals to obtain energy in kWh.

The calculated results are summarized in Table 6 and displayed in Figures 31 to 33. The distribution of wind speeds in each month is represented by minimum, maximum, median, and average values. The 10th, 25th, 75th, and 90th percentile values provide further representations of the differences from month to month. Note that only five of the eighteen months had median wind speeds above the 5.54 m/sec level, and in general the wind speeds exceeded that level only 42 percent of the time in the 544-day period (228 day-equivalents). August 2013 had the lowest energy at 1322 kWh, while May 2013, June 2013, April 2014, and June 2014 all had about 6500 kWh. The total theoretical wind energy for the entire period was estimated at 79,000 kWh. These estimates demonstrated the variability of wind speeds and related energy generation, highlighting the importance of the spring and early summer months.

With the perspective provided by these estimates, the 37,054 kWh generated by the EW50 wind turbine in 4276 hr was reasonable and could be interpreted. Using a portable Fluke multimeter, the power draws of the pumping well and RO system were measured at 7.7 and 5.3 kW, for a total of 13 kW. As noted previously, the well and RO system operated for 250 day-equivalents, giving a total energy demand of 78,000 kWh, or an average of 5.30 kWh/1000 gal permeate. The amount of energy generated by the wind turbine was 47 percent of the total demand of the well and RO system. Unfortunately, the exact times of operation for the turbine

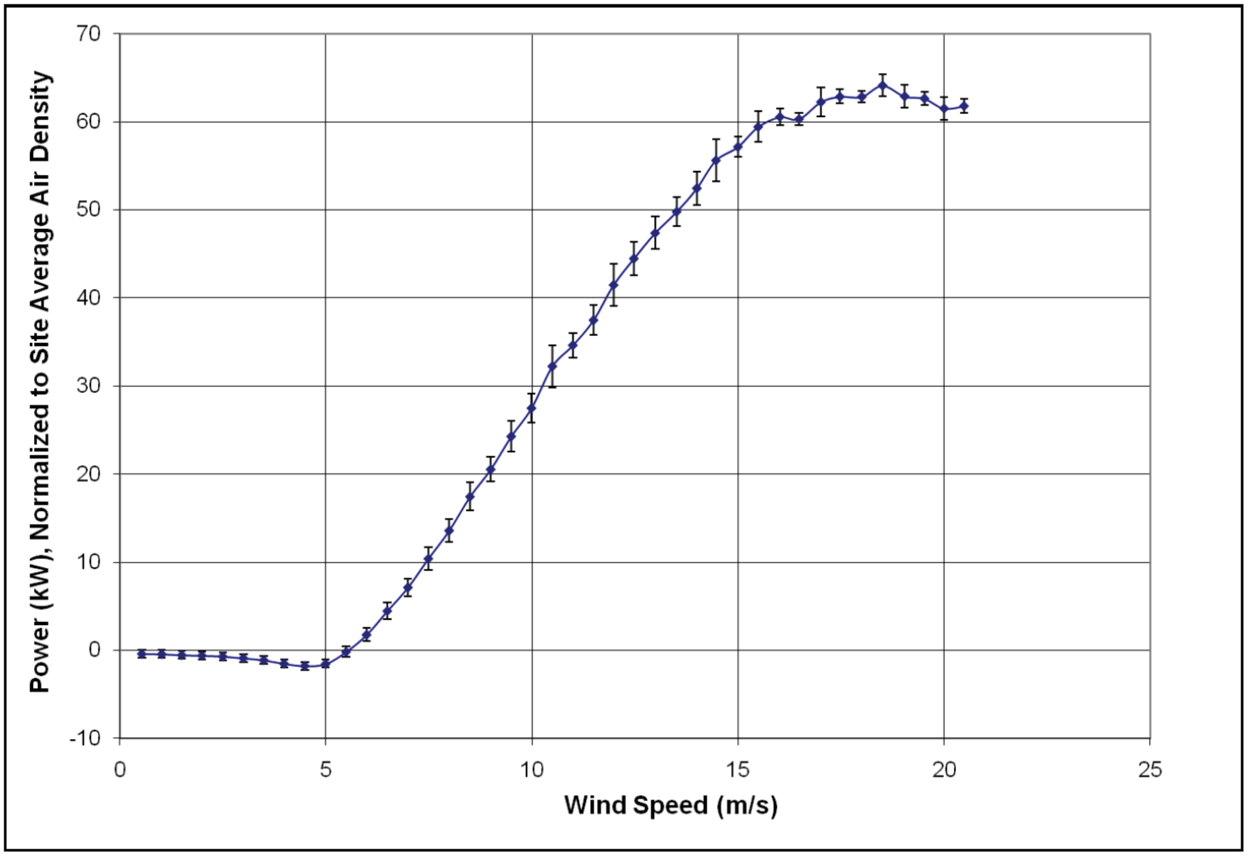


Figure 31. EW50 power curve at Golden site average air density, 1.050 kg/m^3

Table 6. Estimated Wind Energy Generation for Seminole WTM Data and EW50 Power Curve

Month	Wind Speed (m/sec) Minimum	10th percentile	25th percentile	Median	Average	75th percentile	90th percentile	Maximum	Percent of Values > 3.98 m/sec	Percent of Values > 5.54 m/sec	Theoretical Energy (kWh)
Mar-13	0.0	2.3	3.5	4.9	5.5	6.9	9.7	21.3	66.2	40.1	4296
Apr-13	0.0	2.6	3.9	5.7	6.0	7.9	9.9	20.5	73.5	51.9	6047
May-13	0.0	3.0	4.1	5.7	6.2	7.7	10.3	20.1	78.0	52.5	6584
Jun-13	0.0	2.9	4.3	6.3	6.4	8.1	9.7	23.1	79.7	60.2	6487
Jul-13	0.0	2.2	3.4	4.8	5.0	6.4	7.8	18.2	64.5	38.9	2738
Aug-13	0.0	2.0	2.9	4.1	4.3	5.5	6.8	21.2	53.2	24.8	1322
Sep-13	0.0	1.9	3.1	4.4	4.7	6.3	7.7	13.5	58.0	34.8	2276
Oct-13	0.0	2.0	3.0	4.3	4.8	6.3	8.2	15.2	54.9	33.5	3060
Nov-13	0.0	1.3	2.6	4.1	4.7	6.2	8.9	15.4	51.5	31.8	3643
Dec-13	0.0	2.2	3.2	4.6	5.1	6.5	8.9	18.0	60.3	35.4	3864
Jan-14	0.0	3.0	3.9	5.2	5.7	7.1	9.4	17.3	73.5	44.4	4818
Feb-14	0.0	2.2	3.3	4.7	5.2	6.8	8.7	17.2	63.2	39.1	3515
Mar-14	0.0	2.4	3.5	5.5	6.2	8.3	11.1	22.5	68.6	49.6	7708
Apr-14	0.0	2.5	3.8	5.6	6.1	8.0	10.4	18.7	72.3	51.0	6571
May-14	0.0	2.5	3.7	5.3	5.6	7.2	9.1	18.8	71.6	47.0	4774
Jun-14	0.0	2.9	4.3	6.2	6.3	8.2	9.7	17.6	78.3	58.9	6505
Jul-14	0.0	2.3	3.5	5.1	5.2	6.7	8.1	16.1	67.8	42.2	3269
Aug-14	0.0	1.8	2.8	4.1	4.3	5.5	7.1	13.9	51.9	25.1	1493

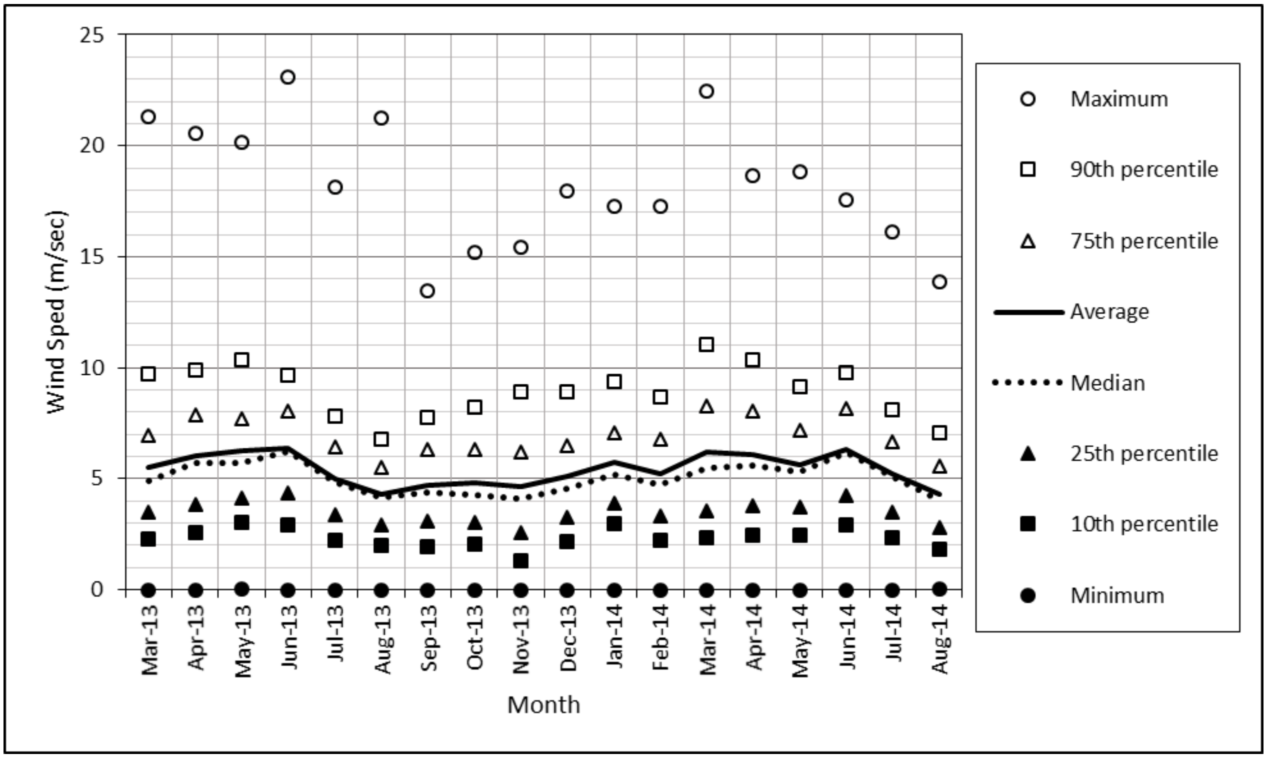


Figure 32. Statistical analyses of monthly wind data from the WTM site Seminole 2NNE

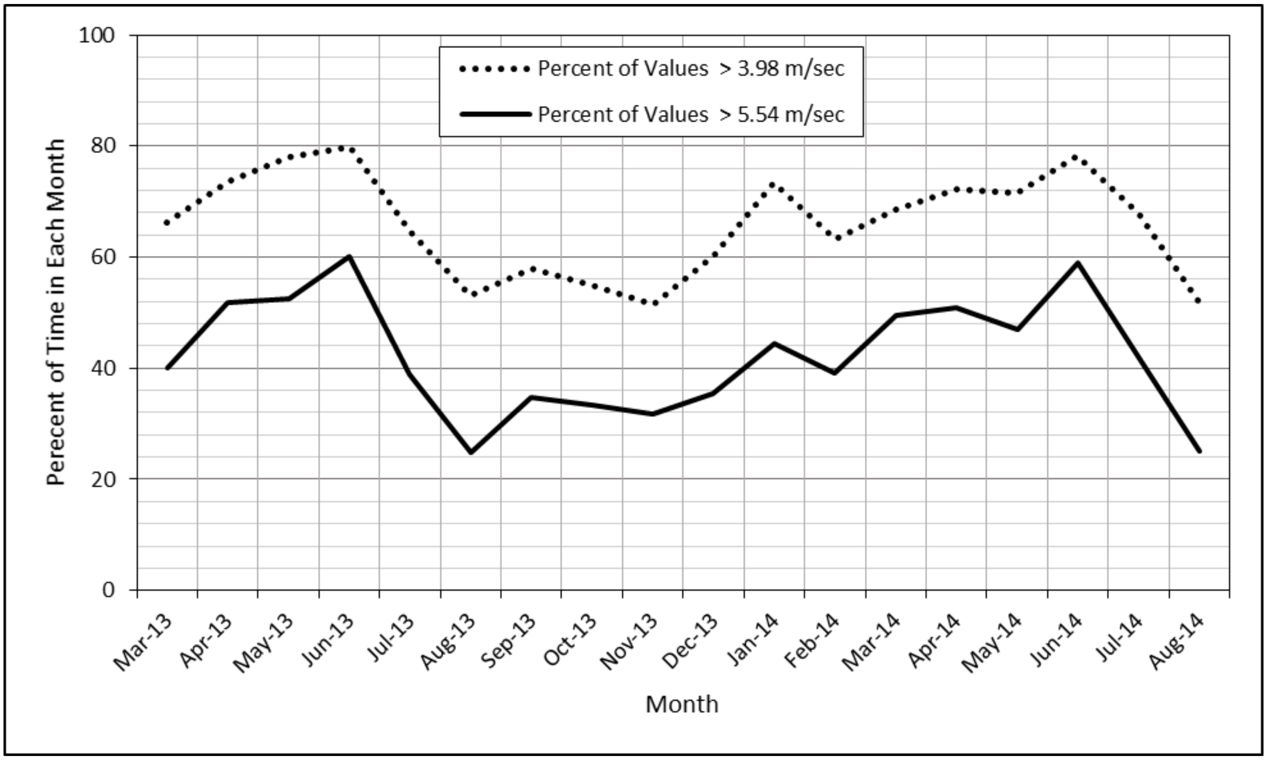


Figure 33. Percent of time each month that wind speeds exceeded 3.98 and 5.54 m/sec

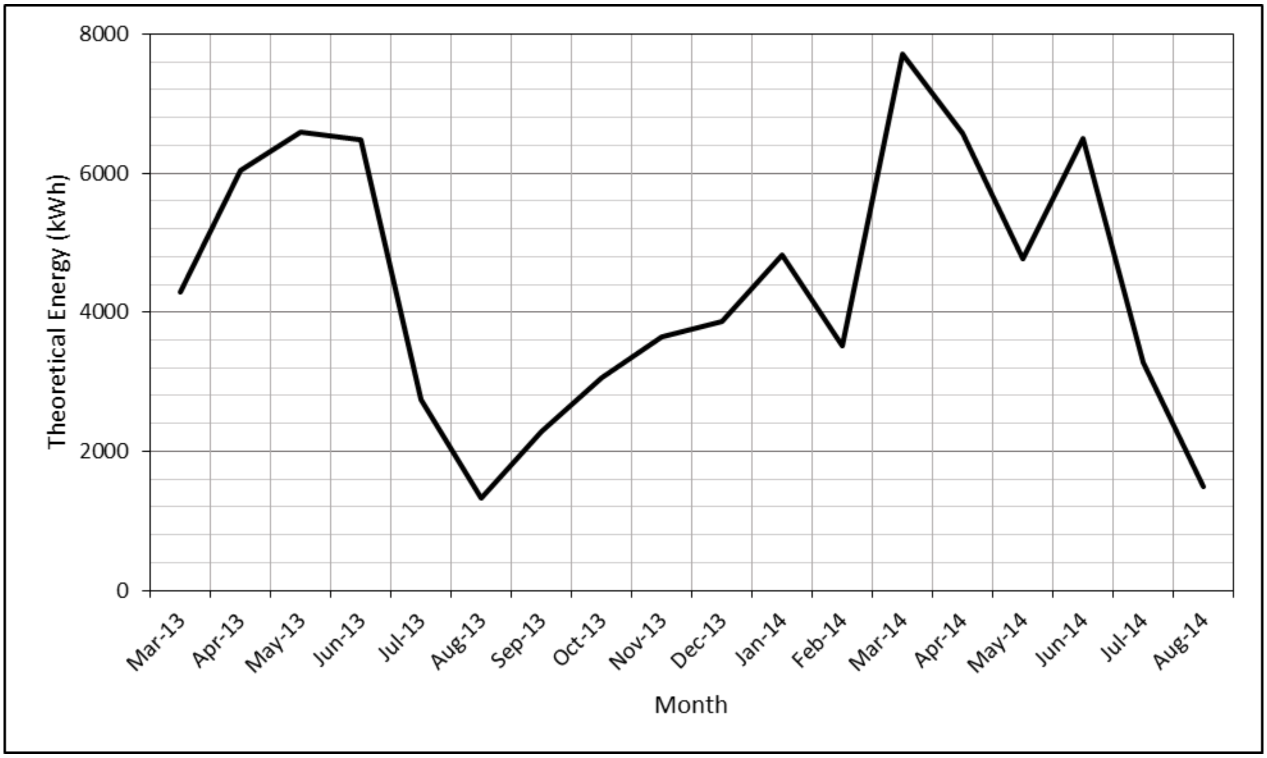


Figure 34. Theoretical energy that could be generated each month

and well and RO system did not always coincide. Still, the amount of energy was significant and encouraging as a renewable energy source alongside the energy from the grid.

The City provided its electric bills for the Xcel Energy meter at the site, which also powered two nearby city wells, 42 and 43 (water quality reported in Table 3). Well 43, closest the RO site, provided 300 gpm consistently, and Well 42 pumped 275 gpm regularly. The two wells provided one-third of the City's water supply according to City staff. The invoice information for the Xcel meter is summarized in Table 7. During the time after the wind turbine was commissioned, this meter recorded a total of 471,970 kWh, for a total cost of $29,195. The total energy demand of the well and RO system would be about 16 percent of the total if the wind turbine was not available. The average unit cost of energy per kWh was $0.062. The equivalent cost of energy to run the well and RO system was then $4,836. The cost of energy per volume of permeate produced at the average of 41 gpm was about $0.33/1000 gal. The value of the energy produced by the wind turbine was $2,300.

4 Conclusions and Path Forward

4.1 Conclusions

In general, RO systems employ established technology and will to work well no matter the source of electricity. Wind turbines can generate electricity when the winds are strong enough and the turbines are in good working condition. The technical elements of this project

Table 7. Seminole Xcel Energy Usage at Site

Date Meter Read	Days	Total Usage (kWh)	Electric Invoice Total ($)	$/kWh
3/20/2013	29	14248	862.69	0.061
4/19/2013	30	17254	1050.57	0.061
5/20/2013	31	24176	1320.01	0.055
6/19/2013	30	22187	1597.51	0.072
7/19/2013	30	34617	2108.65	0.061
8/19/2013	31	34217	2134.71	0.062
9/18/2013	30	37763	2121.13	0.056
10/17/2013	29	29268	1734.62	0.059
10/24/2013	7	5704	0.00	0.000
11/16/2013	23	20049	1524.64	0.076
12/18/2013	32	17252	1152.93	0.067
1/21/2014	34	16307	1201.83	0.074
2/20/2014	30	23190	1288.18	0.056
3/21/2014	29	29995	1767.89	0.059
4/21/2014	31	31582	1885.68	0.060
5/20/2014	29	31036	1874.41	0.060
6/19/2014	30	21385	1550.30	0.072
7/12/2014	32	23033	1678.47	0.073
8/19/2014	29	38707	2341.14	0.060

have been proven successful on their own previously, and this project basically brought the technologies together in an unusual combination. The project was requested by the leadership of the City of Seminole to help them plan for potential future water supply. The biggest challenge as the project began was the uncertainty in the hydrogeologic, hydraulic, and water quality characteristics of the local Dockum Aquifer. The project team brought together TTU researchers with local engineering and geological consultants to cover the required technical and regulatory aspects. The TTU team also worked with the City of Seminole and their grant consultant to build the necessary funding from several local, state, and federal sources. The time and effort necessary caused to project to take several years from conception to completion, but the effort was valuable to the City and other municipalities considering developing local brackish groundwater supplies. The following specific conclusions were also noted.

- The local conditions in the Dockum Aquifer can be projected through study of existing well log databases, but site-specific well conditions must be found through careful drilling and geophysical testing practices.

- The water quality in the Dockum Aquifer appears to become much more saline with depth, and targeting the upper portions of the aquifer may be appropriate if the hydraulic capacity is sufficient.
- The well construction technique used in this project did provide a productive well, but it should be noted that production of aquifer sediments with the pumped water significantly impacts the choices of pretreatment methods upstream of the desalination process.
- When funding allows, it is preferable to have more than one wind turbine so that the renewable energy is still available when one turbine goes down. Preventive maintenance visits are also important to prevent problems.
- The City of Seminole staff were very cooperative in this project and shouldered the majority of the work and costs for regular operation of the system. Day-to-day management of an RO system is challenging and difficult for a small municipal utility to run without additional staff. There is a significant opportunity for third-party companies to provide maintenance and operation services.
- The unplanned fouling of the membrane elements, followed by the autopsy analyses, provided additional information about the nature of the inorganic foulants in this brackish water.
- The RO and wind turbine service providers often commented that the first year of operation of their systems normally has unexpected challenges that provide insight for adjustments to the mechanisms and operating procedures. Our experience was similar, and we stretched the demonstration period as long as we could for that same reason. The additional challenges of the well motor failure, nearby lightning strike impacting the electrical systems, and loss of access to the RO system manufacturer lead to unexpected shutdowns.
- The total time of operation of the well and RO system was 250 day-equivalents, with total well production of 20,115,900 gal at an average flow rate of 56 gpm. The average permeate flow was 41 gpm (14,727,700 gal total) with average concentrate flow of 15 gpm (5,388,200 gal total), for an average volumetric recovery of 73 percent. The average TDS values were 7980, 520, and 20,600 mg/L for the feed, permeate, and concentrate flows, respectively. The permeate values from the laboratory analyses of a grab sample for arsenic, fluoride, and TDS were <0.01, <0.5, and 436 mg/L, respectively. The permeate could be potable water after disinfection, and could also be blended with the local Ogallala water to lower arsenic, fluoride, and TDS levels.
- The EW50 wind turbine generated 37,054 kWh in 4276 hr of operation. The well and RO system demand during their operation was approximately 78,000 kWh, for an average of 5.30 kWh/1000 gal permeate. The cost of energy per volume of permeate produced at the average of 41 gpm was about $0.33/1000 gal at the average $0.062/kWh charged locally by Xcel Energy. The amount of energy generated by the wind turbine was the 47 percent of the demand of the well and RO system. Unfortunately, the exact times of operation for the turbine and well and RO system did not always coincide. Still, the amount of energy was significant and encouraging as a renewable energy source alongside the energy from the grid.
- A total of approximately $1.63 million was assembled from several local, state, and federal sources to design, construct, and operate this demonstration project. The types of grants that were used to make this project happen were very helpful, but typically the available amounts of money were limited so that no single source of funds could have

covered the entire budget. These limitations are also experienced by other rural municipalities and have slowed their adoption of new technologies. Consideration of bonds or state loan programs, such as those managed by the TCEQ, are warranted. Water rates will only go up, whether the actions take place sooner or later.

- This demonstration project did not lend itself to scalable economic analyses for several reasons. First, most of the funds came from grants, so no capital costs were covered by amortizable debt. Second, the sizes of the well pump, RO system, and wind turbine were set by grant funding limitations, and as such their costs per unit of production were relatively high compared to full-scale, larger capacity systems. Third, concentrate management, which is usually a large fraction of the overall costs, was done by simply combining the permeate and concentrate flows for disposal through the city's sanitary sewer system, a choice that would not likely be recommended for a full-scale system. Fourth, the costs of providing drinking water from this conceptual combination of wind-assisted brackish water desalination must be greater than the current City of Seminole water costs based on treatment and distribution of chlorinated groundwater, so we are not promoting savings relative to current practice. Finally, we did estimate the value of the wind-generated electricity at $0.33/1000 gal of permeate. As the wind turbine was purchased with grant funds, the water pumped and treated when the electricity came from the wind essentially cost $0.33/1000 gal less than similar water pumped and treated when the electricity came from the grid.

4.2 Path Forward

As this field demonstration project came a close, the TTU team began discussions with BW Primoris, a company that has entered into a long-term contract with the City of Seminole to provide potable water supply to the City's existing distribution infrastructure. At the time of this report, BW Primoris had completed a successful pilot test of treatment processes to reduce the arsenic, fluoride, and TDS levels in the water produced from the City's existing Ogallala well fields, and has constructed three full-scale plants, including one near our research facility on the south side of Seminole. They are also exploring the potential of their own Dockum wells to support the City's needs. Due to the limited pumping capacities likely in local Dockum wells, they are very interested in our existing Dockum well, as well as the existing RO system and building that was designed for expansion with additional treatment skids, that can be of great value to both BW Primoris and the City as they consider their future capacity development. BW Primoris is currently planning a packer test at our Dockum well to separate the water quality and production capacities for the three perforated zone. It is possible that the shallowest producing zone may have the most attractive combination of water quality and flow capacity. BW Primoris has also contacted the TTU team to provide a third-party evaluation of the concentrate management practices available at Seminole, and we will also encourage the use of renewable energy through wind and solar power generation. For example, a properly managed solar pond can serve both to accept concentrate as make-up water for evaporation losses and provide electricity or heat for desalination or pumping demands. The TTU team provided draft copies of this report and all pertinent information from this project to BW Primoris as we explore the positive interaction. The TDA grant funds used by the City for this project encourage the City to make the best possible use of the new infrastructure to serve its citizens. In addition, the TTU team watching the U.S. Bureau of Reclamation's Desalination Program to propose using their funds for additional research in better operation of the RO treatment system through improvements in pretreatment, adjustments in antiscalant and pH management, and manipulation of recycle and flush scheduling.

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Appendix A. Geologist's Dockum Well Report

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GEOLOGY REPORT
DOCKUM WELL SR-1
CITY OF SEMINOLE
GAINES COUNTY, TEXAS

Prepared for:

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August 2011

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Executive Summary

The Dockum well SR-1 was drilled in the City of Seminole well field from June 21 through July 8, 2011. The Dockum Group of sediments underlies the Tertiary Ogallala and Cretaceous formations, which are the principal water bearing formations in Gaines County, i.e., the Ogallala and the Trinity-Edwards (High Plains) aquifers. Because water is mined at an unsustainable rate in the Ogallala and Trinity-Edwards (High Plains) aquifers, a deep well was installed to evaluate the water bearing zones in the Dockum sediments as potential sources of municipal water supply.

Cirrus Associates, LLC provided geologic services, including preparation of a geologic log based on examination of drill cuttings collected at 10 foot intervals during well placement, evaluation of geophysical logs, and provides this report of findings.

Findings

Based on evaluation of the geologic log developed from cuttings collected at 10 ft. intervals and on the two geophysical logs (gamma ray and compensated neutron density), the recommendation was made to perforate the well in three zones, from 540 ft. to 650 ft., from 890 ft. to 920 ft., and from 1,610 ft. to 1,770 ft.

The Dockum Group at this location consists of porous and permeable zones (including sandstones, siltstones, conglomerates, and gravels) that are interbedded with clays and mudstone/claystone. Thick sections of low permeability sediments, e.g., clay, claystone, mudstone, are the predominant lithology in the borehole.

During drilling, the driller observed that the best water bearing zone was the shallow zone at approximately 583 ft to 651 ft. bgs. Based on the driller’s observations and subsequent evaluation of cuttings, the most prolific aquifer zone is anticipated to be in the upper portion of the Dockum sediments. This zone is comprised of sandstone and/or gravel that is interbedded with clay, claystone, and mudstone. This water bearing zone is interpreted as the lowermost section of the Cooper Canyon Formation. The Trujillo Formation consists of an upward fining sequence of silts and siltstones interbedded with clay that is overlain by clay, claystone and mudstone. A potential water bearing zone was observed in the interval from 890 ft. to 920 ft. The Tecovas Formation consists of a thick section of interbedded clay, claystone, mudstone and siltstone and is considered an aquiclude. The Santa Rosa Formation consists of alternating beds siltstone and sandstone (thin beds) with clay, claystone and mudstone. Permeability may be within the thin siltstone and sandstone beds or may be along the bedding planes, particularly in the interval from 1654 ft. to 1730 ft.

Recommendations

Drilling took twelve days and was interrupted by the Fourth of July holiday weekend and prolonged by equipment problems. The amount of hole that was drilled each day decreased as the hole was drilled deeper. The primary reason for this was because all drill pipe was tripped out of the hole at the end of each day so that the downhole equipment would not be lost due to potential overnight collapse of the hole. Each morning the drill pipe would have to be placed back in the hole. Tripping in and out of the hole each morning and evening took longer and longer each day, resulting in progressively lesser amounts of drilled hole each day. It is recommended that future deep Santa Rosa wells be drilled continuously from start to total depth of the hole, i.e., drill 24 hours per day, 7 days per week from start to finish.

It appeared that the major water bearing zone occurred in the upper Dockum. However, because there is potential for contribution of yield from other zones, hydraulic testing should be conducted to determine the contribution from each zone and discreet water samples should be collect to determine the quality of water in each zone.

Because of the paucity of geologic and geophysical data in the Dockum sediments that underlie the Southern High Plains, it is recommended that drilling data be captured to provide a better geologic and hydrogeologic understanding Dockum Group sediments during future placement of deep wells. This includes preparation of geologic logs, running appropriate suites of geophysical logs, collection of well yield and water quality data, and data analyses.

Section 1.0
Scope of Work and Limitations

1.1 Scope of Work

The scope of work for this project consisted of the following activities:

1. Provide field geological services during well placement, including preparation of a geologic log and collection of cuttings at 10 ft. intervals;

2. Evaluate the geophysical logs and provide recommendations for well completion; and

3. Prepare a summary report.

1.2 Limitations

This assessment is a limited evaluation of subsurface conditions based on compilation of data listed in Section 1.1. The work performed is considered to be a reasonable assessment in accordance with industry standards.

Section 2.0
Regional Geology and Hydrogeology

2.1 Regional Geology

The City of Seminole well SR-1 is located within the Southern High Plains physiographic province. The Southern High Plains province is characterized by broad, nearly flat topography with ephemeral streams, draws, and numerous playa lake basins. Surface sediments typically consist of sand, silt, clay, gravel, and caliche of Quaternary or Tertiary age, (Tertiary Miocene-Pliocene Ogallala and Quaternary Holocene Blackwater Draw formations). Underlying the Ogallala Formation are Cretaceous aged sediments (which pinch out in the southern part of Gaines County) and/or Triassic sediments. Triassic sediments were deposited in a basinal depositional environment that developed on the Paleozoic landscape as a result of the breakup of the super-continent Pangea. Gaines County is located near the center of the basin along the north-south trending axis of the basin. Due to its location near the center of the basin, Dockum sediments in Gaines County are thicker and deeper than the marginal areas of the basin, where thinning occurs.

Table 1 illustrates the stratigraphy on the Southern High Plains.

2.2 Regional Hydrogeology

The principal aquifers underlying the southern portion of the Southern High Plains are the Ogallala aquifer and the Edwards-Trinity (High Plains) aquifer. These aquifers are often grouped together and collectively referred to as the High Plains aquifer. One reason these aquifers are grouped together as a single unit, is because it is difficult to differentiate between the two units based on driller's logs, oftentimes the only source of stratigraphic information.

Underlying the High Plains aquifer in this part of Texas are sediments of Triassic age called the Dockum Group. The Dockum Group is broken down into four formations which are from youngest to oldest: the Cooper Canyon, Trujillo, Tecovas, and Santa Rosa formations. Typically, the best potential water bearing zone occurs in the Santa Rosa Formation; however, water may occur in the Trujillo Formation, and less frequently in the Cooper Canyon Formation. The Tecovas Formation is considered a non-water bearing zone or aquiclude.

The Ogallala aquifer is classified a major aquifer; whereas both the Edwards-Trinity (High Plains) and the Dockum aquifers are classified as minor aquifers in the State of Texas. Minor aquifers in Texas are water bearing zones that typically do not produce large quantities of water, are unable to sustain yield to wells, or produce water of poor quality.

Section 3.0
Well Placement of SR-1

3.1 Well Location

The location of well SR-1 is southwest of Seminole in Gaines County, Texas in a City of Seminole well field. The latitude and longitude is 32º 41' 06.415"N, 102º 40' 0.727"W; elevation is 3300' above mean sea level[1].

The well is located in the upper reaches of the Colorado River Basin between Wordswell and Seminole draws. Seminole Draw joins Monument Draw to the south in Andrews County and eventually becomes Mustang Creek. The well is situated on a pad on the southeast side of an irrigated circle which was planted with rye at the time of drilling. Figure 1 shows the location of SR-1.

3.2 Well Placement Chronology

Table 2 provides the chronology of drilling activities for advancement and installation of SR-1.

3.3 Stratigraphy Based on Soil Cuttings and Geophysical Logs

3.3.1 Quaternary. A red brown silty sand was observed in the mud pit from 0 to 6 ft. This silty sand was underlain by the Ogallala caprock caliche. Flower pot structures, a term used to describe the large bulbous protrusions of red brown sand incised into the top of the caliche, appear to be areas of eroded caprock that were subsequently infilled by Quaternary eolian sand and silt.

3.3.2 Tertiary Ogallala Formation. The Ogallala Formation was observed from 6 ft. to approximately 129 ft. bgs. As typical of the uppermost Ogallala Formation, caprock caliche was observed from 6 ft. to 39 ft. and underlain by sandstone and siltstone. Several thin beds of calcrete are interbedded in the sandstone/siltstone sediments.

3.3.3 Cretaceous. From 129 ft. to 174 ft. a section of siltstone and conglomerate was observed. Based on a change in color, the appearance of shale and limestone, and the thickness of the section, this strata represents either Cretaceous-aged sediments or eroded Cretaceous sediments that were redeposited at a later time.

[1] GPS location provided by West Texas Water Well Service

Based on field observations, the upper part of the section may be Duck Creek Formation sediments (limestone and yellow shale) and the lower part of the section may be Antlers Formation sediments (conglomerate).

It should be noted that most generalized subsurface maps of West Texas indicate that Cretaceous-aged sediments are present in the northern portion of Gaines County, but absent in the southern portion of the county. Observed cuttings from SR-1 suggest that approximately 45 ft. of Cretaceous-aged sediments occur at this location.

3.3.4 Dockum Group. Although the nomenclature for the formations in the Dockum Group has been variously designated by a number of different investigators through time, this report uses the stratigraphic nomenclature used by Lehman (1994a[2] and 1994b[3]) and currently used by the Texas Water Development Board[4]. The formations that comprise the Dockum Group in Texas are, from youngest to oldest, are the Cooper Canyon, Trujillo, Tecovas, and Santa Rosa.

Cooper Canyon Formation. The top of the Dockum was observed at 174 ft. below ground surface, consisting of interbedded clay, mudstone, claystone, siltstone, sandstone, and minor limestone. A zone of higher porosity and permeability was observed from approximately 600 ft. to 665 ft. In this interval, a claystone interbedded with sands and gravels, coarsened with depth until gravels predominated. The gamma ray log shows a distinct signature from 583 ft. to 651 ft. indicative of the sands and gravels. The neutron porosity log shows less porosity, but may be due to borehole washout in this zone.

Based on evaluation of both the cuttings and the geophysical logs, the Cooper Canyon Formation is interpreted as the zone from 174 ft. to 651 ft. bgs. This zone represents a fining upward sequence.

Trujillo Formation. From 651 ft. to 922 ft., clay, claystone, and mudstone predominated; however, coarsening was observed in the cuttings from 900 ft. to 950 ft. with silts and siltstones interbedded with clays.

The gamma ray log shows a distinct signature from approximately 890 ft. to 922 ft. indicative of the sandier zone. The neutron porosity log shows less porosity in

[2] Lehman, T.M. 1994a.
[2] Ewing, J.E., Jones, T.L., Yan, T., Vreugdenhil, A.M., Fryar, D.G., Pickens, J.R., Gordon, K., Nicot, J., Scanlon, B., Ashworth, J.B., Beach, J., 2008.
[3] Lehman, T.M., 1994b.
[4] Ewing, J.E., Jones, T.L., Yan, T., Vreugdenhil, A.M., Fryar, D.G., Pickens, J.R., Gordon, K., Nicot, J., Scanlon, B., Ashworth, J.B., Beach, J., 2008.

this zone, but similar to the 583 ft. to 651 ft. zone in the overlying section, this may be due to washout.

Based on evaluation of both the cuttings and the geophysical logs, the Trujillo Formation is interpreted as the zone from 651 ft. to 922 ft. bgs. This zone represents a fining upward sequence.

Tecovas Formation. From 922 ft. to approximately 1,540 ft. bgs, the section was dominated by red clays, claystone, mudstone, and siltstone. The gamma ray log indicated little variation, except for several shifts in the clay line and a zone with more silt from 930 ft. to 956 ft. (i.e., near the top of the section).

Based on evaluation of both the cuttings and the geophysical logs, the Tecovas Formation is interpreted as the zone from 922 ft. to approximately 1,540 ft.

Santa Rosa Formation. The section from 1,540 ft. to approximately 1,750 ft. is comprised of siltstone and sandstone interbedded with clay, claystone, and mudstone.

The gamma ray log indicated that sandier zones occur from 1,654 ft. to 1,726 ft. and then become more clayey to approximately 1762 ft. The neutron porosity log shows a low porosity zone through this section, but again, may be due to borehole washout.

Based on evaluation of both the cuttings and the geophysical logs, the Santa Rosa Formation is interpreted as the zone from 1,540 ft. to 1,762 ft., with the "best sandstone layer"[5] occurring from 1,654 ft. to 1,730 ft. The Santa Rosa represents a fining upward sequence.

3.3.5 Permian Dewey Lake Formation. From approximately 1,750 ft. to 1,800 ft. (i.e., the total depth of the well), the section was predominated by clay, claystone, and mudstone. A distinct change in the gamma ray signature occurs at approximately 1,760 ft. bgs and this is interpreted as the top of the Permian section.

3.4 Field Observations Regarding Potential Water Supply

During drilling, the driller observed that the best water bearing zone was the shallow zone at approximately 583 ft. to 651 ft. bgs. Based on observation of the cuttings, this was the only zone with significant sands and gravels.

[5] The "best sandstone layer" is a term commonly used (e.g., Bradley and Kalaswad, 2003) to describe the Santa Rosa Formation zone with the greatest potential for porosity and permeability.

3.5 Recommendation for Well Perforations

Based on evaluation of the geologic log developed from cuttings collected at 10 ft. intervals and on the two geophysical logs (gamma ray and compensated neutron density), the recommendation was made to perforate the well in three zones, from 540 ft. to 650 ft., from 890 ft. to 920 ft., and from 1,610 to 1,770 ft.

Section 4.0
Findings and Recommendations

4.1 Findings

Based on evaluation of the geologic log developed from cuttings collected at 10 ft. intervals and on the two geophysical logs (gamma ray and compensated neutron density), the recommendation was made to perforate the well in three zones, from 540 ft. to 650 ft., from 890 ft. to 920 ft., and from 1,610 ft. to 1,770 ft.

The Dockum Group at this location consists of porous and permeable zones (including sandstones, siltstones, conglomerates, and gravels) that are interbedded with clays and mudstone/claystone. Thick sections of low permeability sediments, e.g., clay, claystone, mudstone, are the predominant lithology in the borehole.

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4.2 Recommendations

Drilling took twelve days and was interrupted by the Fourth of July holiday weekend and was prolonged by equipment problems. The amount of hole that was drilled each day decreased as the hole was drilled deeper. The primary reason for this was because all drill pipe was tripped out of the hole at the end of each day so that the downhole equipment would not be lost due to potential overnight collapse of the hole. Each morning the drill pipe would have to be placed back in the hole. Tripping in and out of the hole each morning and evening took longer and longer each day, resulting in progressively lesser amounts of drilled hole each day. It is recommended that future deep

Santa Rosa wells be drilled continuously from start to total depth of the hole, i.e., drill 24 hours per day, 7 days per week from start to finish.

It appeared that the major water bearing zone occurred in the upper Dockum. However, because there is potential for contribution of yield from other zones, hydraulic testing should be conducted to determine the contribution from each zone and discreet water samples should be collect to determine the quality of water in each zone.

Because of the paucity of geologic and geophysical data in the Dockum sediments that underlie the Southern High Plains, it is recommended that drilling data be captured to provide a better geologic and hydrogeologic understanding Dockum Group sediments during future placement of deep wells. This includes preparation of geologic logs, running appropriate suites of geophysical logs, collection of well yield and water quality data, and data analyses. .

Section 5.0

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FIGURES

DOQQ from ESRI ArcGIS

0 0.25 0.5 1 Miles

City of Seminole
Dockum Well

Project No. 02-013600.01	July 2011

Figure 1
SR-1 Well Location

Cirrus Associates, LLC
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TABLES

Table 1
Stratigraphy on the Southern High Plains

Era	*System*	*Series*	*Group*	*Formation*	*General Description*	*Aquifer*
Cenozoic	Quaternary			Blackwater Draw	Fine grained sand, silt, clay	
	Tertiary			Ogallala	Sand, silt, clay, gravel, caliche	Ogallala
Mesozoic	Cretaceous		Washita	Duck Creek	Clay/shale with limestone	Edwards-Trinity (High Plains)
			Fredericksburg	Kiamichi	Massive shale	
				Edwards	Limestone	
				Comanche Peak	Argillaceous limestone	
				Walnut		
			Trinity	Antlers	Sand, sandstone	
	Jurassic					
	Triassic		Dockum	Cooper Canyon	Mudstone with siltstone, sandstone, and conglomerate	Dockum
				Trujillo	Massive crossbedded sandstones and conglomerates	
				Tecovas	Mudstone and siltstone	
				Santa Rosa	Sandstone and conglomerate	
Paleozoic	Permian	Ochoa		Dewey Lake		
		Guadalupe		Rustler	Anhydrite marker bed at top	

Table 2
Activity Log for Placement of SR-1

			Driller: Rory Roach (West Texas Water Well Drillers)
			Rig type: Ingersoll Rand/Sargent 3000
Date	***Interval Drilled***	***Daily Total Drilled***	***Notes***
6/21/2011	0-38'	38'	Started drilling at 2:00 pm; End drilling at 7:00 pm @ 38 ft.
			Drilled 12 1/4" pilot hole; reamed to 14 ¾ in., then 17 ½ in.
6/22/2011	38-275'	237'	End drilling at 2:30 pm.
			Set 12 ¾ in. steel casing to 100 ft. below top of the Dockum Formation. Pressure cemented well annulus (Basic Energy Services).
6/25/2011	275-585'	310'	Drilled 9:00 am to 6:30 pm. Drilled through approximately 20 ft. of cement inside surface casing to a depth of 585'. Bit size is 11 in.
6/26/2011	585-930'	345'	Drilled 9:00 am to 5:00 pm.
6/27/2011	930-1182'	252'	Drilled 10:30 am to 6:00 pm.
6/28/2011	1182-1369'	187'	Drilled 10:15 am to 5:45 pm.
6/29/2011	1369-1570'	201'	Drilled 10:15 am to 6:00 pm.
6/30/2011	1570-1680'	110'	Drilled 12:00 pm to 6:45 pm.
7/1/2011	1680-1740'	60'	Drilled 8:45 am to 12:00 pm.
7/5/2011		0'	Drilling started at ~ 11:00 am (part needed to be welded on the track). Driller determined that the hole had collapsed (probably due to water zone in the upper Dockum that caused the clays to swell). The entire hole needed to be reamed prior to further drilling. At 12:15 pm a valve blew on the circulation system and the rig shut down for the rest of the day for repairs.
7/6/2011		0'	Driller on site at 7:00 am with parts to fix the valve. Repairs took ~ 1 hour. Started back down hole. At ~1500 ft., the bit plugged up and had to come out of the hole. One jet was plugged with a hard clay nodule and not jet was plugged with a bolt.
7/7/2011	1740-1800'	60'	Drilling started at 12:15 pm; TD'd the hole at 5:00 pm.
7/8/2011			Drill crew installed 7 in. casing to 1800 ft. Well annulus pressure cemented.
7/21/2011			Geophysical logs(gamma ray, compensated neutron, and casing collar) run by Schlumberger (from approximately 10 ft. to 1792 ft. bgs)
7/22/2011			Well perforated by Basic Energy. Intervals perforated: 540 - 650' 890 - 920' 1610 - 1770'

ATTACHMENT A

Geologic Log

CLIENT: Dr. Ken Rainwater WELL No.: SR-1 SHEET: 1 OF: 19

SITE: City of Seminole well field DATE: START: June 21, 2011 FINISH: July 7, 2011

GEOLOGIST: Judy A Reeves, Ph.D., P.G.

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT.)	LITHOLOGIC DESCRIPTION
0	Q		0-6'	**Silty sand**, red brown. Flower pot structure observed in the side of the mud pit (silt/sand zone incised into top of caliche to a depth of approximately 6 ft.)
10, 20, 30	T_o		6 - 33.5'	**Caliche (caprock)**, with subrounded pebbles (including chert and jasper) and thin very fine grained sand lenses. Becomes sandier with depth (very fine grained, weakly cemented).
			33.5-39'	**Calcrete**, hard, silicified caliche, light tan.
40, 50, 60, 70, 80, 90			39 -99'	**Sandstone**, 5YR6/6 (reddish yellow), weakly cemented. Sand grains: subrounded, mostly quartz, 0.1 - 0.25 mm dia.
100			99-101'	**Calcrete** (hard, silicified sandy caliche)

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Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SR-1 | SHEET: 2 OF: 19

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT.)	LITHOLOGIC DESCRIPTION
100	T_o		99-101'	**Calcrete** (continued)
			101-105'	**Sandstone**, weakly cemented, tan.
110			105-110'	**Calcrete**
120			110-120'	**Siltstone**, 5YR7/1 (light grey), well cemented (v. hard!), mottled with 7.5YR8/3 (pink) with 7.5YR6/8 (reddish yellow)
130			120-129	**Sandstone**, 2.5YR6/4 (light reddish brown), very fine grained sand, medium hard occasional stringers of clear, quartz (silica) cement.
140, 150	K		129-157	**Siltstone**, 10R5/1 (reddish grey), medium cemented, argillaceous interbedded with sandstone and grey shale, drilled soft light shale per driller with small pebble sized rock fragments (up to 5mm, subangular limestone and jasper), black carbonacious material, and subrounded quartzite at 140': silty clay, 7.5YR5/8 to 7.5YR6/8 (strong brown to reddish yellow) (Kdc?) layered with well cemented sandstone and siltstone (10YR7/6, reddish yellow) and angular to subrounded rock fragments up to 15 mm, including limestone (10YR4/1, dark grey), quartzite (2.5YR5/8, red, translucent)
160, 170			157-174	**Conglomerate** (weakly cemented), grey sand, taking water per driller, gravels (angular, up to ~ 20 mm, quartzite (subrounded, including flint, light colored sandstone rock fragments (vfg), grey siltstone rock fragments
180, 190	TR_C		174-193	**Silty clay**, 10R4/4 (weak red), mottled with reduced clayey silt zones (grey).
200			193-215	**Sandstone** with clay, 2.5YR5/3 (reddish brown) mottled with grey; weakly-to-well cemented, quartz sand grains.

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT.)	LITHOLOGIC DESCRIPTION
200				
210			193-215' (cont)	
220			215-235'	**Silty clay**, dense, 2.5YR3/3 (dark reddish brown), some mottling with grey clay (2.5YR6/0) and greenish grey clay (5GY5/1). at 225': intebedded (?) with with well consolidated sandstone and siltstone, very fine grained, reddish brown.
230				
240			235-240'	**Clay**, dense, 2.5YR3/4 (dark reddish brown) with thinly bedded layers of light grey clay (7.5YR7/0). Minor grey sandy stringers (sand poorly sorted, subrounded to subangular, 5YR7/1).
			240-245'	**Clayey silt**, grey (5YR6/1)
250	TR_C		245-255'	**Silty clay and sand**, becomes more clayey with depth, dark brown (7.5YR3/4) to grey (2.5Y5/0)
260				
270			255-275'	**Siltstone**, blue grey with clay and sand, weakly consolidated @ 269': Dark grey siltstone transitions to well consolidated and interbedded with blue grey clay lenses (thin layers that are harder to drill)
				Set 12 3/4" surface casing to a depth of 275'.
280		N.S.	275-280'	No sample (cement only)
290			280-290'	**Limestone** with pebbles and quartz stringers, variegated pinkish white (5YR8/2) with reddish yellow (5YR7/8) interbedded (?) with clay (unconsolidated, greenish grey (5G6/1)) and siltstone (dark grey (2.5Y4/0), very fine grained, subrounded, some rock clasts (up to 5mm, including pink sandstone, quartzite, red shale).
300			290-310'	**Siltstone and sandstone (interbedded)**, siltstone: reddish (2.5YR4/3), well consolidated with concoidal fracture; sandstone: well consolidated, angular grains, poorly sorted, up to 1mm; with minor greenish gray clay (5BG6/1). Per driller: hard layers (siltstone?) are a couple of inches thick.

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SR-1 | SHEET: 4 OF: 19

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL	LITHOLOGIC DESCRIPTION
300			290-310' (cont.)	
310			310-320'	**Clay**, dark greenish gray (5G4/1), with argillaceous sand lenses (dark reddish brown (5YR3/3))
320			320-360'	**Clayey silt**, blue (5G5/4) and dark reddish brown (5YR3/4), with some sand and very dark grey (10YR3/1) silt
330				
340				at 349': hard layer: light reddish brown sandstone (5YR6/4), vfg sand grains: multicolored, subangular
350	TR_C			at 350': clayey silt becomes dark greenish grey (5G4/1) at 352': hard layer: light reddish brown sandstone (5YR6/4), vfg sand grains: multicolored, subangular at 353': hard layer: light reddish brown sandstone (5YR6/4), vfg sand grains: multicolored, subangular
360			360-370'	**Clayey silt**, blue (5GB5/1), weakly consolidated, with clayey zones. Hard layers at 362'-363'
370			370-400'	**Sandy clay**, reddish brown (5YR4/3), with silt.
380				at 380': becomes dark reddish brown (5YR3/4)
390				at 390': mottled with greenish grey sandy clay(5BG6/1)
400				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SR-1 | SHEET: 5 OF: 19
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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
400				
			400-410'	**Clay**, dark grey (10YR4/1) with sand and silt, also with some angular sandstone clasts.
410				
			410-420'	**Silty clay**, reddish brown (5YR4/3) and blue grey (5BG6/1), with minor stringers of clear mineral (gypsum?) and nodules of $CaCO_3$.
420				
			420-450'	**Clay**, greenish grey (5BG6/1) with very fine grained sand and silt.
430				at 430': clay becomes red (2.5YR4/6) with some thin beds of silt (interbedded?)
440				
				at 440': clay becomes greenish grey (5BG6/1) with large clasts of siltstone, dark greyish brown (2.5Y4/2), up to ~50mm, well cemented, vesicular (small sand sized holes in layers).
450	TR_C			
			450-460'	**Mudstone**, silty, reddish brown (2.5YR4/4), weakly consolidated, mottled with blue clay.
460				
			460-490'	**Clay**, yellowish red (5YR4/6), with silt and sand.
470				at 470': clay becomes greenish grey (5BG5/1); with some sandstone (weakly consolidated, vfg, <0.1mm, with gypsum(?) sand grains); lacustrine varves?
480				
490				
			490-512'	**Mudstone**, silty, reddish brown (2.5YR4/4), weakly consolidated, easy drilling.
500				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SR-1 | SHEET: 6 OF: 19

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
500			500-512'	**Mudstone (continued)**
510				
520			512-530'	**Clay**, greenish grey (5G6/1), very silty with very fine grained sands (<0.1mm). at 520: with thin beds (?) of weakly consolidated reddish brown silty shale and gypsum (secondary?)
530			530-540'	**Silty clay** with sand, greenish grey (5GY5/1), some zones weakly consolidated.
540			540-550'	**Silt and sand**, greenish grey (5GY5/1), becomes more sandy and more consolidated with depth, some clay.
550	TR_C		550-570'	**Siltstone**, grey (5YR6/1), weakly consolidated, iron oxide stringers (secondary), with minor sandy carbonaceous nodules. at 560': becomes more clayey with depth
560				
570			570-580'	**Clayey silt**, grey (5Y5/1)
580			580-600'	**Clay**, dark reddish brown (5YR3/3), weakly consolidated, with silt and sand. at 590': clay becomes very dark grey (10YR3/1) at 599': thin hard layer (carbonate or caliche?)
590				
600				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SR-1 | SHEET: 7 OF: 19

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
600	TR_C		600-612'	**Claystone**, grey (10YR5/1), weakly consolidated, with occasional rock fragments including milky colored quartzite (?) - jasper, rounded to subrounded; up to 7mm.
610			600-635'	at 612' to 620': claystone becomes black (10YR2/1), gravels (thin layer?) include rounded to subangular rock fragments including quartzite and charcoal.
620			620-635'	at 620' to 630': with gravels (broken rock fragments (up to ~10mm) including milky colored quartzite) ~25% dark reddish brown (2.5YR3/4) mudstone nodules.
630				
640			635-665'	**Gravel,** rock fragments are well rounded to subangular, mostly quartzite (milky), sandstone nodules with calcite and/or gypsum(?), up to 10mm. at 645'to 656' - with sand and pebbles up to 15mm, rock fragments include grey sandstone, black aphanitic rock, chert with concoidal fracture, obsidian, milky quartz, and quartzite. Per driller: zone of soft drilling.
650				
660				
670	TR_j		665-670'	**Clay**, greyish green (5G5/2)
680			670-680'	**Claystone**, dark reddish brown (2.5YR3/4), weakly consolidated.
690				at 690': claystone become red (2.5YR4/6)
700				

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
700				
			690-710' (cont)	**Claystone** (continued)
710				
720			710-740'	**Clayey silt**, reddish brown (2.5YR5/4). at 720': alternating layers of clayey silt and silty clay; occasional light grey (2.5YR6/0) mottling of the siltier zones.
730				at 730': becomes weak red (2.5YR4/2) and more sandy (sand grains - vfg, clear quartz), with $CaCO_3$ nodules.
740				
750	TR_j		740-770'	**Claystone**, reddish brown (2.5YR4/3), weakly consolidated, occasional light grey shale (2.5YR6/0) in thin layers. at 750': minor mottling with greenish grey (5G6/1).
760				
770			770-780'	**Clay**, weak red (10R4/4), with silty clay stringers (greenish grey (5G6/1)).
780			780-790'	**Claystone**, dark reddish brown (5YR3/2), competent with minor greenish grey sandy, silty clay stringers (unconsolidated).
790			790-800'	**Clay**, reddish brown (2.5YR5/3), very silty with light grey, clayey silt stringers (5YR7/1).
800				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SB-1 | SHEET: 9 OF: 19

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DEPTH (FEET)	STRATIGRAPHY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
800		800-810'	**Silty clay**, red (2.5YR4/6), mottled with grey clayey silt (some mineralization around margins of mottled zones).
810		810-820'	**Claystone**, dark reddish brown (2.5YR3/3), weakly consolidated with very dark grey competent shale (thin layers); ~3% sandstone with $CaCO_3$ matrix (or caliche?).
820			
830		820-838'	**Silty Clay**, greenish grey (5GY6/1), with 1% caliche(?) fragments.
			at 850': but becomes less silty with depth and more competent.
840			
			Mudstone, dark reddish brown (2.5YR3/3), weakly consolidated.
850	TR_j	838-900'	at 850': ~10% reduced to light grey (2.5Y7/1).
860			at 860' to 870': with thin layer(s?) of competent red (10R5/6) siltstone.
870			at 870' to 880': reddish brown (2.5YR4/3), competent.
880			at ~885': becomes greenish grey (5BG5/1).
890			at 890": becomes dark brown (7.5YR4/2), well consolidated.
900			

Geologic Log

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
900	TR$_j$		900-910'	**Siltstone**, grey (2.5YR5/0), argillaceous.
910	TR$_j$		910-920'	**Silty Clay**, greenish grey (5G5/1), interbedded (?) with slightly consolidated layers (thin). Per driller - softer drilling between 910-920'.
920			920-940'	**Clayey Silt**, greenish grey (5G5/1), very sandy with vfg sand (up to 0.5mm).
930				
940			940-945'	**Clay**, reddish brown (2.5YR4/3), with grey mottling.
			945-950'	**Siltstone**, weak red (10R4/2), competent.
950			950-1010'	**Clay**, reddish brown (2.5YR4/3), minor grey mottling.
960	TR$_V$			at 960': weak red (10R4/3), weakly consolidated, with silty/sandy stringers.
970				at 970': weak red (10R4/2) with some blue mottling.
980				at 980': weak red (10R5/4) with increased blue grey mottling in siltier zones.
990				at 990': weak red (10R4/4) with small (<2mm) white soft clasts of $CaCO_3$ (?) (could crush clasts to a powder).
1000				

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1000				
			950-1010' (cont.)	**Clay** (continued): red (10R4/6) with greenish grey (5G6/1) clay stringers.
1010				
			1010-1020'	**Mudstone**, reddish brown (2.5YR4/3), weakly consolidated.
1020				
			1020-1060'	**Clay**, weak red (10R5/3), with thin layers that are slightly consolidated.
1030				at 1030': mottled with light greenish grey (5GY7/1) clayey silt.
1040				
1050	TR_V			
1060				
			1060-1070'	**Claystone**, weak red (10R4/3) very weakly consolidated.
1070				
			1070-1120'	**Clay**, weak red (10R4/4), unconsolidated to weakly consolidated.
1080				at 1080': becomes light greenish grey (5BG7/1).
				at 1085' - weak red (10R4/4) clay mottled with brownish yellow clay (10YR6/8).
1090				at 1090 - 1100': with thin siltstone beds (?) that are reddish brown (2.5YR4/4) to grey (2.5Y6/0).
1100				

Geologic Log

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DEPTH (FEET)	STRATIGRAPHY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1100		1070-1120' (cont.)	**Clay (continued)** with small silty clasts (grey) that crumble easily; mottled with light grey clay (minor). at 1100': hard layer thin layer (thin carbonate layer interbedded with weakly consolidated shale?
1110			at 1110': reddish brown (2.5YR4/4).
1120		1120-1130'	**Claystone**, dusky red (10R3/3), weakly consolidated, mottled with dark reddish grey (10R4/1), with gypsum(?) and/or calcite (?) stringers (secondary mineralization).
1130		1130-1150'	**Clay**, yellowish red (5YR4/6), interbedded with weakly consolidated claystone. at 1137': thin hard layer
1140			at 1140': becomes red (2.5YR4/6), silty, unconsolidated to weakly consolidated.
1150	TR_V	1150-1160'	**Claystone**, weak red (10R4/3), weakly consolidated, with hard chert with cocoidal fracture, very hard, thin layer?
1160		1160-1180'	**Clay**, red (2.5YR4/8), with some silt, unconsolidated to weakly consolidated.
1170			at 1170': becomes weak red (10R5/4) with minor mottling with clayey silts (greenish grey (5G6/1).
1180		1180-1190'	**Claystone**, red (2.5YR4/6), weakly consolidated with thin layers of light grey (5YR7/1) hard siltstone(?); layers a couple of inches thick with concoidal-like fracture.
1190		1190-1218'	**Siltstone**, weak red (10R4/4).
1200			

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DEPTH (FEET)	STRATIGRAPHY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1200		1190-1218' (cont.)	**Siltstone (continued)** at 1200 - 1210": well consolidated, thinly laminated.
1210			at 1210': interbedded with mudstone (~50-50). mudstone: reddish brown (2.5YR4/3) with rock fragments (well rounded, up to 2mm).
1220		1218-1230'	**Mudstone**, dark reddish brown (2.5YR3/3), occasional small rounded rock pebbles imbedded in the mudstone. ~3% clasts of light sandstone, light red (2.5YR6/6) with CaCO3 cement(?) - medium-to-coarse grained sands.
1230		1230-1260'	**Siltstone**, dark reddish brown (2.5YR3/4).
1240			at 1240': with mudstone (minor mottling ; light grey, yellow, and red)
1250	TR_V		at 1250': dark red (10R3/6) siltstone and weak red (10R5/3) mudstone (~50-50); both weakly consolidated.
1260		1260-1270'	**Claystone**, red (2.5YR4/6) to dusky red (2.5YR3/3), large black shard-liked rock fragment with coarse soft sandstone, weak red (10R4/3).
1270		1270-1285'	**Clay**, dark grey (10YR4/1)
1280			
1290		1285-1320'	**Claystone**, greenish grey (5G5/1), weakly consolidated and weak red (10R4/1) clay.
1300			

Geologic Log

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11757 Katy Freeway
Suite 1300
Houston, TX 77079
(281) 854-2383

DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1300				**Claystone (continued)**, weak red (10R4/2), competent.
				at 1305': minor sand
1310			1285-1320'	at 1310': with thin lenses of weak red siltstone (well-cemented).
1320				
				Siltstone, reddish brown (2.5YR4/3), with some laminations, laminated zones are more coarse, grey, may be reduced zones.
1330			1320-1340'	at 1330': occasional well cemented vfg sandstone clast (pink (5YR7/3)) (thin layer ~1/8" thick?).
1340				
			1340-1350'	**Mudstone**, weak red (2.5YR3/2), interbedded with greenish grey (5G5/1) and dusky red (2.5YR3/2) siltstone layers.
1350	TR_V			
			1350-1360'	**Clay**, dark grey (10YR4/1). at 1356' : hard layer serveral inches thick, grey, siliceous siltstone (?)
1360				
				Siltstone, dusky red (10R3/3), well cemented.
1370				at 1370': dark reddish brown (2.5YR3/4), and mudstone/shale, very dark grey (2.5YR3/0).
1380			1360-1410'	
1390				at 1390' to 1400': interbedded (?) with sandstone, reddish grey (10R5/1), well consolidated.
1400				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SB-1 | SHEET: 15 OF: 19

SITE: City of Seminole well field | DATE: START: June 21, 2011 | FINISH: July 7, 2011

GEOLOGIST: Judy A Reeves, Ph.D., P.G.

Cirrus Associates, LLC

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1400				
			1400-1410'	**Siltstone**, weak red (10R4/2), occasional thinly laminated with grey sandy zone (~1/8" thick) and thin layers(?) of very dark grey shale (crumbles).
1410				
			1410-1420'	**Claystone**, weak red (2.5YR4/2).
1420				
			1420-1430'	**Siltstone**, weak red (10R4/3), weakly cemented, mottled with greenish grey (5BG6/1) clay.
1430				
			1430-1470'	**Clay**, reddish brown (5YR4/3), with sand and silt, and light grey, thin sandy lenses.
1440				
				at 1440': clay becomes greenish grey (5GY5/1), mottled with brownish yellow (10YR6/6) and weak red (10R5/4); minor sand and silt.
1450	TR_V			
				at 1450': greenish grey (5G5/1) clay is interbedded with weak red (10R5/4) siltstone.
1460				
				at 1460': clay becomes greenish grey (5BG5/1) and weak red (10R4/4).
1470				
			1470-1480'	**Mudstone** and siltstone (~50-50), mudstone is weak red (10R5/4) to dark reddish grey (10R4/1); siltstone is N4 (dark grey).
1480				
			1480-1520'	**Clay**, weak red (10R4/3), very dense.
1490				
				at 1490': becomes sandier.
				at 1493' - thin hard layer of silicified siltstone(?), weak red (2.5YR5/2) with secondary mineralization (gypsum?) in fractures and blue green reduction halo around margins of rocks. Rock fragments up to ~ 40mm x 20mm.
1500				

Geologic Log

CLIENT Dr. Ken Rainwater | WELL No: SB-1 | SHEET: 16 OF: 19

SITE: City of Seminole well field | DATE: START: June 21, 2011 | FINISH: July 7, 2011

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1500		Clay	1480-1520' (cont.)	**Clay (continued)**. at 1500': clay is weak red (10R4/3) with reddish brown mudstone (2.5YR4/3) with ~7% angular to subrounded rock fragments (including $CaCO_3$).
1520		Mudstone	1520-1540'	**Mudstone**, dense weak red (10R5/4), mottled throughout, red/yellow/grey; with well cemented gravel sized rocks (~50mm), rounded, very silty, fractured. at 1530': reddish brown mudstone (2.5YR4/3) with weak red clay (10R4/3) and ~7% angular to subrounded rock fragments (including CaCO3).
1540		Siltstone	1540-1550'	**Siltstone**, reddish brown (2.5YR4/4) and mudstone, weak red (2.5YR4/2), competent (better consolidated). Softer drilling at 1548' per driller.
1550		Sandstone	1550-1560'	**Sandstone**, weak red (10R4/2), very fine grained.
1560	TR_S	Clay	1560-1580'	**Clay**, red (2.5YR4/6), silty. at 1570' to 1580': with ~2% clasts of greenish grey (5GY5/1) claystone and ~1% carbonate fragments (~1mm).
1580		Claystone	1580-1610'	**Claystone**, dusky red (10R3/2) and dark reddish grey (10R4/1), silty, interbedded(?) with thin layers of greenish grey (5G5/1) soft claystone. at 1590': dark reddish brown (2.5YR3/3); with occasional thin layer(?) of very fine grained sandstone; and ~10% greenish grey (5G5/1) mudstone.
1600				

Geologic Log

CLIENT Dr. Ken Rainwater | WELL No: SB-1 | SHEET: 17 OF: 19

SITE: City of Seminole well field | DATE: START: June 21, 2011 | FINISH: July 7, 2011

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DEPTH (FEET)	STRATIGRAPH	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1600			1580-1610' (cont.)	**Claystone (continued)**. at 1600': as above but no sandstone lenses.
1610			1610-1620'	**Siltstone**, weak red (10R4/3), well consolidated with mudstone (~50-50). Mudstone is poorly consolidated with occasional black subrounded rock fragments (pebble sized) and some yellow mottling.
1620			1620-1650'	**Claystone**, weak red (10R4/3), weakly consolidated, with thin lenses(?) of grey mudstone (5Y5/1). at 1625': drill bit started to drop a couple of times (?) claystone becomes weak red (2.5YR4/4) with mudstone with occasional blue grey mottling with some very fine grained sand (minor). at 1630': claystone is weak red (2.5YR4/2). at 1640': claystone becomes dark reddish grey (10R3/1) and mudstone, dark reddish grey (10R4/1) (~50/50) with some clasts of weakly consolidated siltstone (dark greenish grey (5GY4/1) and weak red (2.5YR4/2)).
1650	TR_S		1650-1670'	**Clay**, red (2.5YR4/6) at 1668' - hard layer of claystone (very dark grey (2.5YR3/0), well consolidated).
1670			1670-1690'	**Sandstone**, pale red (10R6/2), very fine to medium grained, well consolidated to weakly consolidated, with silt and clay. Sand grains: black and red rock fragments (subrounded, ~0.1mm), quartz (0.25mm, subangular) Per driller: drills faster. at 1680': hard layer ~6" thick (claystone and/or mudstone). **Sandstone**, fine to medium grained, weakly consolidated, subangular quartz grains with silt and clay (back in clay before 1690' per driller).
1690			1690-1700'	**Mudstone** and **Siltstone**, weakly consolidated, laminated with thin very fine grained sandstone zones. Mudstone mottled dusky red (10R3/2) and weak red (10R4/4); siltstone dusky red (10R3/2) at 1697' : hard layer several inches thick.
1700				

Geologic Log

CLIENT: Dr. Ken Rainwater | WELL No: SB-1 | SHEET: 18 OF: 19

SITE: City of Seminole well field | DATE: START: June 21, 2011 | FINISH: July 7, 2011

GEOLOGIST: Judy A Reeves, Ph.D., P.G.

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Cirrus

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DEPTH (FEET)	STRATIGRAPHY	LITHOLOGY	INTERVAL (FT)	LITHOLOGIC DESCRIPTION
1700	TR_S		1700-1730'	**Sandstone, Claystone, and Mudstone** (interbedded) with silt and clay. Sandstone is mostly reddish brown (2.5YR4/4) and weakly cemented. (quartz grains 0.25mm, subrounded to subangular) Claystone is dusky red (10R3/4); mudstone is reddish brown (2.5YR4/3) and competent. at 1704': hard layer (mudstone?). at 1710": more clayey with minor greenish grey silty sandstone (5G6/1). at 1720': ~ 25% clasts of black, siliceous,angular, carbonaceous material (~2mm).
1710				
1720				
1730			1730-1750'	**Siltstone**, red (10R4/6), and **Mudstone**, dark reddish grey (10R4/1), (thin, interbedded layers?). at 1740': mudstone and siltstone become weak red, with claystone and thin sandstone beds (very fine to medium grained) and ~1-2% greenish grey (5BG5/1) very fine grained sandstone.
1740				
1750			1750-1760'	**Claystone** reddish brown (2.5YR4/4), with siltstone layers, dark reddish brown (2.5YR3/3). Both weakly consolidated; minor blue mottling, some zones of silicified stringers in claystone.
1760	P_{DL}		1760-1770'	**Mudstone**, weak red (10R4/4)mottled with red (10R5/6) and greenish grey (5G5/1), weakly cemented. With greenish grey (5GY7/1) clasts of laminated silty sandstone (weakly cemented, sands: vfg, black rock, quartz, pink feldspar?),and minor red (10R4/6) claystone clasts; ~1% pebble sized limestone nodules.
1770			1770-1780'	**Claystone**, weakly cemented, reddish brown (2.5YR4/4), silty, rock fragment that "sparkles," with 25% greenish grey (5GY5/1) sandy siltstone, weakly cemented, sand grains very fine grained.
1780			1780-1790'	**Siltstone**, clayey, very dense, dark reddish brown (5YR3/3) and **claystone**, dusky red (2.5YR3/2) to very dark grey - (2.5YR3/). Some mudstone**,** weak red (10R4/4) mottled with greenish grey (5G5/1); all weakly-to-medium consolidated.
1790			1790-1800'	**Silty Clay,** greenish grey (5GY5/1) interbedded with weak red (10R4/3) claystone mottled with greenish grey (5GY6/1). at 1795': hard layer of dark reddish brown (5YR3/4) claystone, dense, well consolidated, mottled with greenish grey (5GY5/1), layer ~10mm thick. **Clay**, dark reddish brown (5YR3/3), dense to slightly consolidated; TD - 1800 ft.
1800				

Geologic Log

CLIENT Dr. Ken Rainwater — WELL No: SB-1 — SHEET: 19 OF: 19

SITE: City of Seminole well field — DATE: START: June 21, 2011 — FINISH: July 7, 2011

GEOLOGIST: Judy A Reeves, Ph.D., P.G.

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LEGEND

Q	Quarternary, Blackwater Draw Formation
T_O	Tertiary Ogallala
K	Cretaceous
TR_C	Triassic, Dockum - Cooper Canyon
TR_j	Triassic, Dockum Trujillo
TR_V	Triassic, Dockum Tecovas
TR_S	Triassic, Dockum Santa Rosa
P_{DL}	Permian Dewey Lake

Note: The stratigraphic units have been picked based on analyses of both cuttings and geophysical logs.

ATTACHMENT B

STATE OF TEXAS WELL REPORT for Tracking #259331

Owner:	**City of Seminole**	Owner Well #:	**NewMuni.Well**
Address:	**302 S. Main** **Seminole , TX 79360**	Grid #:	**27-19-5**
Well Location:	**CR 306** **Seminole , TX 79360**	Latitude:	**32° 41' 06" N**
Well County:	**Gaines**	Longitude:	**102° 40' 01" W**
Elevation:	**3300 ft.**	GPS Brand Used:	**Garmin**
Type of Work:	**New Well**	Proposed Use:	**Test Well**

Drilling Date:	Started: **6/21/2011** Completed: **7/7/2011**
Diameter of Hole:	Diameter: **17-1/2 in From Surface To 275 ft** Diameter: **11 In From 275 ft To 1808 ft**
Drilling Method:	**Mud Rotary**
Borehole Completion:	**Straight Wall**
Annular Seal Data:	1st Interval: **From 0 ft to 275 ft with 350 Class C Cem (#sacks and** material) 2nd Interval: **From 0 ft to 1800 ft with 800 Class C Cem (#sacks and** material) 3rd Interval: **No Data** Method Used: **Pressure Cement** Cemented By: **Basic Energy** Distance to Septic Field or other Concentrated Contamination: **N/A ft** Distance to Property Line: **65 ft** Method of Verification: **Measured** Approved by Variance: **No Data**
Surface Completion:	**Surface Sleeve Installed**
Water Level:	Static level: **No Data** Artesian flow: **No Data**
Packers:	**No Data**
Plugging Info:	Casing or Cement/Bentonite left in well: **No Data**
Type Of Pump:	**No Data**
Well Tests:	**No Data**
Water Quality:	Type of Water: **Fresh** Depth of Strata: **640 - 1800 ft.** Chemical Analysis Made: **No** Did the driller knowingly penetrate any strata which contained undesirable constituents: **No**
Certification Data:	The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the log(s) being returned for completion and resubmittal.
Company	**West Texas Water Well Service**

Information:	**3410 Mankins** **Odessa , TX 79764**
Driller License Number:	**54815**
Licensed Well Driller Signature:	**Rory Roach**
Registered Driller Apprentice Signature:	**No Data**
Apprentice Registration Number:	**No Data**
Comments:	**No Data**

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

TEX. OCC. CODE Title 12, Chapter 1901.251, authorizes the owner (owner or the person for whom the well was drilled) to keep information in Well Reports confidential. The Department shall hold the contents of the well log confidential and not a matter of public record if it receives, by certified mail, a written request to do so from the owner.

Please include the report's Tracking number (Tracking **#259331**) on your written request.

Texas Department of Licensing & Regulation
P.O. Box 12157
Austin, TX 78711
(512) 463-7880

DESC. & COLOR OF FORMATION MATERIAL

From (ft) To (ft) Description
0 3 Top soil
3 31 Caliche
31 33 Red sand
33 39 Calcrete
39 98 Brown sandstone
98 101 Calcrete
101 109 Brown sandstone
109 120 Calcrete
120 129 Brown & tan sandstone
129 173 Small sand & gravel, some gray shale
173 240 Red clay
240 275 Red clay, brown sandstone
275 350 Brown clay, gray shale
350 360 Gray shale
360 470 Brown clay, gray shale
470 480 Gray shale
480 510 Brown clay
510 520 Gray shale
520 645 Brown clay, gray shale
645 656 Small sand & gravel
656 770 Brown clay
770 790 Brown clay w/small gravel
790 880 Brown & red clay
880 920 Brown clay, gray shale
920 930 Small gray shale, silt

CASING, BLANK PIPE & WELL SCREEN DATA

Dia. New/Used Type Setting From/To
12-3/4 New Steel 0 - 274 Blank
7 New Steel 0 - 1800 Blank

930 1030 Brown clay, gray shale
1030 1260 Brown clay
1260 1550 Brown clay, gray shale
1550 1670 Brown clay
1670 1808 Brown clay, gray shale

ATTACHMENT C

Schlumberger

Company: **City of Seminole**

Well: **Seminole Santa Rosa Well**

Field:

County: **Gaines** State: **Texas**

County: Gaines
Field:
Location:
Well: Seminole Santa Rosa Well
Company: City of Seminole

Compensated Neutron Log
Gamma Ray
Casing Collar Log

LOCATION

		Elev.:	K.B.
			G.L.
			D.F.
Permanent Datum:	GROUND LEVEL	Elev.:	0.00 ft
Log Measured From:	GROUND LEVEL	0.00 ft	above Perm. Datum
Drilling Measured From:	GROUND LEVEL		

API Serial No.	Section	Township	Range

Logging Date	21−Jul−2011	
Run Number	1	
Depth Driller	1800 ft	
Schlumberger Depth	1791 ft	
Bottom Log Interval	1789 ft	
Top Log Interval	0 ft	
Casing Fluid Type		
Salinity		
Density	8.4 lbm/gal	
Fluid Level		
BIT/CASING/TUBING STRING		
Bit Size	11.000 in	
From	200 ft	
To	1800 ft	
Casing/Tubing Size	7.000 in	
Weight	26 lbm/ft	
Grade		
From	0 ft	
To	1800 ft	
Maximum Recorded Temperatures		
Logger On Bottom / Time	21−Jul−2011 10:24	
Unit Number / Location	378 Hobbs, NM	
Recorded By	Anthony Charleston	
Witnessed By	Gil Gillespie	

	Run 1	Run 2	Run
PVT DATA			
Oil Density			
Water Salinity			
Gas Gravity			
Bo			
Bw			
1/Bg			
Bubble Point Pressure			
Bubble Point Temperature			
Solution GOR			
Maximum Deviation			
CEMENTING DATA			
Primary/Squeeze	Primary		
Casing String No			
Lead Cement Type			
Volume			
Density			
Water Loss			
Additives			
Tail Cement Type			
Volume			
Density			
Water Loss			
Additives			
Expected Cement Top			

Logging Date		
Run Number		
Depth Driller		
Schlumberger Depth		
Bottom Log Interval		
Top Log Interval		
Casing Fluid Type		
Salinity		
Density		
Fluid Level		
BIT/CASING/TUBING STRING		
Bit Size		
From		
To		
Casing/Tubing Size		
Weight		
Grade		
From		
To		
Maximum Recorded Temperatures		
Logger On Bottom / Time		
Unit Number / Location		
Recorded By		
Witnessed By		

	Run 3
	Run 4

DISCLAIMER

THE USE OF AND RELIANCE UPON THIS RECORDED−DATA BY THE HEREIN NAMED COMPANY (AND ANY OF ITS AFFILIATES, PARTNERS, REPRESENTATIVES, AGENTS, CONSULTANTS AND EMPLOYEES) IS SUBJECT TO THE TERMS AND CONDITIONS AGREED UPON BETWEEN SCHLUMBERGER AND THE COMPANY, INCLUDING: (a) RESTRICTIONS ON USE OF THE RECORDED−DATA; (b) DISCLAIMERS AND WAIVERS OF WARRANTIES AND REPRESENTATIONS REGARDING COMPANY'S USE OF AND RELIANCE UPON THE RECORDED−DATA; AND (c) CUSTOMER'S FULL AND SOLE RESPONSIBILITY FOR ANY INFERENCE DRAWN OR DECISION MADE IN CONNECTION WITH THE USE OF THIS RECORDED−DATA.

OTHER SERVICES1	OTHER SERVICES2
OS1: none	OS1:
OS2:	OS2:
OS3:	OS3:
OS4:	OS4:
OS5:	OS5:

REMARKS: RUN NUMBER 1	REMARKS: RUN NUMBER 2
No correlation log provided	
Neutron porosity logged on a Sandstone Matrix	
Porosity logged from 1791' to surface	
Gamma Ray/ CCL logged from 1791' to surface	
PBTD at 1791'	
Crew: Eddie, Terry, Dan	
Thank you for using Schlumberger!	

RUN 1			RUN 2		
SERVICE ORDER #:			SERVICE ORDER #:		
PROGRAM VERSION:		18C0−147	PROGRAM VERSION:		
FLUID LEVEL:			FLUID LEVEL:		
LOGGED INTERVAL	START	STOP	LOGGED INTERVAL	START	STOP

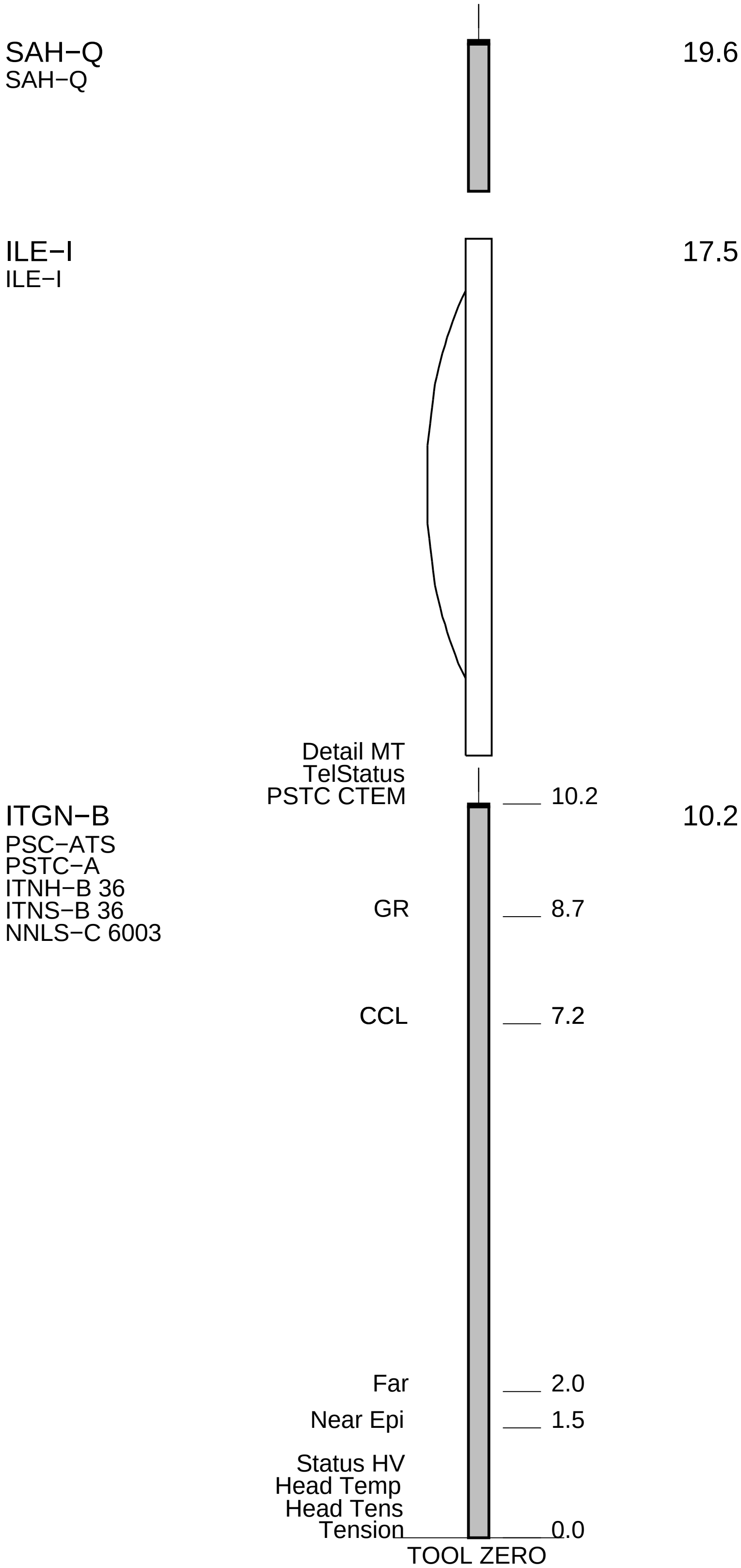
EQUIPMENT DESCRIPTION

RUN 1	RUN 2
SURFACE EQUIPMENT	
WITM−A PSC_16MHZ	

DOWNHOLE EQUIPMENT

MH−22 21.4
MH−22

AH−38 19.8



MAXIMUM STRING DIAMETER 2.25 IN
MEASUREMENTS RELATIVE TO TOOL ZERO
ALL LENGTHS IN FEET

MAXIS Field Log

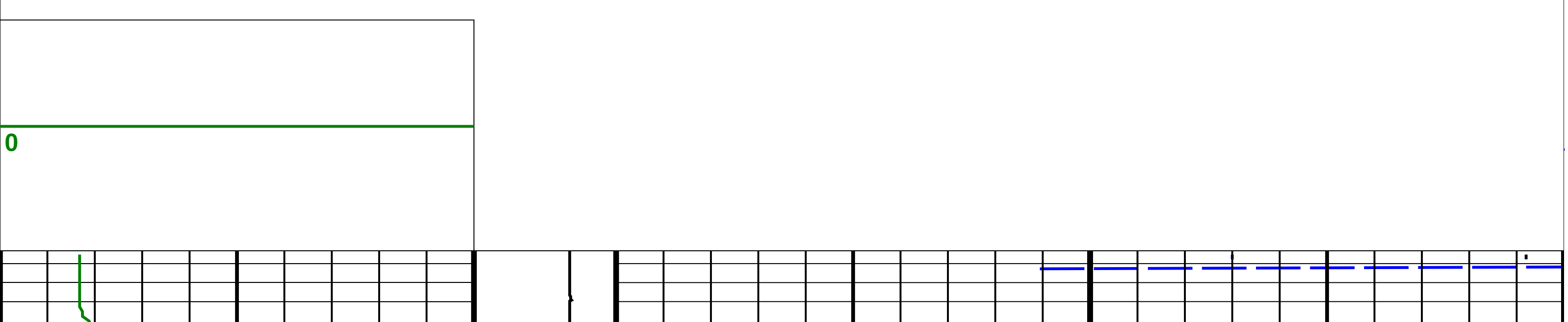
Company: City of Seminole	Well: Seminole Santa Rosa Well

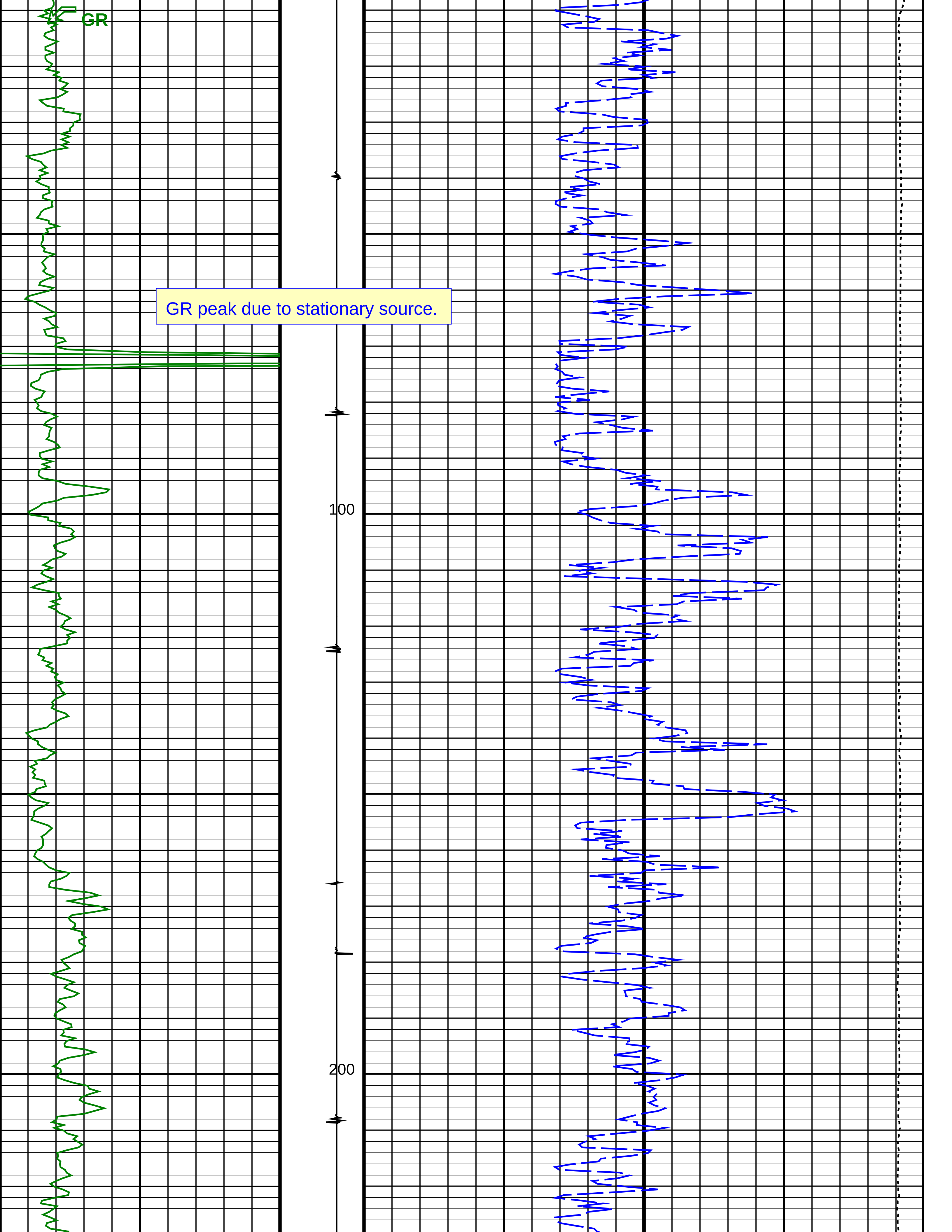
Input DLIS Files

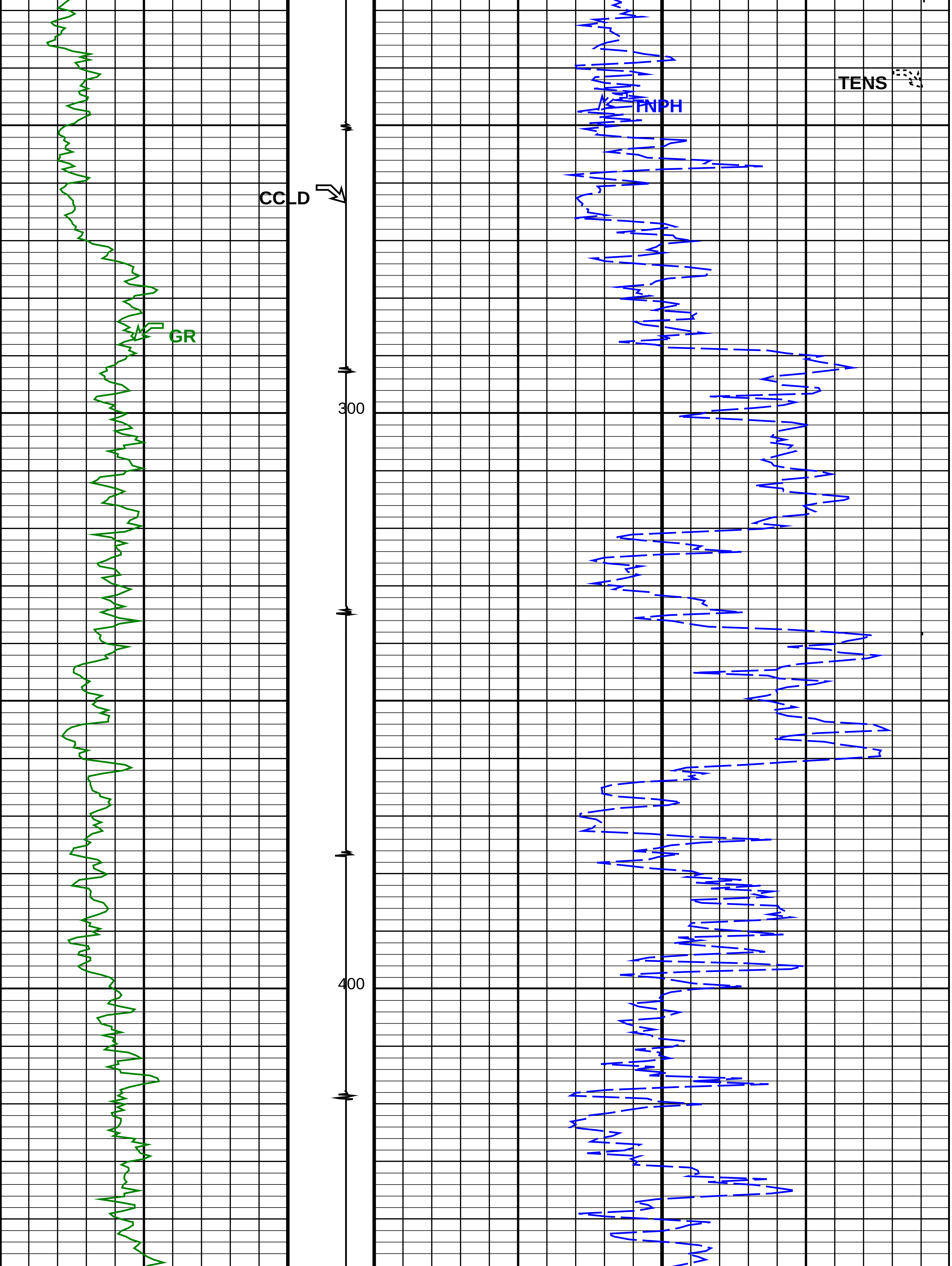
DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT

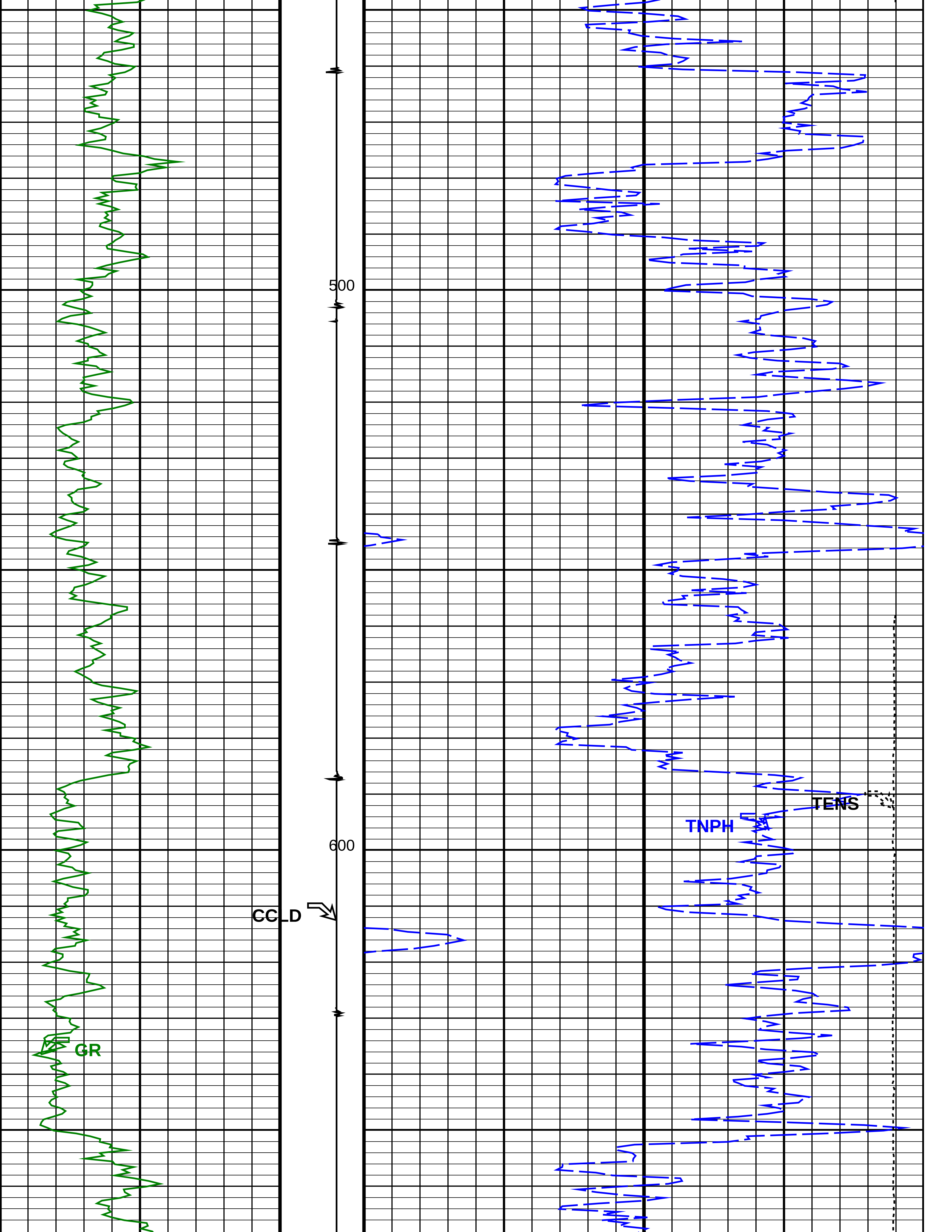
Output DLIS Files

DEFAULT	CNL_009PUP	FN:8	PRODUCER	21−Jul−2011 10:19	1800.0 FT	0.5 FT

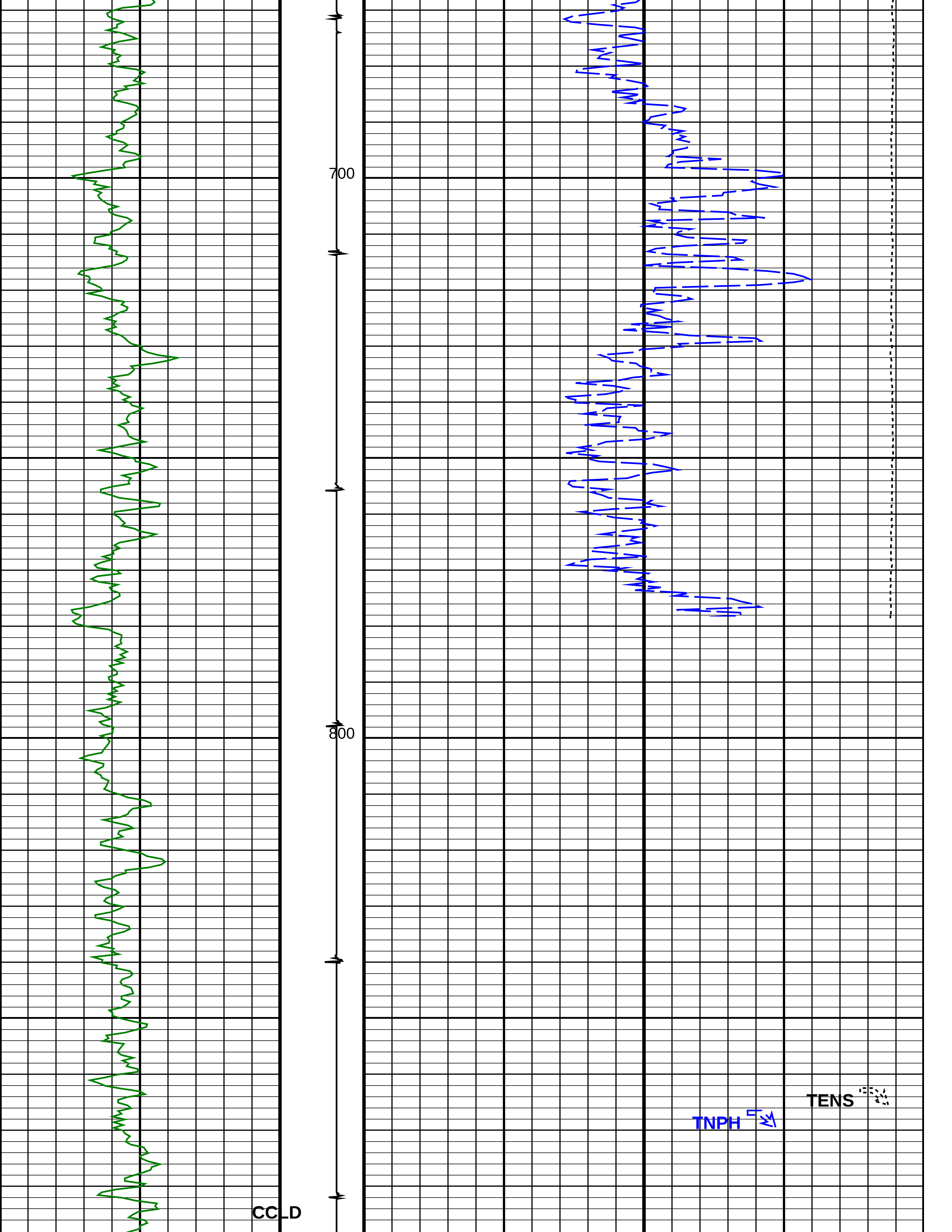


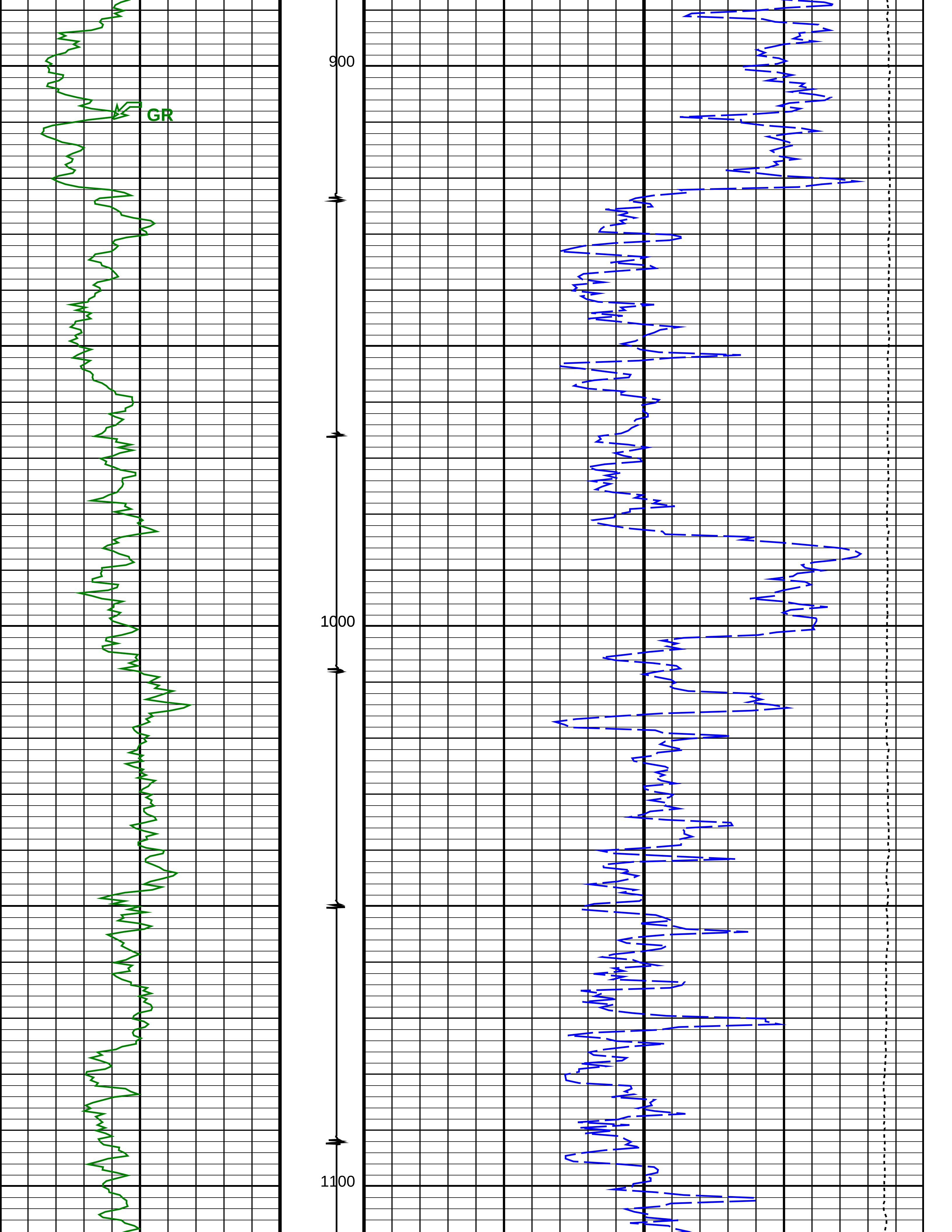

GR
GR peak due to stationary source.
100
200

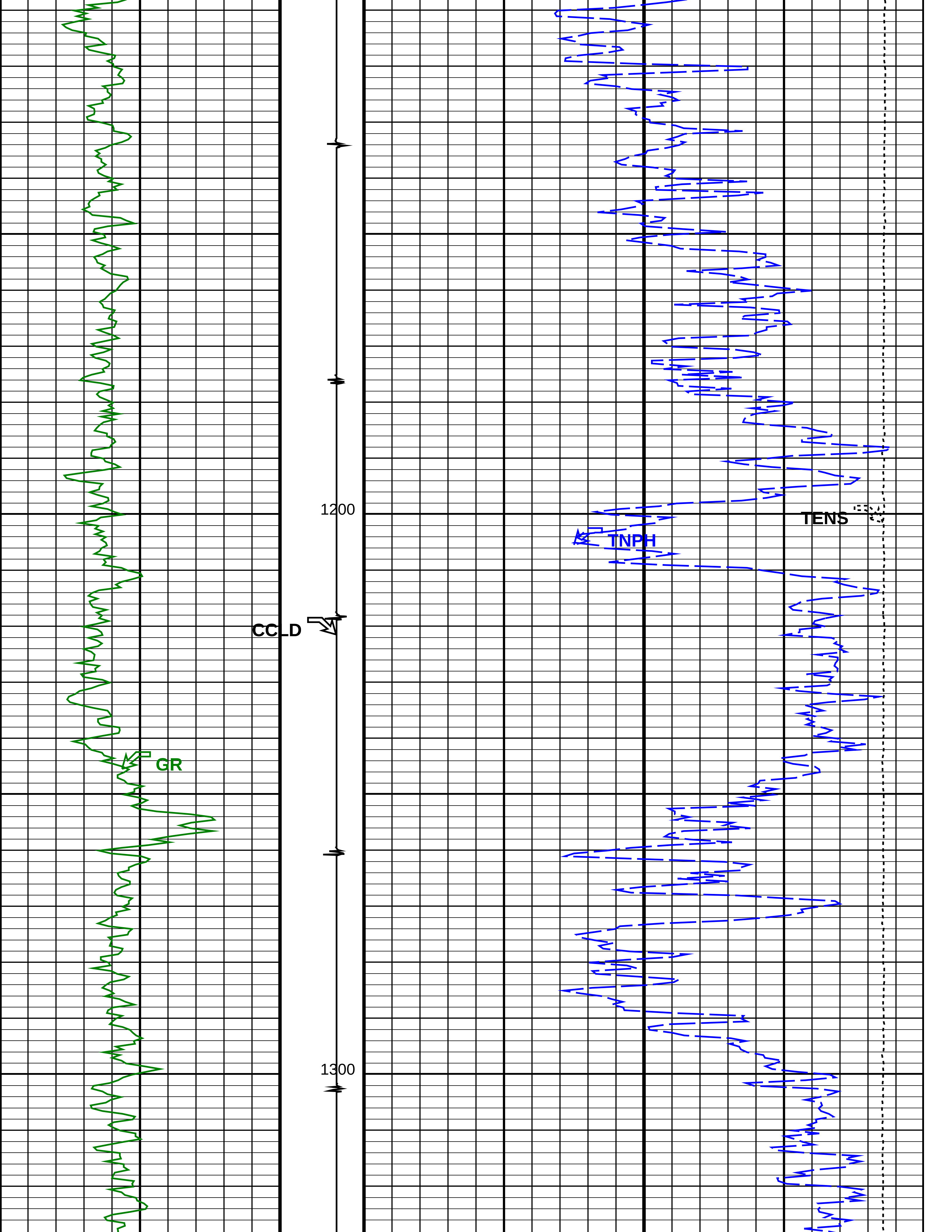

TENS
TNPH
CCLD
GR
300
400



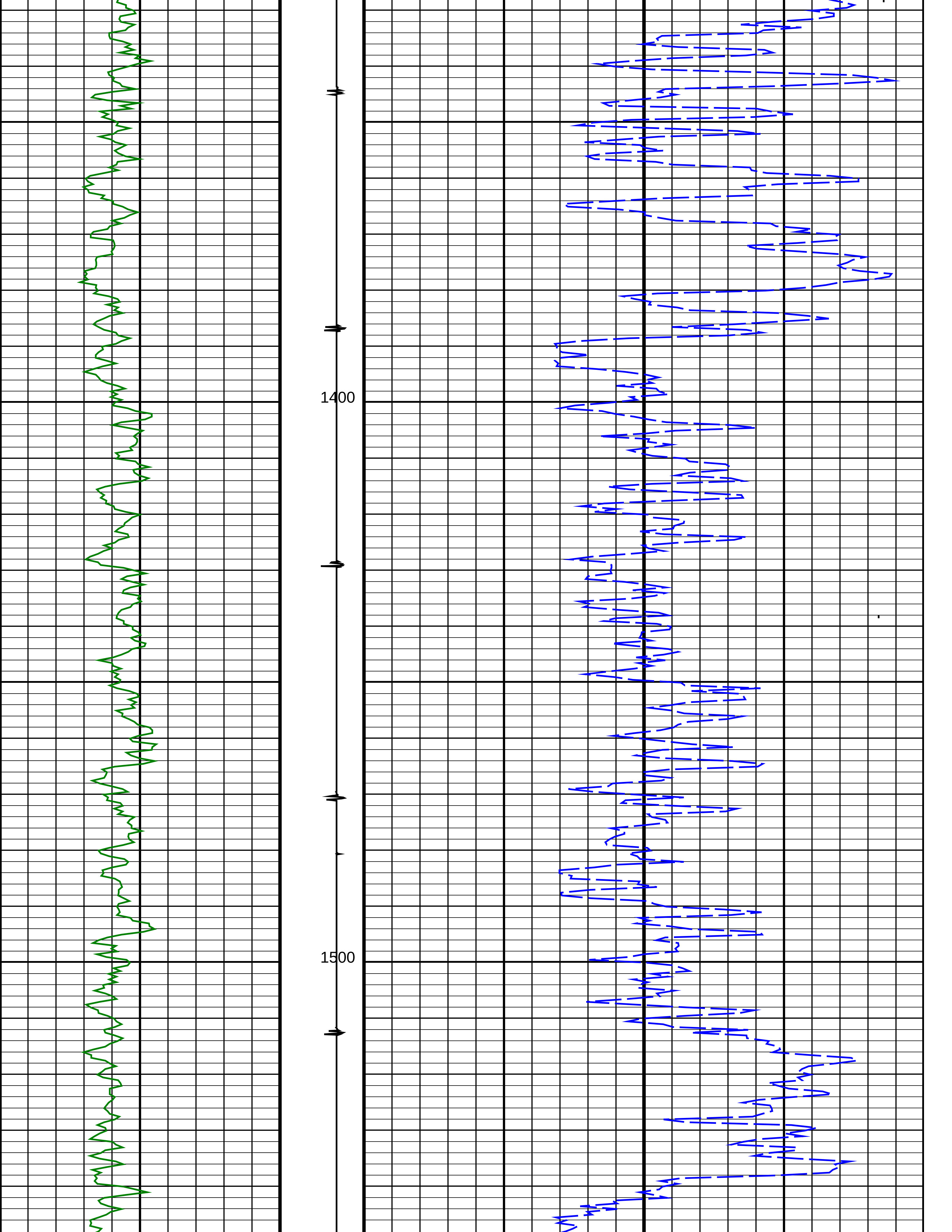
500
600
CCLD
TENS
TNPH
GR


700
800
CCLD
TNPH
TENS

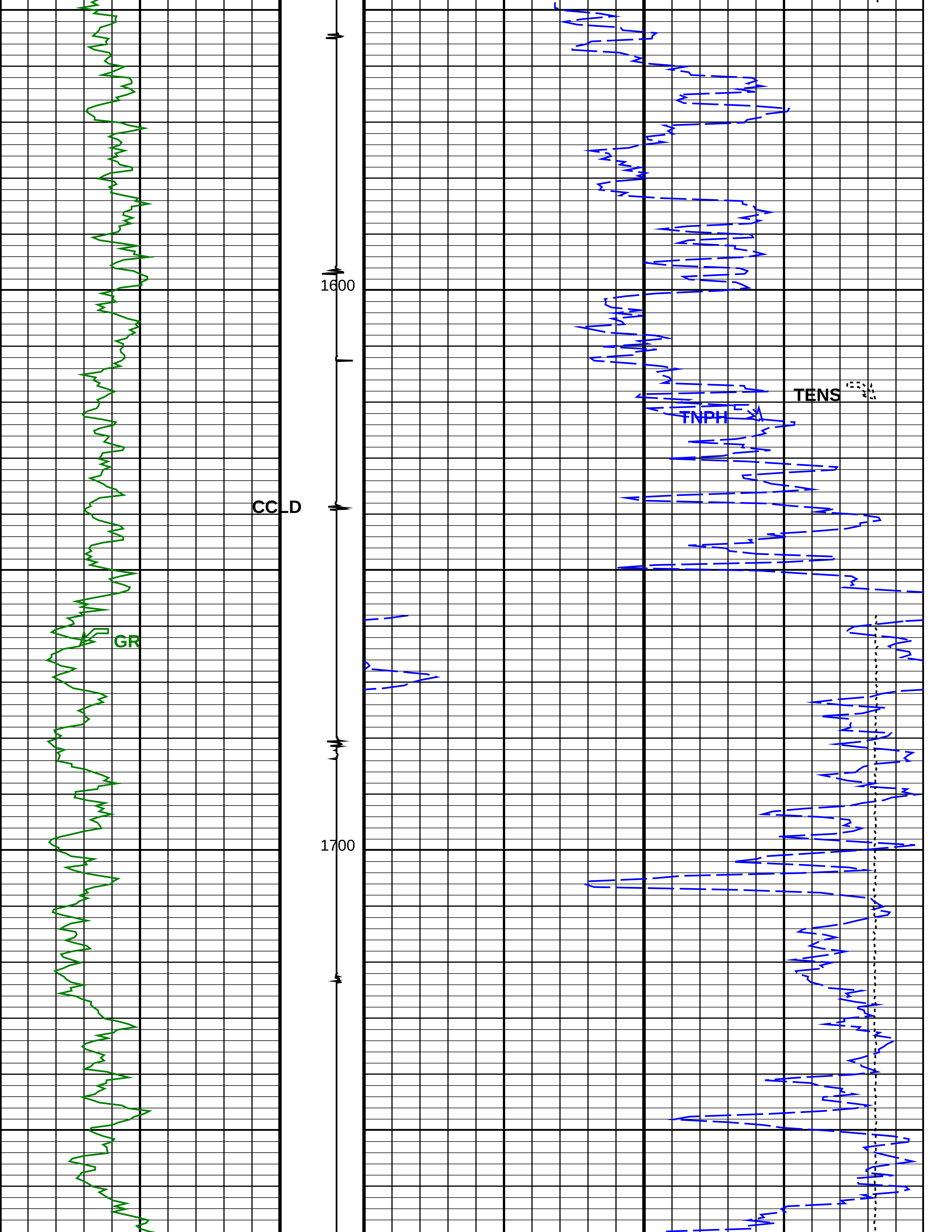

GR
900
1000
1100



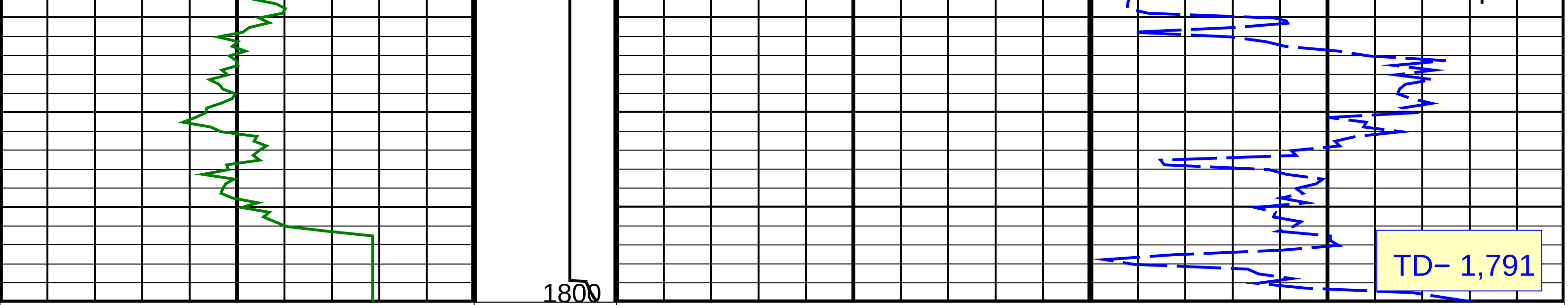
1200
TENS
TNPH
CCLD
GR
1300



1400
1500



1600
TENS
TNPH
CCLD
GR
1700



Gamma Ray (GR) 0 (GAPI) 150	Discriminated Casing Collar Locator Amplitude (CCLD) −10(−−−−) 5	Thermal Neutron Porosity (TNPH) 0.3 (V/V) −0.1
		Tension (TENS) 2000 (LBF) 0

Parameters

DLIS Name	Description	Value	
	ITGN−B: iFlex Telemetry Gamma Neutron Tool		
BARI_ITGN	Barite Mud Presence Flag	NO	
BHS	Borehole Status	CASED	
BSCO	Borehole Salinity Correction Option	NO	
CCCO	Casing & Cement Thickness Correction Option	YES	
DFT_IFLEX	Drilling Fluid Type	WATER	
FSAL	Formation Salinity	−50000	PPM
FSCO	Formation Salinity Correction Option	NO	
GCSE	Generalized Caliper Selection	BS	
HSCO	Hole Size Correction Option	YES	
MATR	Rock Matrix for Neutron Porosity Corrections	SANDSTONE	
MCCO	Mud Cake Correction Option	NO	
MWCO	Mud Weight Correction Option	NO	
NICO	Neutron Interference Correction Option	YES	
PTCO	Pressure Temperature Correction Option	NO	
PVN_ITGN	ITGN Computation Version	1.005	
SDAT	Standoff Data Source	SOCN	
SOCN	Standoff Distance	2	IN
SOCO	Standoff Correction Option	YES	
TBHDS	Tool Borehole Diameter Source	CALI	
TBHTS	Tool Borehole Temperature Source	GTSE	
	System and Miscellaneous		
BS	Bit Size	11.000	IN
BSAL	Borehole Salinity	−50000.00	PPM
CSIZ	Current Casing Size	0.000	IN
CWEI	Casing Weight	26.00	LB/F
DFD	Drilling Fluid Density	8.40	LB/G
DO	Depth Offset for Playback	0.0	FT
DORL	Depth Offset for Repeat Analysis	0.0	FT
PP	Playback Processing	NORMAL	

Format: NUC_5 Vertical Scale: 5" per 100’ Graphics File Created: 21−Jul−2011 10:19

OP System Version: 18C0−147

ITGN−B SPC−5020−IFLEX

Input DLIS Files

DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT

Output DLIS Files

DEFAULT	CNL_009PUP	FN:8	PRODUCER	21−Jul−2011 10:19

Schlumberger

Compensated Neutron Log

Repeat Analysis (1650−1740)

MAXIS Field Log

Company: City of Seminole | Well: Seminole Santa Rosa Well

Input DLIS Files

DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT
DEFAULT	CNL_006LUP	FN:5	PRODUCER	21−Jul−2011 09:39	1805.0 FT	1645.5 FT

Output DLIS Files

DEFAULT	CNL_009PUP	FN:8	PRODUCER	21−Jul−2011 10:19

OP System Version: 18C0−147

ITGN−B SPC−5020−IFLEX

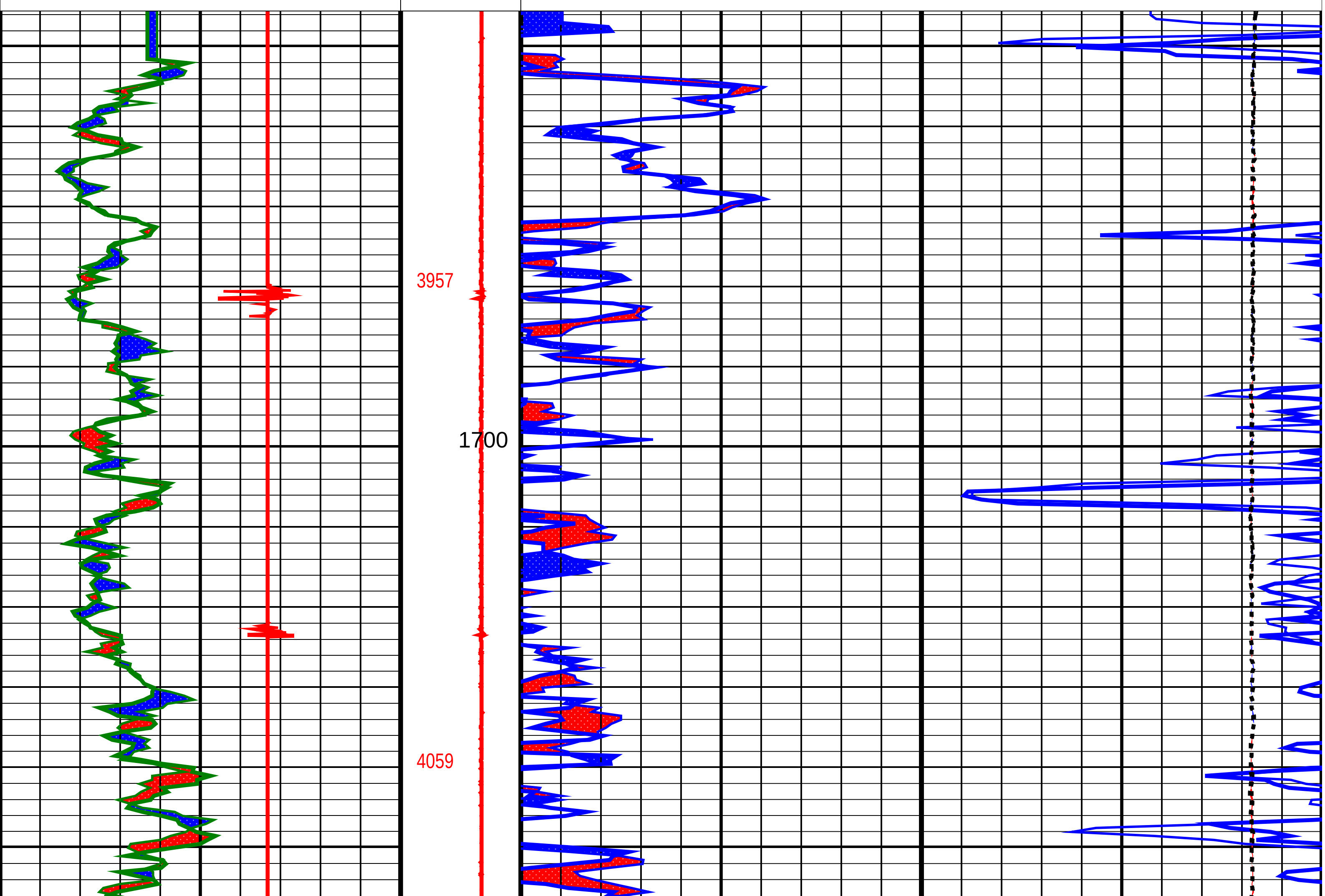
IFLEX/DiscriminatedCcl/Curve_REP Curve (CCLD_REP)
−10 (−−−−) 5

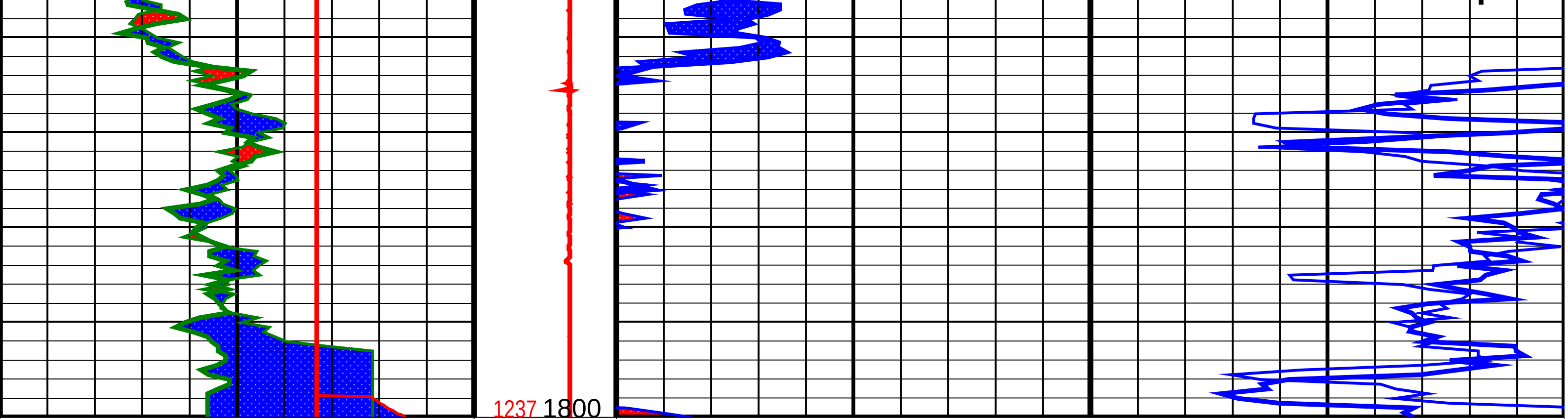
TENS_REP Curve (TENS_REP)
2000 (LBF) 0

GammaRay_REP Curve (GR_REP)
0 (GAPI) 150

IFLEX/Corr Ccl/Curve_ REP Curve (CCL_REP)
−10(−−−−) 5

ITGN/ThermPorosityLime/Curve_REP Curve (TNPH_LIM_REP)
0.3 (V/V) −0.1





GammaRay_REP Curve (GR_REP)
0 (GAPI) 150

IFLEX/Corr Ccl/Curve_REP Curve (CCL_REP)
−10(−−−−) 5

ITGN/ThermPorosityLime/Curve_REP Curve (TNPH_LIM_REP)
0.3 (V/V) −0.1

IFLEX/DiscriminatedCcl/Curve_REP Curve (CCLD_REP)
−10 (−−−−) 5

TENS_REP Curve (TENS_REP)
2000 (LBF) 0

Parameters

DLIS Name	Description	Value	
	ITGN−B: iFlex Telemetry Gamma Neutron Tool		
BARI_ITGN	Barite Mud Presence Flag	NO	
BHS	Borehole Status	CASED	
BSCO	Borehole Salinity Correction Option	NO	
CCCO	Casing & Cement Thickness Correction Option	YES	
CCLD	CCL reset delay	12	IN
CCLT	CCL Detection Level	0.3	V
DFT_IFLEX	Drilling Fluid Type	WATER	
FSAL	Formation Salinity	−50000	PPM
FSCO	Formation Salinity Correction Option	NO	
GCSE	Generalized Caliper Selection	BS	
HSCO	Hole Size Correction Option	YES	
MATR	Rock Matrix for Neutron Porosity Corrections	SANDSTONE	
MCCO	Mud Cake Correction Option	NO	
MWCO	Mud Weight Correction Option	NO	
NICO	Neutron Interference Correction Option	YES	
PTCO	Pressure Temperature Correction Option	NO	
PVN_ITGN	ITGN Computation Version	1.005	
SDAT	Standoff Data Source	SOCN	
SOCN	Standoff Distance	2	IN
SOCO	Standoff Correction Option	YES	
TBHDS	Tool Borehole Diameter Source	CALI	
TBHTS	Tool Borehole Temperature Source	GTSE	
	System and Miscellaneous		
BS	Bit Size	11.000	IN
BSAL	Borehole Salinity	−50000.00	PPM
CSIZ	Current Casing Size	0.000	IN
CWEI	Casing Weight	26.00	LB/F
DFD	Drilling Fluid Density	8.40	LB/G
DO	Depth Offset for Playback	0.0	FT
DORL	Depth Offset for Repeat Analysis	0.0	FT
PP	Playback Processing	NORMAL	

Format: NUC_5_REP Vertical Scale: 5" per 100' Graphics File Created: 21−Jul−2011 10:19

OP System Version: 18C0−147

ITGN−B SPC−5020−IFLEX

Input DLIS Files

DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT
DEFAULT	CNL_006LUP	FN:5	PRODUCER	21−Jul−2011 09:39	1805.0 FT	1645.5 FT

Output DLIS Files

DEFAULT	CNL_009PUP	FN:8	PRODUCER	21−Jul−2011 10:19

DEFAULT CNL_009PUP FN:8 PRODUCER 21−Jul−2011 10:19

Compensated Neutron Log
Repeat Analysis (600−670)

MAXIS Field Log

Company: City of Seminole | Well: Seminole Santa Rosa Well

Input DLIS Files

DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT
DEFAULT	CNL_004LUP	FN:3	PRODUCER	21−Jul−2011 09:29	683.0 FT	585.0 FT

Output DLIS Files

DEFAULT	CNL_010PUP	FN:9	PRODUCER	21−Jul−2011 10:21

OP System Version: 18C0−147

ITGN−B SPC−5020−IFLEX

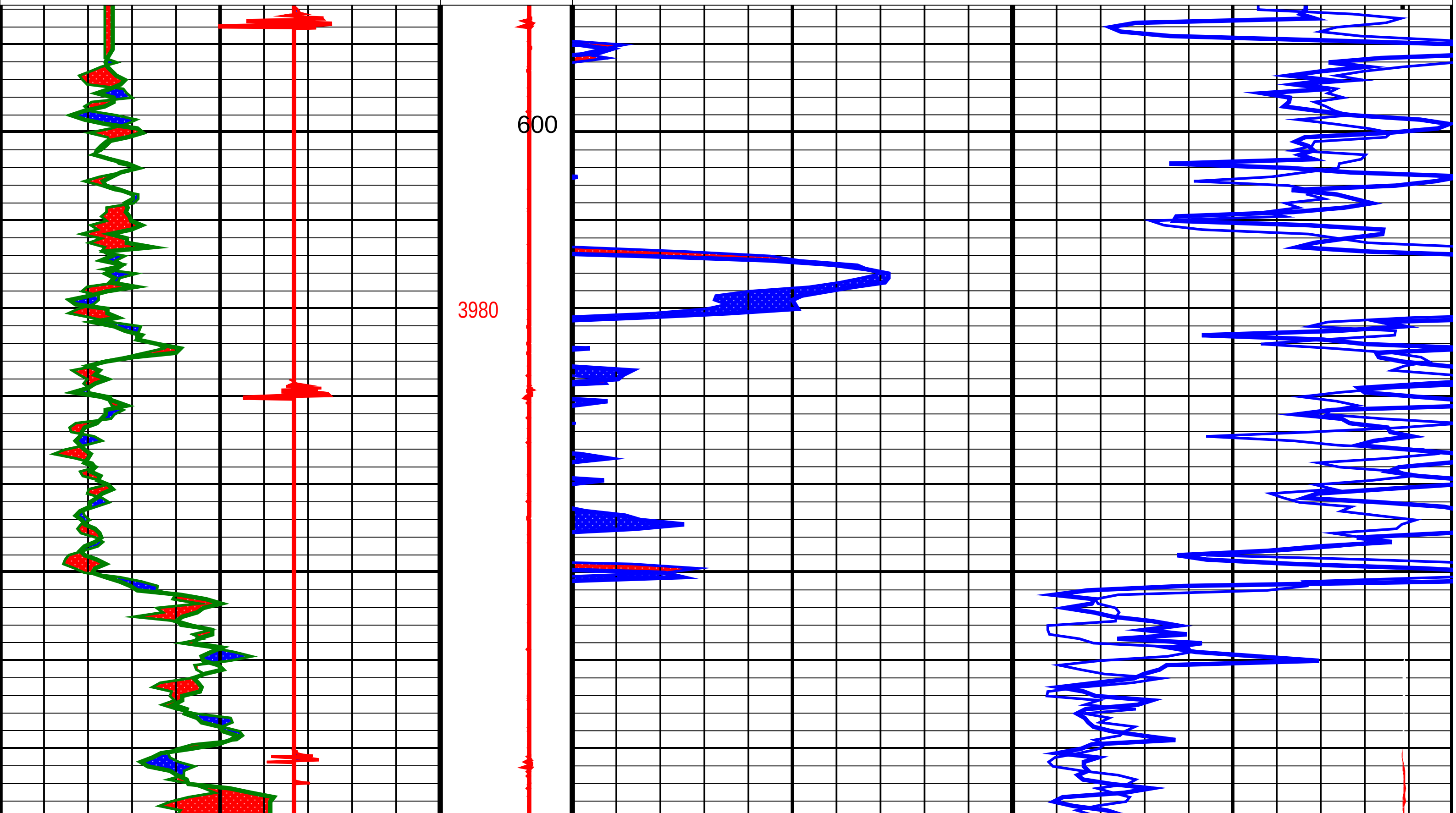
IFLEX/DiscriminatedCcl/Curve_REP Curve (CCLD_REP)
−10 (−−−−) 5

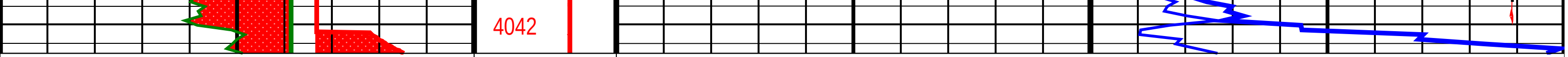
TENS_REP Curve (TENS_REP)
2000 (LBF) 0

GammaRay_REP Curve (GR_REP)
0 (GAPI) 150

IFLEX/Corr Ccl/Curve_ REP Curve (CCL_REP)
−10(−−−−) 5

ITGN/ThermPorosityLime/Curve_REP Curve (TNPH_LIM_REP)
0.3 (V/V) −0.1





GammaRay_REP Curve (GR_REP)	IFLEX/Corr Ccl/Curve_REP Curve (CCL_REP)	ITGN/ThermPorosityLime/Curve_REP Curve (TNPH_LIM_REP)
0 (GAPI) 150	−10(−−−−) 5	0.3 (V/V) −0.1
IFLEX/DiscriminatedCcl/Curve_REP Curve (CCLD_REP)		TENS_REP Curve (TENS_REP)
−10 (−−−−) 5		2000 (LBF) 0

Parameters

DLIS Name	Description	Value	
	ITGN−B: iFlex Telemetry Gamma Neutron Tool		
BARI_ITGN	Barite Mud Presence Flag	NO	
BHS	Borehole Status	CASED	
BSCO	Borehole Salinity Correction Option	NO	
CCCO	Casing & Cement Thickness Correction Option	YES	
CCLD	CCL reset delay	12	IN
CCLT	CCL Detection Level	0.3	V
DFT_IFLEX	Drilling Fluid Type	WATER	
FSAL	Formation Salinity	−50000	PPM
FSCO	Formation Salinity Correction Option	NO	
GCSE	Generalized Caliper Selection	BS	
HSCO	Hole Size Correction Option	YES	
MATR	Rock Matrix for Neutron Porosity Corrections	SANDSTONE	
MCCO	Mud Cake Correction Option	NO	
MWCO	Mud Weight Correction Option	NO	
NICO	Neutron Interference Correction Option	YES	
PTCO	Pressure Temperature Correction Option	NO	
PVN_ITGN	ITGN Computation Version	1.005	
SDAT	Standoff Data Source	SOCN	
SOCN	Standoff Distance	2	IN
SOCO	Standoff Correction Option	YES	
TBHDS	Tool Borehole Diameter Source	CALI	
TBHTS	Tool Borehole Temperature Source	GTSE	
	System and Miscellaneous		
BS	Bit Size	11.000	IN
BSAL	Borehole Salinity	−50000.00	PPM
CSIZ	Current Casing Size	0.000	IN
CWEI	Casing Weight	26.00	LB/F
DFD	Drilling Fluid Density	8.40	LB/G
DO	Depth Offset for Playback	0.0	FT
DORL	Depth Offset for Repeat Analysis	0.0	FT
PP	Playback Processing	NORMAL	

Format: NUC_5_REP   Vertical Scale: 5" per 100'   Graphics File Created: 21−Jul−2011 10:21

OP System Version: 18C0−147

ITGN−B   SPC−5020−IFLEX

Input DLIS Files

DEFAULT	CNL_007LUP	FN:6	PRODUCER	21−Jul−2011 09:43	1800.0 FT	0.1 FT
DEFAULT	CNL_004LUP	FN:3	PRODUCER	21−Jul−2011 09:29	683.0 FT	585.0 FT

Output DLIS Files

DEFAULT	CNL_010PUP	FN:9	PRODUCER	21−Jul−2011 10:21

Company: **City of Seminole**

Schlumberger

Well: **Seminole Santa Rosa Well**

Field:

County: **Gaines**

State: **Texas**

Compensated Neutron Log
Gamma Ray
Casing Collar Log

ATTACHMENT D

PHOTO NO. 1 DESCRIPTION:	"Flower pot" structures in the side of the mud pit. Reddish brown silty sand of the Blackwater Draw formation overlies the Ogallala caprock caliche. The flower pot structures are the silty sands incised into the top of the caliche zone.

PHOTO NO. 2 DESCRIPTION:	Basic Energy cementing the surface casing.

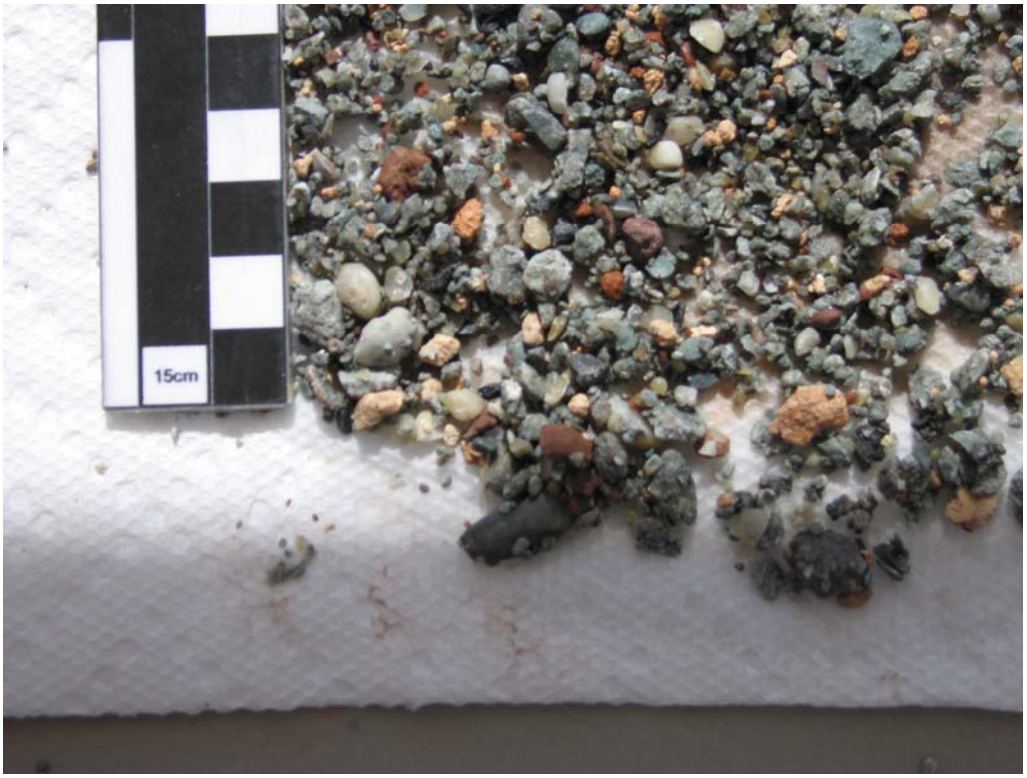


PHOTO NO. 3 DESCRIPTION:	Gravel section at a depth of 640' bgs. Each unit on the right side of the scale is equal to 1cm.

PHOTO NO. 4 DESCRIPTION:	The driller laid out soil samples collected at 10' intervals from the shaker and prepared the driller's log based on these cuttings.

PHOTO NO. 5 **DESCRIPTION:**	Cuttings collected from the “shaker” were used for preparation of the geologic log. The “fines” are separated out by the shaker, thereby biasing the soil samples. Sandy zones (i.e., fines) were noted based on the volume of sand from the sand separator.

PHOTO NO. 6 **DESCRIPTION:**	Near the bottom of the hole, approximately 60 drill stems (shown in the rack) were tripped in and out of the hole each day. The drill stems are approximately 30 feet in length.

PHOTO NO. 7 **DESCRIPTION:**	Steel casing being delivered to the site. Seven inch casing was used to complete the well.

Appendix B. State of Texas Driller's Log # 259331

STATE OF TEXAS WELL REPORT for Tracking #259331

Owner:	**City of Seminole**	Owner Well #:	**NewMuni.Well**
Address:	**302 S. Main Seminole , TX 79360**	Grid #:	**27-19-5**
Well Location:	**CR 306 Seminole , TX 79360**	Latitude:	**32° 41' 06" N**
Well County:	**Gaines**	Longitude:	**102° 40' 01" W**
Elevation:	**3300 ft.**	GPS Brand Used:	**Garmin**
Type of Work:	**New Well**	Proposed Use:	**Test Well**

Drilling Date:	Started: **6/21/2011** Completed: **7/7/2011**
Diameter of Hole:	Diameter: **17.5 in From Surface To 275 ft** Diameter: **11 in From 275 ft To 1808 ft**
Drilling Method:	**Mud Rotary**
Borehole Completion:	**Straight Wall**
Annular Seal Data:	1st Interval: **From 0 ft to 275 ft with 350 Class C Cem (#sacks and material)** 2nd Interval: **From 0 ft to 1800 ft with 800 Class C Cem (#sacks and material)** 3rd Interval: **No Data** Method Used: **Pressure Cement** Cemented By: **Basic Energy** Distance to Septic Field or other Concentrated Contamination: **N/A ft** Distance to Property Line: **65 ft** Method of Verification: **Measured** Approved by Variance: **No Data**
Surface Completion:	**Surface Sleeve Installed**
Water Level:	Static level: **No Data** Artesian flow: **No Data**
Packers:	**No Data**
Plugging Info:	Casing or Cement/Bentonite left in well: **No Data**
Type Of Pump:	**No Data**
Well Tests:	**No Data**
Water Quality:	Type of Water: **Fresh** Depth of Strata: **640 - 1800 ft.** Chemical Analysis Made: **No** Did the driller knowingly penetrate any strata which contained undesirable constituents: **No**
Certification Data:	The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the log(s) being returned for completion and resubmittal.

Company Information: **West Texas Water Well Service**
3410 Mankins
Odessa , TX 79764

Driller License Number: **54815**

Licensed Well Driller Signature: **Rory Roach**

Registered Driller Apprentice Signature: **No Data**

Apprentice Registration Number: **No Data**

Comments: **No Data**

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

TEX. OCC. CODE Title 12, Chapter 1901.251, authorizes the owner (owner or the person for whom the well was drilled) to keep information in Well Reports confidential. The Department shall hold the contents of the well log confidential and not a matter of public record if it receives, by certified mail, a written request to do so from the owner.

Please include the report's Tracking number (Tracking **#259331**) on your written request.

Texas Department of Licensing & Regulation
P.O. Box 12157
Austin, TX 78711
(512) 463-7880

DESC. & COLOR OF FORMATION MATERIAL

From (ft) To (ft) Description
0 3 Top soil
3 31 Caliche
31 33 Red sand
33 39 Calcrete
39 98 Brown sandstone
98 101 Calcrete
101 109 Brown sandstone
109 120 Calcrete
120 129 Brown & tan sandstone
129 173 Small sand & gravel, some gray shale
173 240 Red clay
240 275 Red clay, brown sandstone
275 350 Brown clay, gray shale
350 360 Gray shale
360 470 Brown clay, gray shale
470 480 Gray shale
480 510 Brown clay
510 520 Gray shale
520 645 Brown clay, gray shale
645 656 Small sand & gravel
656 770 Brown clay
770 790 Brown clay w/small gravel
790 880 Brown & red clay
880 920 Brown clay, gray shale
920 930 Small gray shale, silt
930 1030 Brown clay, gray shale
1030 1260 Brown clay
1260 1550 Brown clay, gray shale
1550 1670 Brown clay
1670 1808 Brown clay, gray shale

CASING, BLANK PIPE & WELL SCREEN DATA

Dia. New/Used Type Setting From/To
12-3/4 New Steel 0 - 274 Blank
7 New Steel 0 - 1800 Blank

Appendix C. Dr. Tom Lehman's Geologic Log

LOG OF SR - 1 [T. Lehman, 11/2011] *page 1 of 5*

depth (ft)	*color*	*Munsell color (wet)*	*lithology*
BLACKWATER DRAW FORMATION (0 to 3 feet)			
0 - 3	reddish brown	5 YR 4/4 to 7.5 YR 4/4	silty very fine to fine quartzose sand, weakly consolidated [sample collected from surface]
OGALLALA FORMATION (3 to 105 feet)			
"Caprock" Caliche (weakly developed)			
3 - 10	pinkish white	7.5 YR 8/2	hard sandy pisolitic caliche in very fine/fine sand [sample collected from surface]
10	light brown	7.5 YR 6/3	sandy caliche
fine-grained eolian facies of Ogallala			
20	light brown	7.5 YR 6/3	fine/medium-grained sandstone, weakly cemented with calcite, sublithic, some sandy caliche
30	"	"	fine/medium-grained sandstone, very well indurated @ 35-40' (possible silcrete), sublithic
40	brown	7.5 YR 4/4	medium-grained sandstone, well indurated, sublithic
50	"	"	"
60	"	"	"
70	"	"	"
80	"	"	"
90	"	"	" (very well indurated, calcite cement)
100	"	"	" (contact with underlying limestone in this interval)
COMANCHE PEAK LIMESTONE (105 to 135 feet)			
110	light brownish gray	2.5 Y 6/2	limestone, sandy, argillaceous, slightly fossiliferous
120	pale yellow	2.5 Y 7/2 - 7/3	"
130	"	"	" (contact with underlying shale in this interval)
WALNUT FORMATION (135 to 155 feet)			
140	gray - light brownish gray	2.5 YR 6/1 - 6/2	shale and argillaceous limestone
150	"	"	" (contact with underlying sandstone in this interval)
ANTLERS SANDSTONE (155 to 175 feet)			
160	light gray	10 YR 7/2	medium to coarse sandstone, weakly cemented, quartzose, some granular chert conglomerate, ferruginous intervals
170	white	10 YR 8/1	fine quartzose sandstone and granular chert conglomerate (contact with underlying mudstone)

DOCKUM GROUP (175 to 1808 feet, td @ 1808') *page 2 of 5*

upper mudstone interval (Cooper Canyon Formation, 175 to 625 feet)

180	reddish brown - brown	5 YR 4/4	mudstone with interbedded friable fine sandstone
190	"	7.5 YR 4/4	fine to medium sandstone, some coarse grains, lithic, poorly consolidated, some light green spots
200	brown	7.5 YR 5/3	medium to coarse sandstone, lithic, poorly consolidated
210	reddish brown	5 YR 4/4	mudstone, some light green reduction spots
220	"	"	"
230	"	"	"
240	brownish gray	2.5 YR 5/2 - 6/2	fine to medium sandstone, lithic, poorly consolidated
250	"	"	" (some mudstone interbedded)
260	"	"	fine to medium sandstone, conglomeratic, lithic, poorly consolidated
270	gray - olive gray	5 Y 5/1 - 5/2	mudstone with large concretions
280	"	"	"
290	"	"	"
300	reddish brown	5 YR 4/4	mudstone, with green reduction spots
310	"	"	"
320	"	"	"
330	"	"	" (one large sandy ?caliche pebble, probable caving)
340	"	"	red mudstone
350	"	"	mudstone with interbedded friable fine lithic sandstone (two sandy ?caliche pebbles, probable cavings, labelled @ 352')
360	olive gray - green	5 Y 5/2	fine to medium sandstone, lithic, poorly consolidated
370	reddish brown	5 YR 4/4	mudstone, some green reduction spots
380	"	"	mudstone
390	"	"	"
400	"	"	mudstone, interbedded friable fine lithic sandstone, green reduction spots
410	"	"	mudstone
420	"	"	mudstone with green reduction spots
430	reddish brown	5 YR 5/4	claystone
440	"	5 YR 4/4	mudstone with green reduction spots
450	"	"	"
460	"	"	"
470	olive gray - green	5 Y 5/2	fine to medium sandstone, lithic, poorly consolidated, interbedded with mudstone
480	"	"	"
490	reddish brown	5 YR 4/4	mudstone with green reduction spots
500	"	"	mudstone
510	"	"	mudstone with green reduction spots
520	"	"	mudstone interbedded with friable fine lithic sandstone, green reduction spots
530	"	"	mudstone interbedded with friable fine lithic sandstone, green reduction spots
540	"	"	mudstone interbedded with friable fine lithic sandstone, green reduction spots

550	olive gray - green	5 Y 5/2	medium to coarse sandstone, poorly consolidated, abundant carbonized plant fragments
560	"	"	mudstone with interbedded friable fine sandstone
570	olive gray - green	5 Y 5/1	mudstone with carbonized plant fragments
580	reddish brown	5YR 4/4	mudstone with green reduction spots
590	olive gray	5 Y 5/1	clayshale, well laminated
600	olive gray - green	5 Y 5/2	clayshale, well laminated
610	reddish brown	5 YR 4/4	mudstone
620	"	"	mudstone, contact with underlying sandstone

upper sandstone interval (Trujillo Sandstone, 625 to 660 feet)

630	olive gray - green	5 Y 5/1 - 5/2	coarse conglomeratic sandstone, lithic, poorly consolidated, pebbles of chert and quartzite
640	"	"	"
650	"	"	coarse sandy conglomerate, chert and quartzite pebbles
660	"	"	"

lower mudstone interval (Tecovas Formation, 660 to 1808 feet)

670	reddish brown	5 YR 5/3 - 5/4	mudstone
680	"	"	"
690	"	"	mudstone with green reduction spots
700	"	"	mudstone
710	"	"	mudstone
720	"	"	mudstone with green reduction spots
730	"	"	mudstone, green reduction spots, carbonate nodules
740	"	"	mudstone with green reduction spots
750	"	"	"
760	"	"	"
770	"	"	"
780	"	"	mudstone
790	"	"	mudstone
800	"	"	mudstone with green reduction spots
810	"	"	mudstone
820	"	"	mudstone with abundant green reduction spots
830	"	"	mudstone with green reduction spots
840	"	"	mudstone with green reduction spots
850	"	"	mudstone
860	"	"	"
870	"	"	"
880	"	"	"
890	"	"	"
900	"	"	"
910	light olive brown	2.5 Y 5/2 - 5/3	mudstone
920	light olive brown	2.5 Y 5/2 - 5/3	mudstone
930	light olive brown	2.5 Y 5/2 - 5/3	mudstone
940	reddish brown	5 YR 4/4	mudstone with green reduction spots
950	"	"	mudstone
960	"	"	mudstone

970	"	"	mudstone with green reduction spots
980	"	"	"
990	"	"	"
1000	"	"	mudstone
1010	"	"	mudstone
1020	"	"	mudstone
1030	"	"	mudstone
1040	"	"	"
1050	"	"	"
1060	"	"	"
1070	"	"	"
1080	"	"	mudstone with green reduction spots
1090	"	"	mudstone
1100	"	"	mudstone with green reduction spots
1110	"	"	mudstone
1120	"	"	mudstone with green and dark purple spots
1130	"	"	mudstone
1140	"	"	mudstone
1150	"	"	mudstone
1160	"	"	"
1170	"	"	"
1180	"	"	"
1190	"	"	"
1200	"	"	"
1210	"	"	"
1220	"	"	"
1230	"	"	"
1240	"	"	"
1250	"	"	"
1260	"	"	mudstone with green reduction spots
1270	dark gray	5 YR 4/1	mudstone
1280	light greenish gray	10 GY 7/1	mudstone
1290	reddish brown	5 YR 4/4	mudstone
1300	reddish brown	5 YR 4/4	mudstone
1310	"	"	"
1320	"	"	"
1330	"	"	"
1340	"	"	mudstone with green reduction spots
1350	dark gray	10 GY 7/1	mudstone with hard concretions (@ 1356')
1360	reddish brown	5 YR 4/4	mudstone with green reduction spots
1370	dark gray	10 GY 7/1	mudstone with some red beds
1380	dark gray	10 GY 7/1	"
1390	dark gray	10 GY 7/1	"
1400	"	"	"
1410	reddish brown	5 YR 4/4	mudstone with green reduction spots
1420	reddish brown	5 YR 4/4	"
1430	reddish brown	5 YR 4/4	"
1440	reddish brown	5 YR 4/4	mudstone with green and purple spots
1450	reddish brown	5 YR 4/4	mudstone with green reduction spots

1460	reddish brown	5 YR 4/4	mudstone
1470	"	"	"
1480	"	"	"
1490	"	"	mudstone with concretion horizon @ 1493'
1500	"	"	mudstone with dark gray interbeds
1510	"	"	mudstone with green reduction spots
1520	"	"	"
1530	"	"	mudstone
1540	"	"	mudstone
1550	"	"	"
1560	"	"	mudstone with green reduction spots
1570	"	"	mudstone
1580	dark gray	10 GY 7/1	mudstone
1590	reddish brown	5 YR 4/4	mudstone with green reduction spots
1600	reddish brown	5 YR 4/4	mudstone with green reduction spots
1610	"	"	mudstone
1620	"	"	"
1630	"	"	"
1640	"	"	"
1650	"	"	"
1660	"	"	mudstone
1670	grayish brown	2.5 Y 5/1 - 5/2	fine to medium sandstone, lithic, poorly consolidated, slightly conglomeratic
1680	grayish brown	2.5 Y 5/1 - 5/2	medium to coarse sandstone, lithic, poorly consolidated, slightly conglomeratic (contact with underlying mudstone in this interval)
1690	dark gray	10 GY 7/1	mudstone
1700	grayish brown	2.5 Y 5/1 - 5/2	medium sandstone, lithic, poorly consolidated
1710	grayish brown	2.5 Y 5/1 - 5/2	fine sandstone, lithic, poorly consolidated, interbedded with red mudstone
1720	reddish brown	5 YR 4/4	mudstone
1730	grayish brown	2.5 Y 5/1 - 5/2	very fine sandstone, lithic, poorly consolidated, interbedded with red mudstone
1740	grayish brown	2.5 Y 5/1 - 5/2	very fine sandstone, lithic, poorly consolidated, interbedded with red mudstone
1750	reddish brown	5 YR 4/4	mudstone
1760	reddish brown	5 YR 4/4	mudstone with green reduction spots
1770	"	"	mudstone
1780	reddish brown	5 YR 4/4	mudstone with green reduction spots
1790	"	"	mudstone with green and dark gray spots
1800	reddish brown	5 YR 4/4	mudstone

total depth @ 1808', base of Dockum Group not reached

Appendix D. Cartridge Filter Autopsy

Wardle, C., 2014a. Cartridge Filter Examination and Foulant Analysis, Professional Water Technologies, Vista, CA, 11 p.

MEMBRANE AUTOPSY REPORT

MEMBRANE FORENSICS

Cartridge Filter Examination and Foulant Analysis

Texas Tech University
Lubbock, Texas

Produced By: Charles Wardle, Technical Support Engineer
Professional Water Technologies

Date: 11 August 2014

Membrane® Forensics
Powered by Professional Water Technologies

PROFESSIONAL WATER TECHNOLOGIES™

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INTRODUCTION

One cartridge filter was received from Texas Tech University for examination and foulant analysis.

FOULANT OBSERVATIONS

The cartridge filter was covered in a heavy layer of brown colored foulant (Figures 1-3). Brown discoloration was also noted on the interior of the filter (Figure 2). The filter was soaked in DI water overnight and the foulant was collected for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted-Energy Dispersive X-Ray Analysis (T-EDXA) and Fourier Transform Infrared Spectroscopy (FTIR).

Figure 1. Cartridge filter as received from Texas Tech University.

Figure 2. End of cartridge filter, note the light brown discoloration of the interior.

Figure 3. Close-up of cartridge filter surface, note the heavy coating of brown foulant.

PROFESSIONAL WATER TECHNOLOGIES™

LOSS OF IGNITION (LOI)

PROCEDURE: The foulant sample collected from the cartridge filter was first dried at 110°C and heated to 550°C which destroys the organic material in the sample. The weight loss on ignition is calculated from measured weights obtained before and after exposure to the higher temperature. The LOI is referred to as a percentage of the foulant sample and is generally considered to be the organic portion of the foulant (see Results and Figure 4).

RESULTS: 91.2% Ash (Inorganic Material) and 8.8% Volatile (Organic Material).

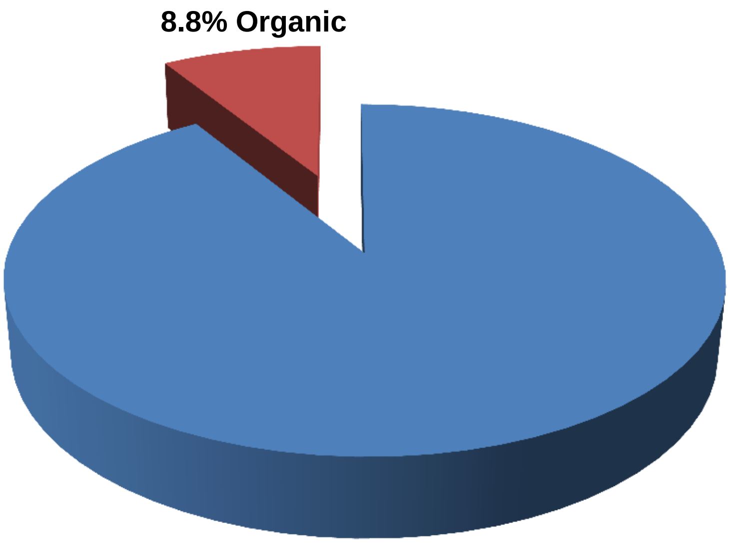

Figure 4. Graphical representation of the organic and inorganic portions of the foulant sample removed from the surface of the cartridge filter.

SCANNING ELECTRON MICROSCOPY (SEM)

PROCEDURE: A small portion of the foulant material removed from the cartridge filter was examined using a Scanning Electron Microscope (SEM). Secondary electron images, such as that shown below, were taken at 1050X. An examination using SEM analysis is useful in determining particle size and morphology.

RESULTS: See Figures 5 & 6.

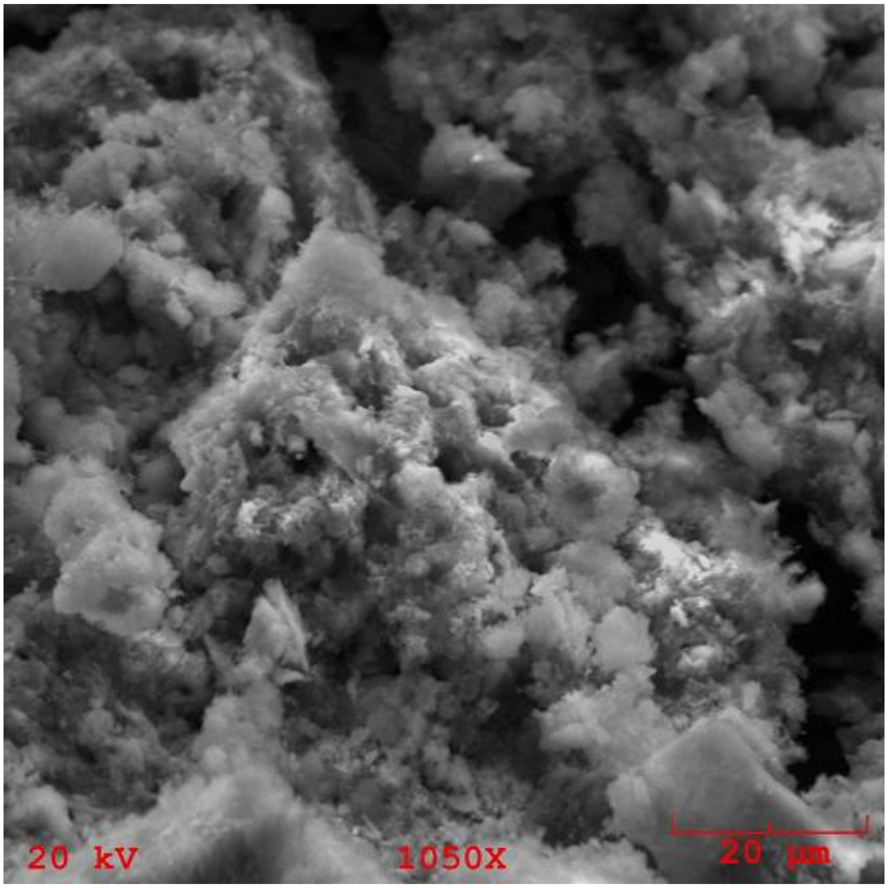

Figure 5. Scanning electron microscope image of the foulant collected from the surface of the cartridge filter at 1050X Magnification.

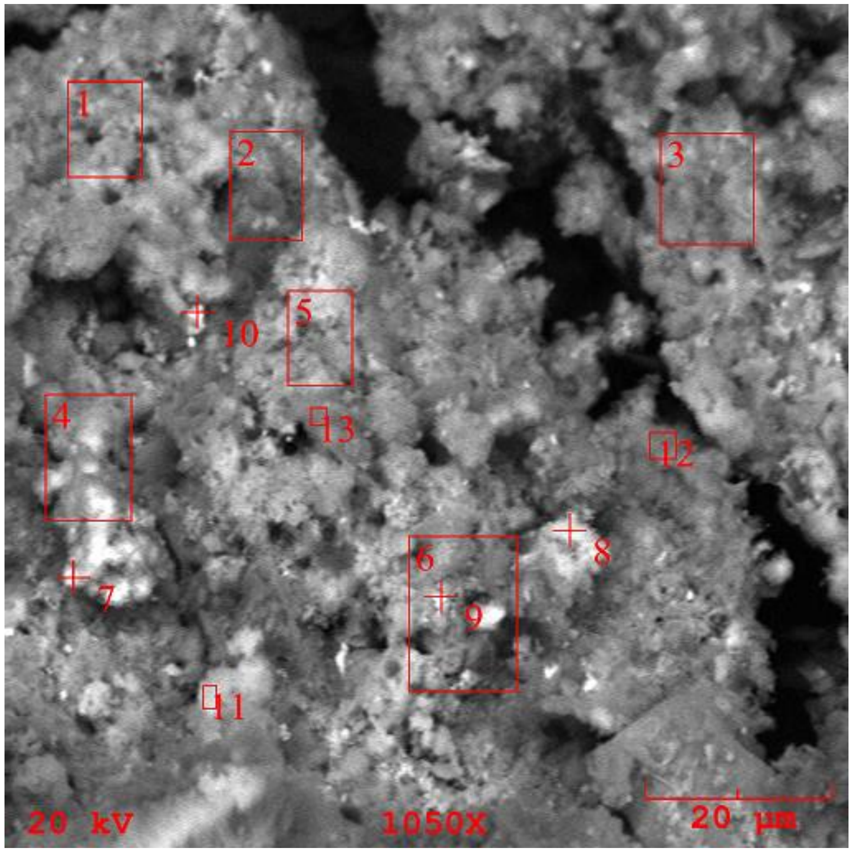

Figure 6. Backscatter scanning electron microscope image of the foulant collected from the surface of the cartridge filter at 1050X magnification. The red numbers indicate sample areas selected for targeted-EDXA.

TARGETED ENERGY DISPERSIVE X-RAY ANALYSIS (T-EDXA)

PROCEDURE: A small portion of the foulant material removed from the cartridge filter was examined in a scanning electron microscope. The wavelengths or energy levels of the X-rays produced are used to identify the presence (and relative amounts) of the chemical elements found in the foulant sample. This test is most useful in determining the nature of the inorganic portion of the foulant.

RESULTS: The foulant removed was target analyzed at six different areas (as shown in Figure 6). Targeted-EDXA determined the largest inorganic constituent of the foulant to be iron at 71.30%. The remaining inorganic constituents were a combination of silicon (11.97%), calcium (4.57%), sulfur (3.70%), chlorine (2.95%), aluminum (2.70%), potassium (2.06%), manganese (0.39%), titanium (0.28%), and magnesium (0.02%).

Examples of the T-EDXA spectra are shown in Figures 7 and 8. Figure 9 shows the combined average weight percentage of the inorganic elements in all six T-EDXA areas.

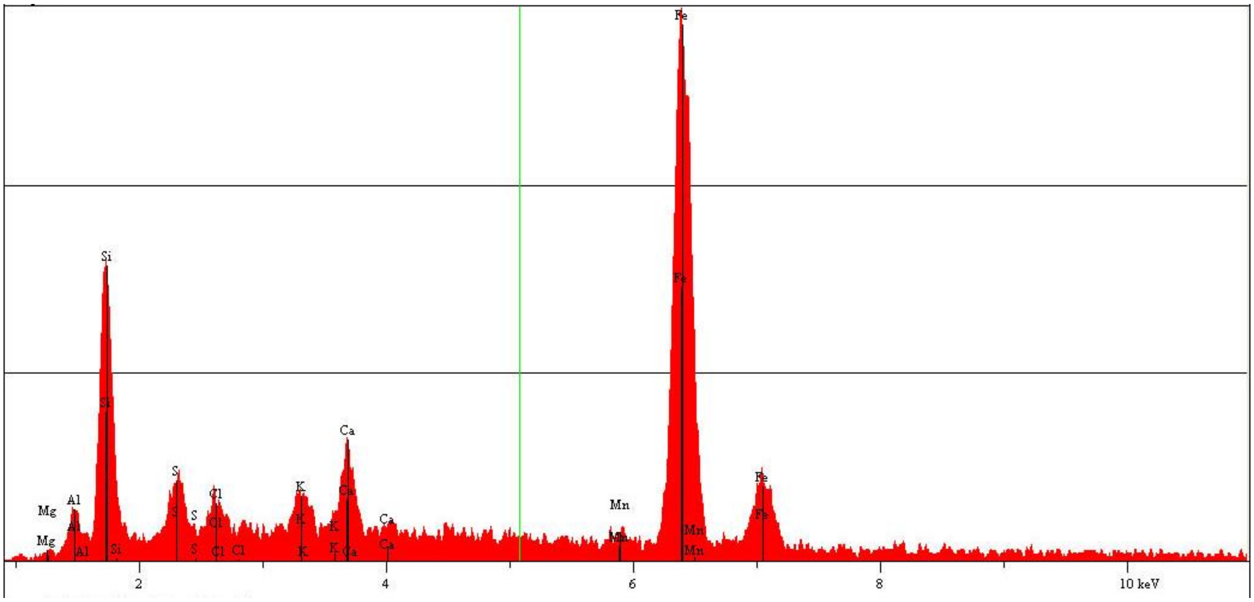

Figure 7. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of the cartridge filter, target area 2 (Figure 6).

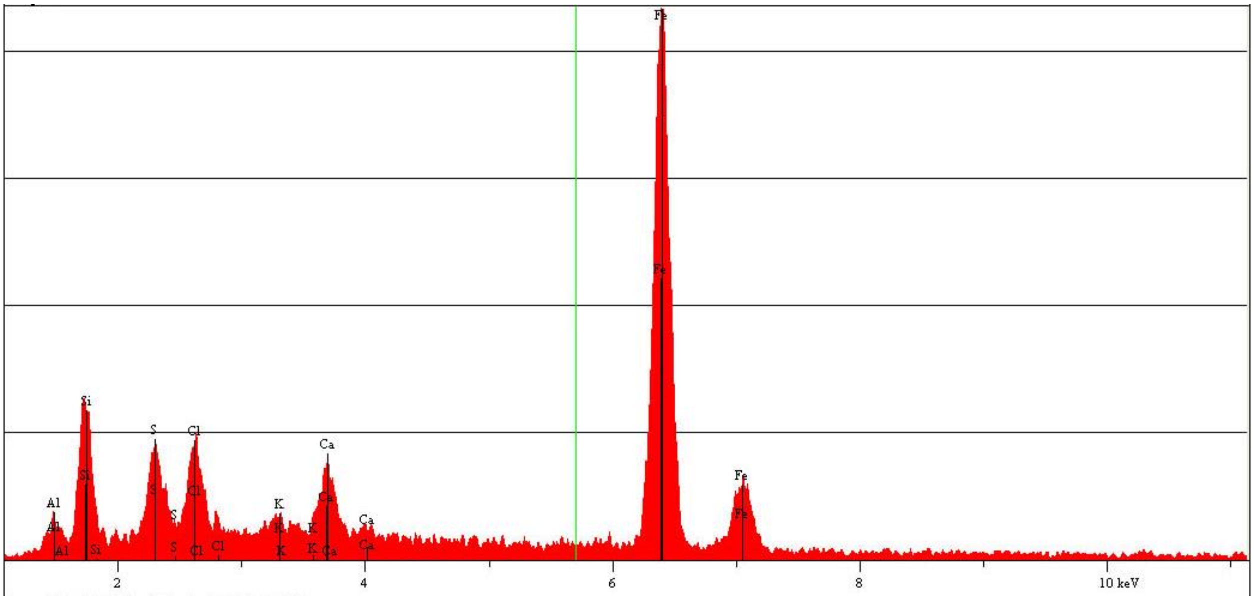

Figure 8. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of the cartridge filter, target area 5 (Figure 6).

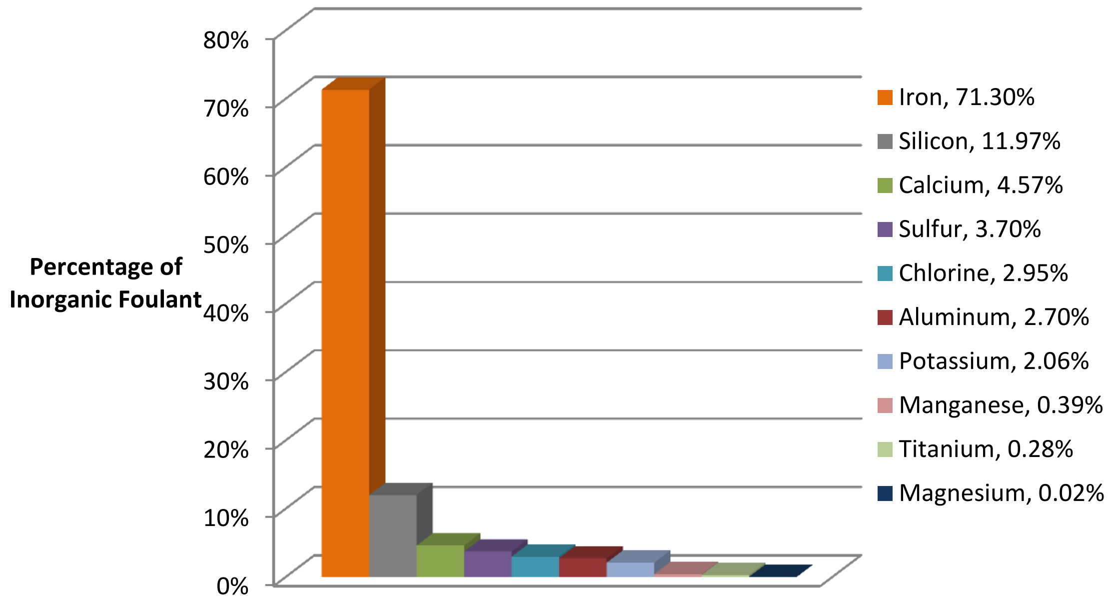

Figure 9. Graphical representation of the inorganic constituents found in the foulant sample removed from the surface of the cartridge filter. It is important to note that the inorganic portion of the foulant was 91.2%.

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

The FTIR analysis is used to identify organic compounds in a sample. An infrared transmittance spectrum is produced creating a "fingerprint." The spectrum is compared to a 70,000 spectral library and subject to interpretation.

SAMPLE PREPERATION: Samples of foulant from the cartridge filter were ground fine in an agate mortar and pestle.

PROCEDURE: The fine powder was loaded into a cavity in a holder for HATR attachment. The samples were analyzed using a PE 1600 FT-IR instrument.

RESULTS: Organic extractions, analysis, spectral interpretation and library search were performed on the foulant sample. The analysis indicated the foulant was mostly alumio-silicate clays, with small amounts of carbohydrates and polysaccharides.

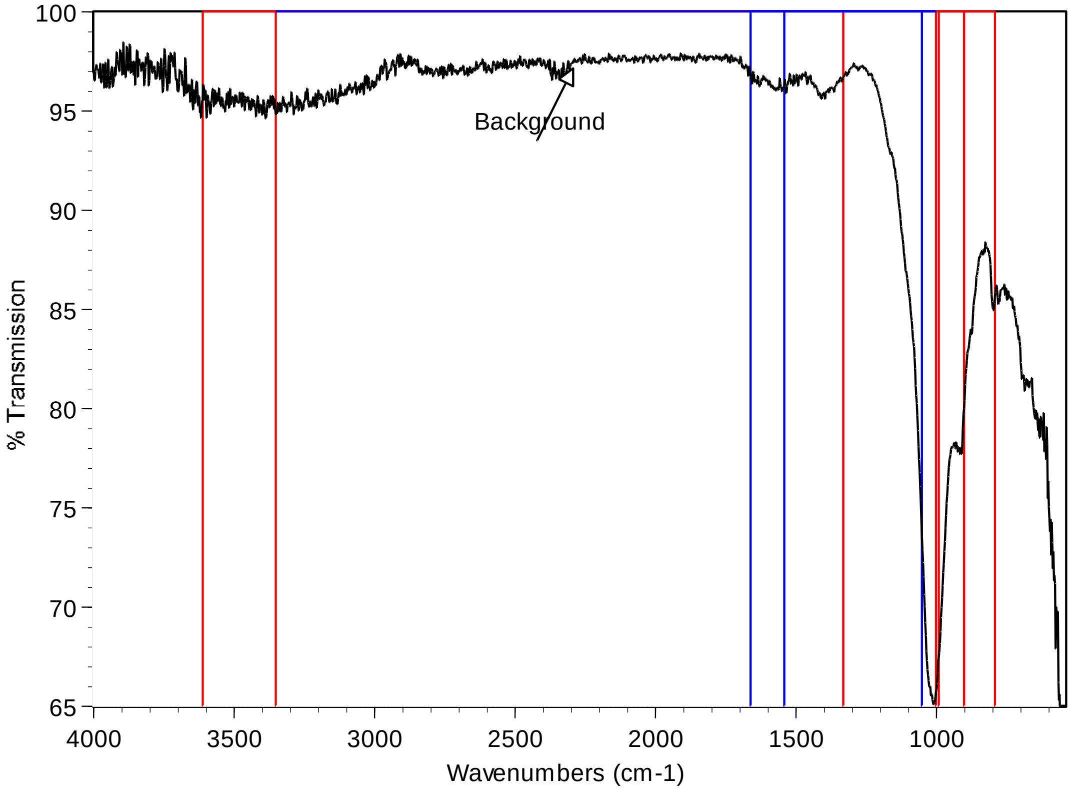

Figure 10. FTIR spectrum of the foulant removed from the cartridge filter.

CONCLUSIONS

One cartridge filter was received from Texas Tech University for examination and foulant analysis.

The cartridge filter was covered in a heavy layer of brown colored foulant. Brown discoloration was also noted on the interior of the filter. The filter was soaked in DI water overnight and the foulant was collected for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted-Energy Dispersive X-Ray Analysis (T-EDXA), and Fourier Transform Infrared Spectroscopy (FTIR).

LOI testing indicated the foulant from the cartridge filter was composed of 8.8% volatile organic material and 91.2% inorganic material.

SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant to be iron at 71.30%. The remaining inorganic constituents were a combination of silicon (11.97%), calcium (4.57%), sulfur (3.70%), chlorine (2.95%), aluminum (2.70%), potassium (2.06%), manganese (0.39%), titanium (0.28%), and magnesium (0.02%).

FTIR analysis of the foulant removed from the cartridge filter indicated it was mostly alumio-silicate clays, with small amounts of carbohydrates and polysaccharides.

Charles Wardle

Technical Support Engineer

Appendix E. Lead Element Autopsy

Wardle, C., 2014b. Element Autopsy and Foulant Analysis: Lead Element - SN F5375550, Membrane Autopsy Report, Professional Water Technologies, Vista, CA, 15 p.

MEMBRANE AUTOPSY REPORT

MEMBRANE FORENSICS

Element Autopsy and Foulant Analysis
Lead Element - SN F5375550

Texas Tech University
Lubbock, Texas

Produced By: Charles Wardle, Technical Support Engineer
Professional Water Technologies

Date: 11 August 2014

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Powered by Professional Water Technologies

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INTRODUCTION

One Dow LE-400 membrane element with SN# F5375550 was received from Texas Tech University for examination, autopsy, and foulant analysis. The element was pulled from the lead position.

The element was initially examined, photographed, bubble tested, weighed, and characterized for current performance values.

BUBBLE TESTS

Bubble testing of RO membrane elements is useful in determining if the mechanical integrity of the element has been compromised. RO elements are constructed using glue lines to seal the membrane leaves, and when subjected to permeate backpressure, extreme fouling, etc. these glue lines can become damaged leading to reduced rejection and increased permeate flow in the RO system.

PROCEDURE: The permeate tube is sealed and a small amount of pressure (3 – 5 psi) is pumped into the permeate tube while the element is submerged vertically under water. An element with good mechanical integrity will not emit bubbles and will hold the pressure steady. If the element continually emits bubbles and cannot hold the air pressure, then the element exhibits compromised mechanical integrity.

RESULTS: The element did not exhibited visible bubbles while subjected to 5 psi of air pressure. This indicated the element had good mechanical integrity.

PERFORMANCE TESTS

PROCEDURE: The element was first weighed, and then gently rinsed prior to performance testing. Following the rinse, the element was characterized according to the manufacturer's test conditions.

MANUFACTURER'S SPECIFICATIONS: LE-400: 11,500 GPD @ 99.3% nominal NaCl rejection, on 2,000 mg/L NaCl, 150 psi applied pressure.

TEST CONDITIONS: 150 psi and 40 GPM feed flow on 2,000 mg/L NaCl.

RESULTS: Performance results can be found in Table 1.

TABLE 1: ELEMENT PERFORMANCE RESULTS

	Weight (lbs)	% Salt rejection	Permeate Flow (GPD)	Delta P (PSI)
F5375550	30	98.3%	10,658	6
Manufacturer's Specifications	-	99.3%	11,500	-

ELEMENT EXTERNAL INSPECTIONS

Element F5375550 was examined, the fiberglass shell, ATD's, permeate tube and brine seal were all intact and in good condition (Figures 1-3). Orange deposition was found on the fiberglass wrap of the element. Significant foulant build-up was found on the feed end ATD (Figure 2). There were no significant odors detected from the membrane. Telescoping was not observed to have occurred to the RO element.

Figure 1. Element F5375550 as received.

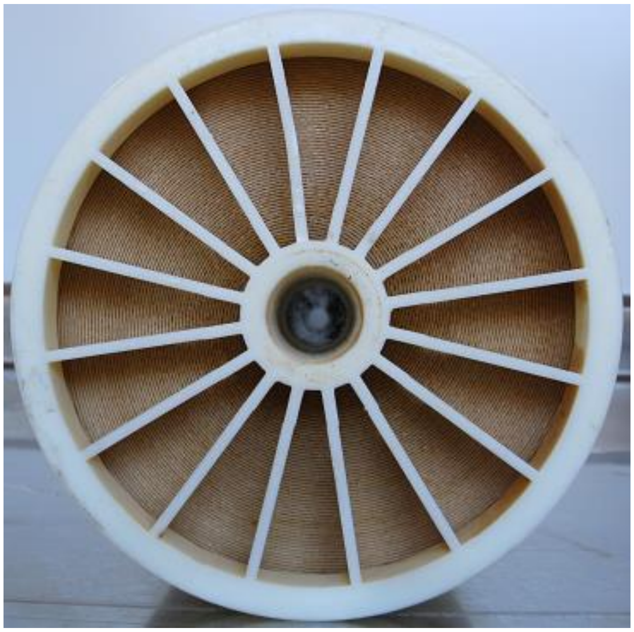

Figure 2. Feed-end of element F5375550, note the foulant build-up.

Figure 3. Concentrate-end of element F5375550.

AUTOPSY ANALYSIS

Once the ATD's were removed, the scroll ends of the membrane leaves were examined for the presence of colloidal particles, biofouling, feed spacer extrusion, membrane gapping, etc. There was foulant build-up on the feed scroll end of the element. Dissection of the element revealed a coating of orange colored foulant on the membrane surface (Figures 6-7). Staining of the membrane backing material was found on several of the leaves (Figure 8). The integrity of the glue lines and channel spacer netting material was good. Samples of foulant were removed for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted- Energy Dispersive X-Ray Analysis (T-EDXA), and Fourier Transform Infrared Spectroscopy (FTIR).

Figure 4. Feed-end of element F5375550.

Figure 5. Concentrate-end of element F5375550.

Figure 6. Element F5375550 unrolled.

Figure 7. Close-up of the membrane surface from element F5375550.

Figure 8. Close-up of the membrane backing material from element F5375550.

LOSS OF IGNITION (LOI)

PROCEDURE: The foulant sample collected from element F5375550 was first dried at 110°C and heated to 550°C which destroys the organic material in the sample. The weight loss on ignition is calculated from measured weights obtained before and after exposure to the higher temperature. The LOI is referred to as a percentage of the foulant sample and is generally considered to be the organic portion of the foulant (see Results and Figure 9).

RESULTS: 89.5% Ash (Inorganic Material) and 10.5% Volatile (Organic Material).

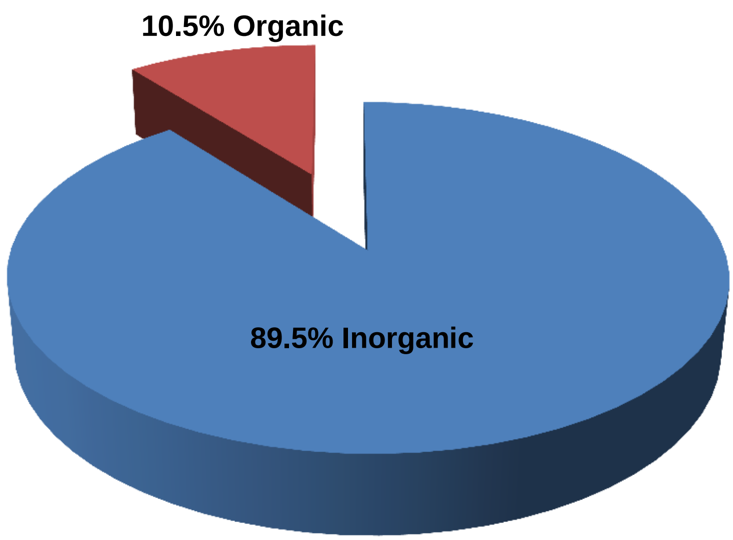

Figure 9. Graphical representation of the organic and inorganic portions of the foulant sample removed from the surface of element F5375550.

SCANNING ELECTRON MICROSCOPY (SEM)

PROCEDURE: A small portion of the foulant material removed from the membrane surface of element F5375550 was examined using a Scanning Electron Microscope (SEM). Secondary electron images, such as that shown below, were taken at 1050X. An examination using SEM analysis is useful in determining particle size and morphology.

RESULTS: See Figures 10 & 11

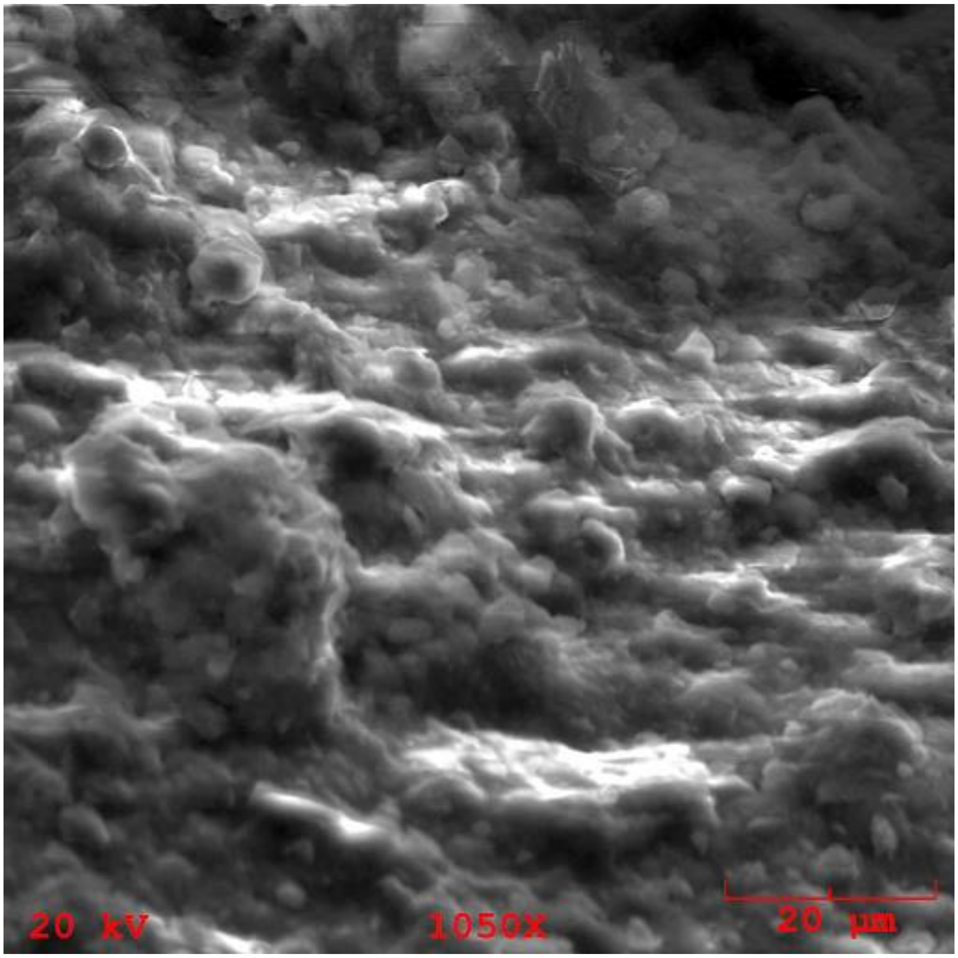

Figure 10. Scanning electron microscope image of the foulant collected from the surface of element F5375550 at 1050X Magnification.

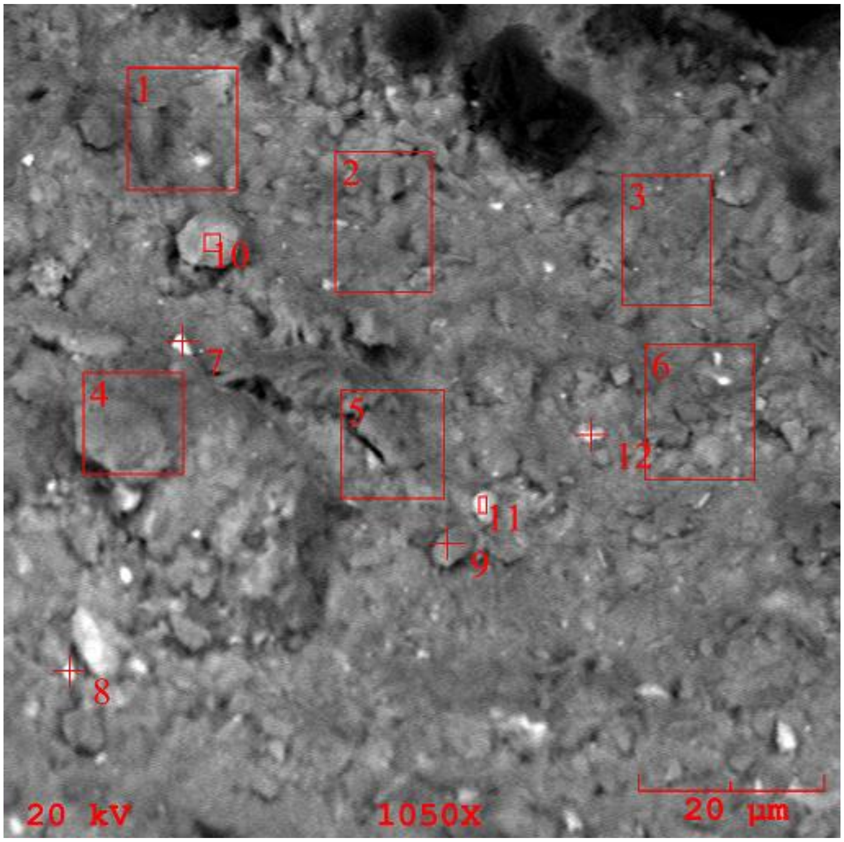

Figure 11. Backscatter scanning electron microscope image of the foulant collected from the surface of element F5375550 at 1050X magnification. The red numbers indicate sample areas selected for targeted-EDXA.

TARGETED ENERGY DISPERSIVE X-RAY ANALYSIS (T-EDXA)

PROCEDURE: A small portion of the foulant material removed from the membrane surface of element F5375550 was examined in a scanning electron microscope. The wavelengths or energy levels of the X-rays produced are used to identify the presence (and relative amounts) of the chemical elements found in the foulant sample. This test is most useful in determining the nature of the inorganic portion of the foulant.

RESULTS: The foulant removed was target analyzed at six different areas (as shown in Figure 10). Targeted-EDXA determined the largest inorganic constituent of the foulant to be silicon at 41.57%. The remaining inorganic constituents were a combination of iron (31.19%), aluminum (11.56%), calcium (7.22%), potassium (6.91%), titanium (1.23%), chlorine (0.14%), and magnesium (0.14%).

Examples of the T-EDXA spectra are shown in Figures 12 and 13. Figure 14 shows the combined average weight percentage of the inorganic elements in all six T-EDXA areas.

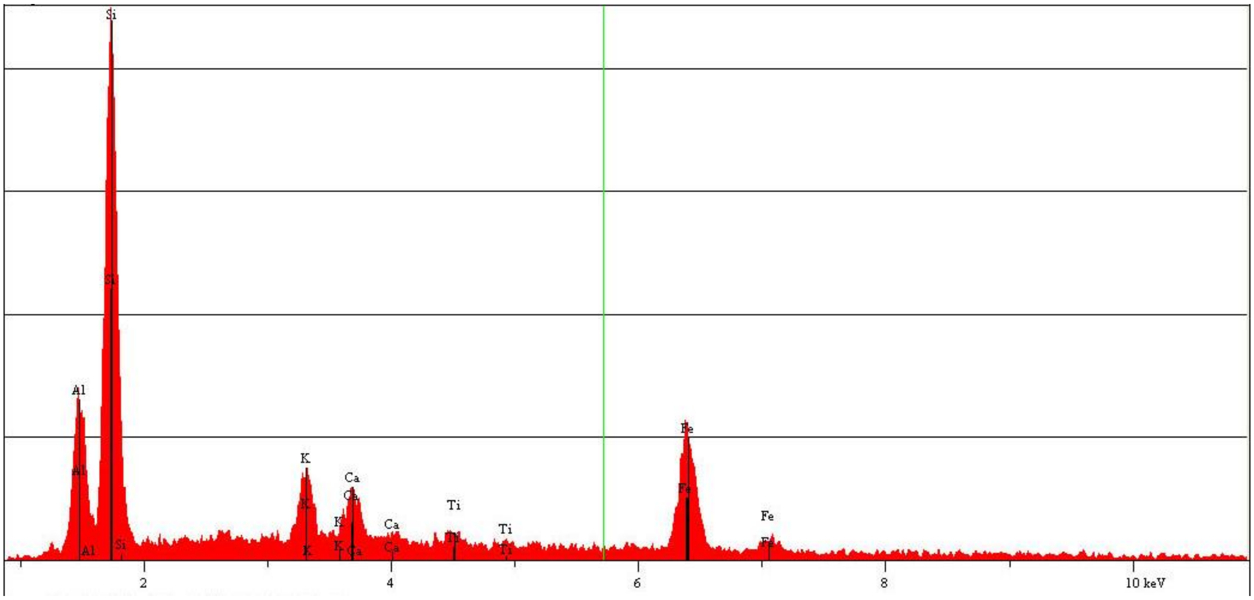

Figure 12. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of element F5375550, target area 2 (Figure 11).

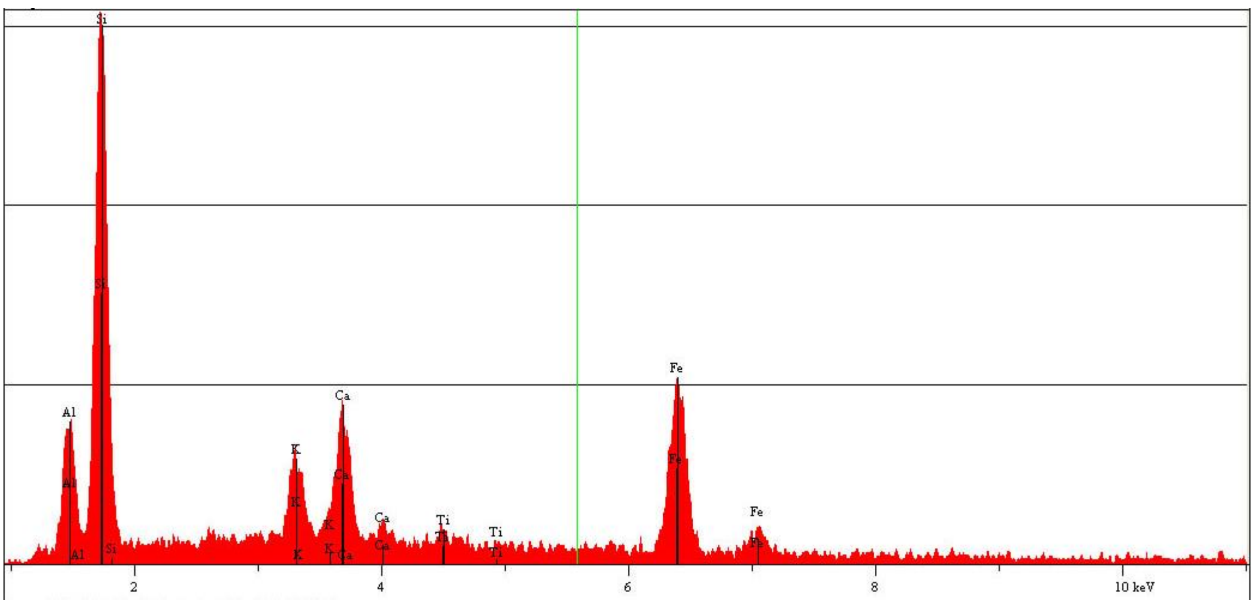

Figure 13. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of element F5375550, target area 5 (Figure 11).

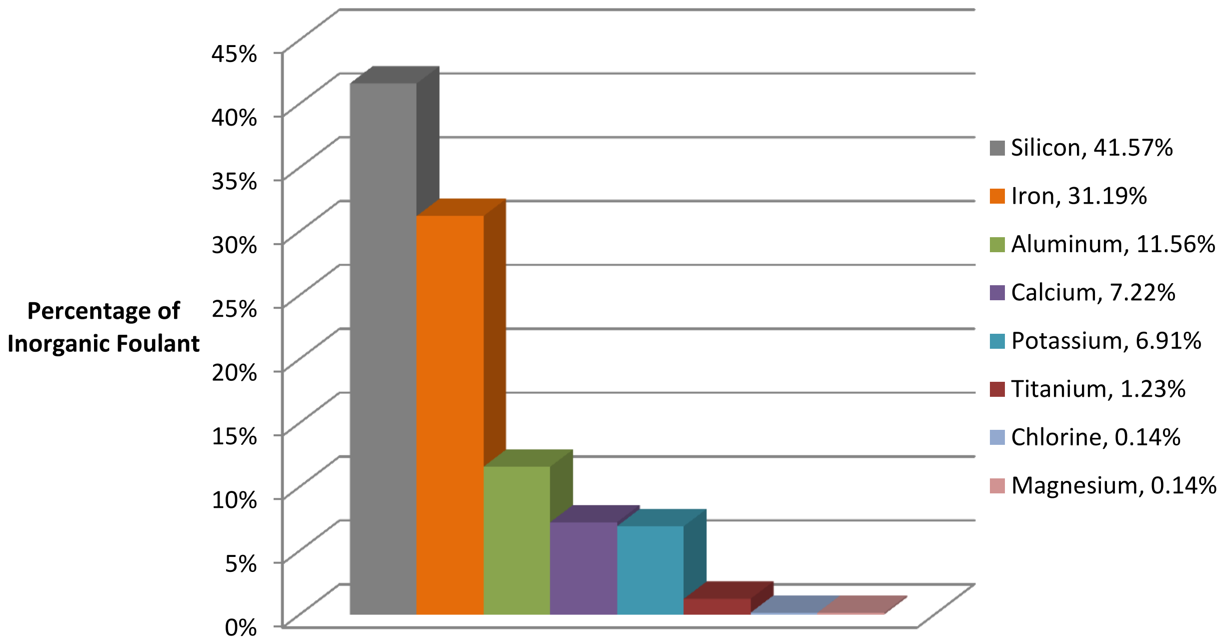

Figure 14. Graphical representation of the inorganic constituents found in the foulant sample removed from the surface of element F5375550. It is important to note that the inorganic portion of the foulant was 89.5%.

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

The FTIR analysis is used to identify organic compounds in a sample. An infrared transmittance spectrum is produced creating a “fingerprint.” The spectrum is compared to a 70,000 spectral library and subject to interpretation.

SAMPLE PREPERATION: Samples of foulant from element F5375550 were ground fine in an agate mortar and pestle.

PROCEDURE: The fine powder was loaded into a cavity in a holder for HATR attachment. The samples were analyzed using a PE 1600 FT-IR instrument.

RESULTS: Organic extractions, analysis, spectral interpretation and library search were performed on the foulant sample. The analysis indicated the foulant was mostly alumio-silicate clays with small amounts of carbohydrates and polysaccharides.

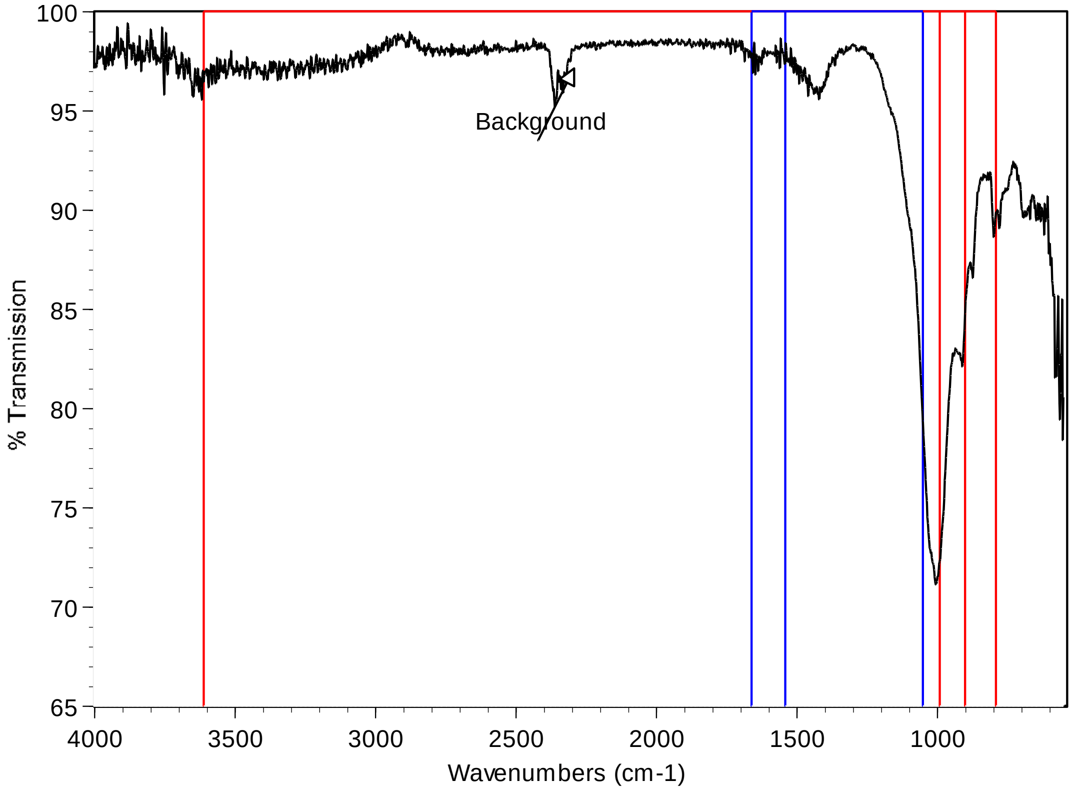

Figure 16. FTIR spectrum of the foulant removed from the membrane surface of element F5375550.

CONCLUSIONS

One Dow LE-400 membrane element with SN# F5375550 was received from Texas Tech University for examination, autopsy, and foulant analysis. The element was pulled from the lead position.

The element was wet tested and data was normalized to the manufacture's standard conditions. The element produced both slightly lower than normal flow and rejection.

Element F5375550 had good mechanical integrity. The fiberglass shell, ATD's, permeate tube and brine seal were all intact and in good condition. Orange deposition was found on the fiberglass wrap of the element. There was foulant build-up on the feed scroll end of the element. Dissection of the element revealed a coating of orange colored foulant on the membrane surface. Staining of the membrane backing material was found on several of the leaves. The integrity of the glue lines and channel spacer netting material was good. Samples of foulant were removed for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted-Energy Dispersive X-Ray Analysis (T-EDXA) and Fourier Transform Infrared Spectroscopy (FTIR).

LOI testing indicated the foulant from element F5375550 was composed of 10.5% volatile organic material and 89.5% inorganic material.

SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant from element F5375550 to be silicon at 41.57%. The remaining inorganic constituents were a combination of iron (31.19%), aluminum (11.56%), calcium (7.22%), potassium (6.91%), titanium (1.23%), chlorine (0.14%), and magnesium (0.14%).

FTIR analysis of the foulant removed from element F5375550 indicated it was mostly alumio-silicate clays with small amounts of carbohydrates and polysaccharides.

Charles Wardle

Technical Support Engineer

Appendix F. Tail Element Autopsy

Wardle, C., 2014c. Element Autopsy and Foulant Analysis: Tail Element - SN F5375511, Membrane Autopsy Report, Professional Water Technologies, Vista, CA, 14 p.

MEMBRANE AUTOPSY REPORT

MEMBRANE FORENSICS

Element Autopsy and Foulant Analysis
Tail Element - SN F5375511

Texas Tech University
Lubbock, Texas

Produced By: Charles Wardle, Technical Support Engineer
Professional Water Technologies

Date: 11 August 2014

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INTRODUCTION

One Dow LE-400 membrane element with SN# F5375511 was received from Texas Tech University for examination, autopsy, and foulant analysis. The element was pulled from the tail position.

The element was initially examined, photographed, bubble tested, weighed, and characterized for current performance values.

BUBBLE TESTS

Bubble testing of RO membrane elements is useful in determining if the mechanical integrity of the element has been compromised. RO elements are constructed using glue lines to seal the membrane leaves, and when subjected to permeate backpressure, extreme fouling, etc. these glue lines can become damaged leading to reduced rejection and increased permeate flow in the RO system.

PROCEDURE: The permeate tube is sealed and a small amount of pressure (3 – 5 psi) is pumped into the permeate tube while the element is submerged vertically under water. An element with good mechanical integrity will not emit bubbles and will hold the pressure steady. If the element continually emits bubbles and cannot hold the air pressure, then the element exhibits compromised mechanical integrity.

RESULTS: The element did not exhibited visible bubbles while subjected to 5 psi of air pressure. This indicated the element had good mechanical integrity.

PERFORMANCE TESTS

PROCEDURE: The element was first weighed, and then gently rinsed prior to performance testing. Following the rinse, the element was characterized according to the manufacturer's test conditions.

MANUFACTURER'S SPECIFICATIONS: LE-400: 11,500 GPD @ 99.3% nominal NaCl rejection, on 2,000 mg/L NaCl, 150 psi applied pressure.

TEST CONDITIONS: 150 psi and 40 GPM feed flow on 2,000 mg/L NaCl.

RESULTS: Performance results can be found in Table 1.

TABLE 1: ELEMENT PERFORMANCE RESULTS

	Weight (lbs)	% Salt rejection	Permeate Flow (GPD)	Delta P (PSI)
F5375511	43	97.1%	639	16
Manufacturer's Specifications	-	99.3%	11,500	-

ELEMENT EXTERNAL INSPECTIONS

Element F5375511 was examined, the fiberglass shell, ATD's, permeate tube and brine seal were all intact and in good condition (Figures 1-3). Orange deposition was found on the fiberglass wrap and both ATD's of the element. There were no significant odors detected from the membrane. Telescoping was not observed to have occurred to the RO element.

Figure 1. Element F5375511 as received.

Figure 2. Feed-end of element F5375511, note the orange discoloration.

Figure 3. Concentrate-end of element F5375511, note the orange and grey discoloration.

AUTOPSY ANALYSIS

Once the ATD's were removed, the scroll ends of the membrane leaves were examined for the presence of colloidal particles, biofouling, feed spacer extrusion, membrane gapping, etc. There was orange foulant on both the feed and concentrate scroll end of the element. Dissection of the element revealed a coating of a crystalline foulant and orange discoloration on the membrane surface. The integrity of the glue lines and channel spacer netting material was good. Samples of foulant were removed for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted- Energy Dispersive X-Ray Analysis (T-EDXA) and Fourier Transform Infrared Spectroscopy (FTIR).

Figure 4. Feed-end of element F5375511.

Figure 5. Concentrate-end of element F5375511.

Figure 6. Element F5375511 unrolled.

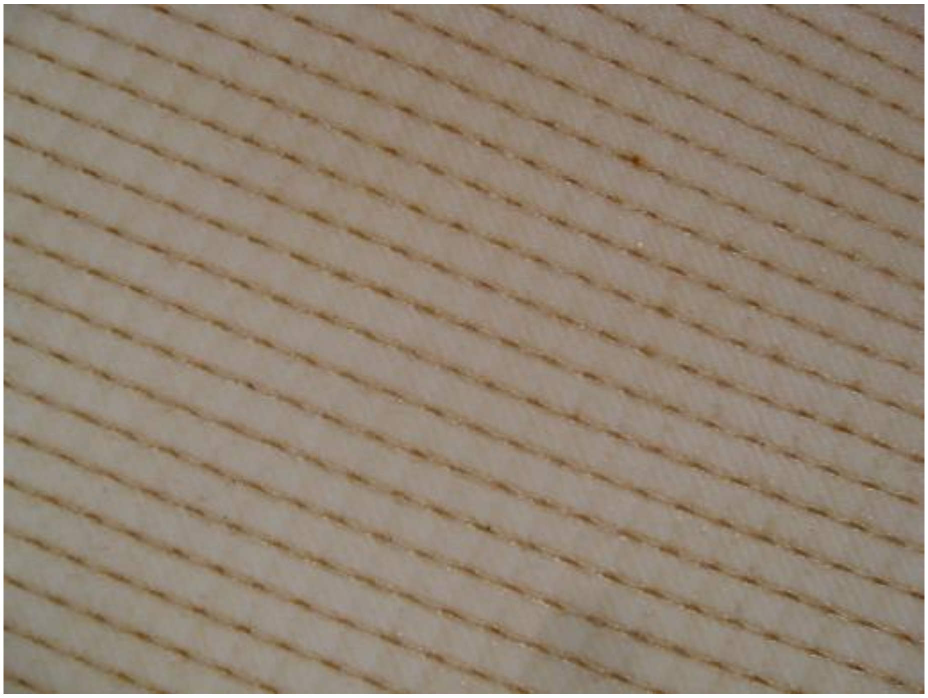

Figure 7. Close-up of the membrane surface from element F5375511.

LOSS OF IGNITION (LOI)

PROCEDURE: The foulant sample collected from element F5375511 was first dried at 110°C and heated to 550°C which destroys the organic material in the sample. The weight loss on ignition is calculated from measured weights obtained before and after exposure to the higher temperature. The LOI is referred to as a percentage of the foulant sample and is generally considered to be the organic portion of the foulant (see Results and Figure 8).

RESULTS: 98.6% Ash (Inorganic Material) and 1.4% Volatile (Organic Material).

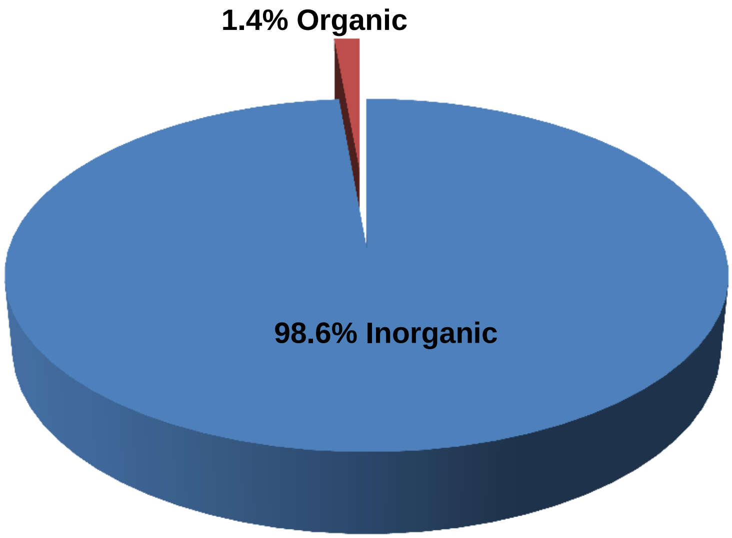

Figure 8. Graphical representation of the organic and inorganic portions of the foulant sample removed from the surface of element F5375511.

SCANNING ELECTRON MICROSCOPY (SEM)

PROCEDURE: A small portion of the foulant material removed from the membrane surface of element F5375511 was examined using a Scanning Electron Microscope (SEM). Secondary electron images, such as that shown below, were taken at 1050X. An examination using SEM analysis is useful in determining particle size and morphology.

RESULTS: See Figures 9 & 10

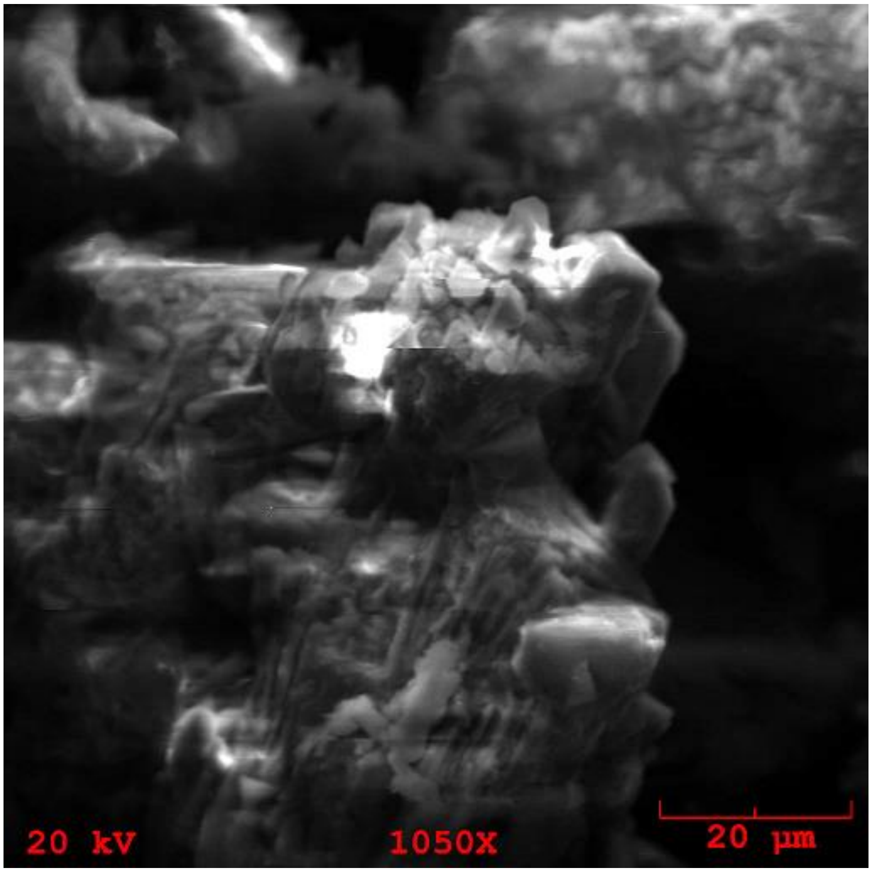

Figure 9. Scanning electron microscope image of the foulant collected from the surface of element F5375511 at 1050X Magnification.

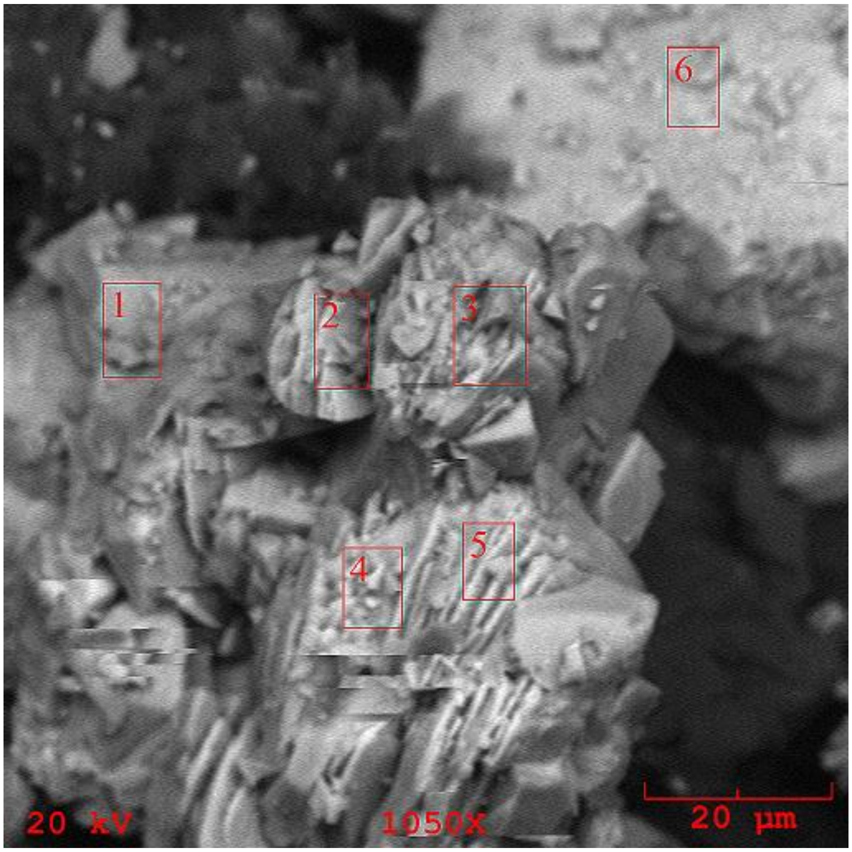

Figure 10. Backscatter scanning electron microscope image of the foulant collected from the surface of element F5375511 at 1050X magnification. The red numbers indicate sample areas selected for targeted-EDXA.

TARGETED ENERGY DISPERSIVE X-RAY ANALYSIS (T-EDXA)

PROCEDURE: A small portion of the foulant material removed from the membrane surface of element F5375511 was examined in a scanning electron microscope. The wavelengths or energy levels of the X-rays produced are used to identify the presence (and relative amounts) of the chemical elements found in the foulant sample. This test is most useful in determining the nature of the inorganic portion of the foulant.

RESULTS: The foulant removed was target analyzed at six different areas (as shown in Figure 10). Targeted-EDXA determined the largest inorganic constituent of the foulant to be calcium at 91.96%. The remaining inorganic constituents were a combination of manganese (3.16%), iron (3.10%), sulfur (1.20%), and silicon (0.56%).

Examples of the T-EDXA spectra are shown in Figures 11 and 12. Figure 13 shows the combined average weight percentage of the inorganic elements in all six T-EDXA areas.

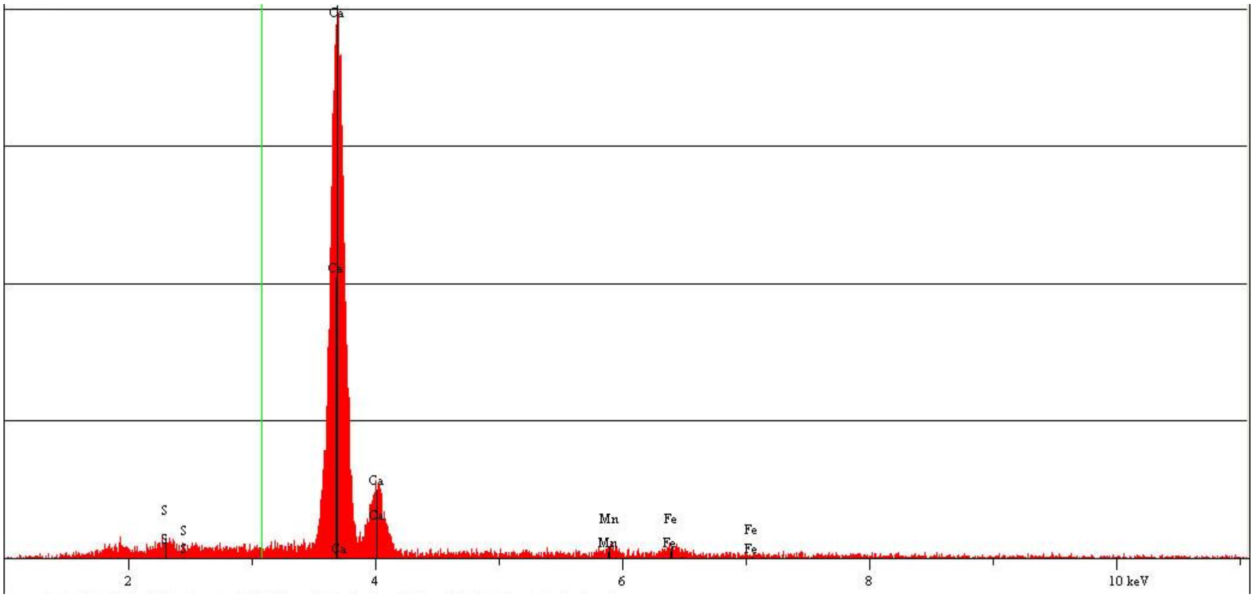

Figure 11. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of element F5375511, target area 3 (Figure 10).

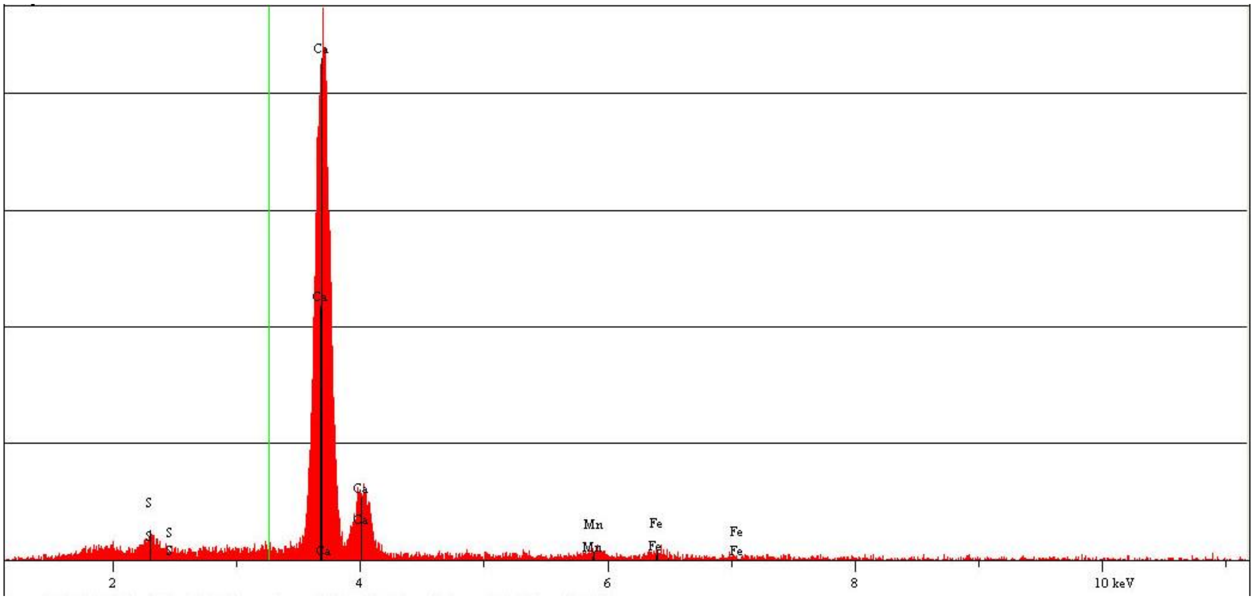

Figure 12. T-EDXA spectrum of the inorganic elemental portion of the foulant collected from the surface of element F5375511, target area 5 (Figure 10).

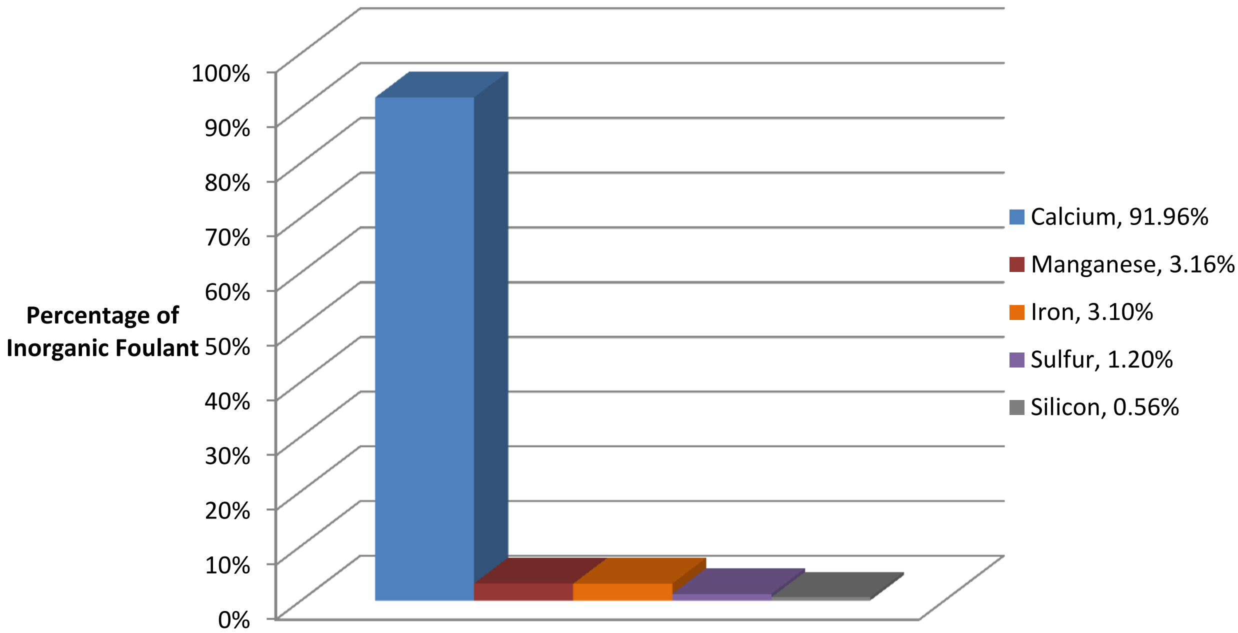

Figure 13. Graphical representation of the inorganic constituents found in the foulant sample removed from the surface of element F5375511. It is important to note that the inorganic portion of the foulant was 98.6%.

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

The FTIR analysis is used to identify organic compounds in a sample. An infrared transmittance spectrum is produced creating a "fingerprint." The spectrum is compared to a 70,000 spectral library and subject to interpretation.

SAMPLE PREPERATION: Samples of foulant from element F5375511 were ground fine in an agate mortar and pestle.

PROCEDURE: The fine powder was loaded into a cavity in a holder for HATR attachment. The samples were analyzed using a PE 1600 FT-IR instrument.

RESULTS: Organic extractions, analysis, spectral interpretation and library search were performed on the foulant sample. The analysis indicated the foulant was mostly $CaCO_3$ with small amounts of alumio-silicate clays.

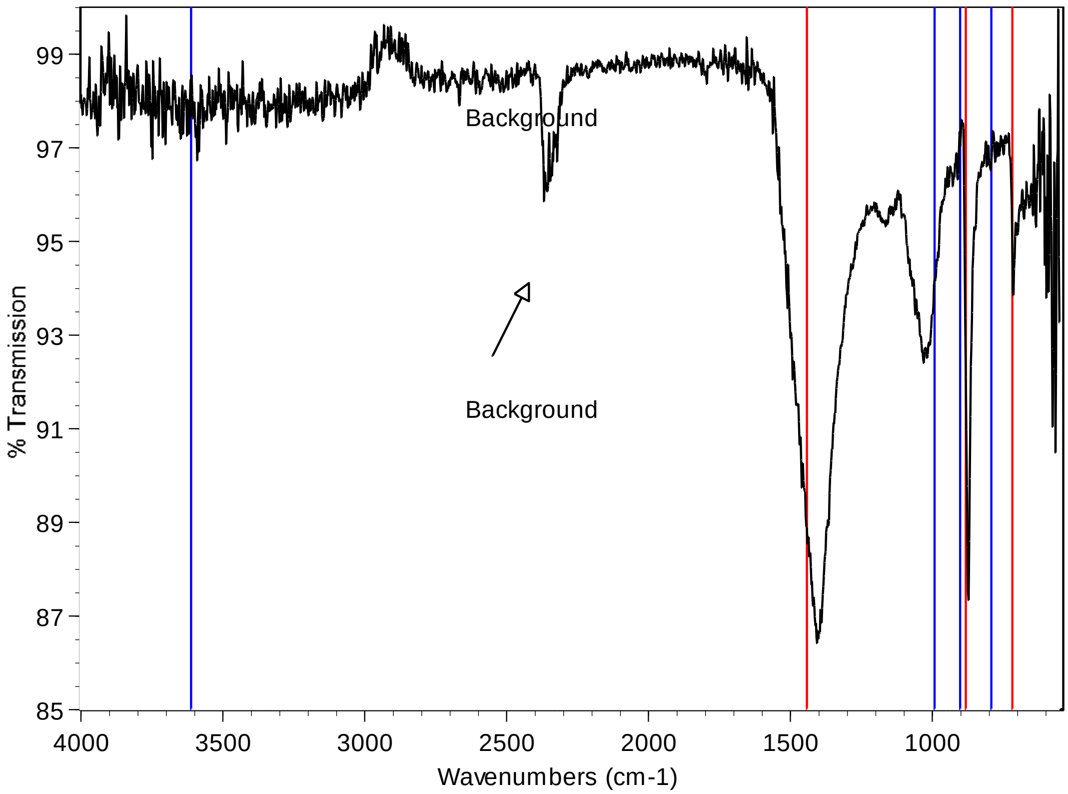

Figure 16. FTIR spectrum of the foulant removed from the membrane surface of element F5375511.

CONCLUSIONS

One Dow LE-400 membrane element with SN# F5375511 was received from Texas Tech University for examination, autopsy, and foulant analysis. The element was pulled from the tail position.

The element was wet tested and data was normalized to the manufacture's standard conditions. The element produced significantly lower than normal flow and low rejection.

Element F5375511 had good mechanical integrity. The fiberglass shell, ATD's, permeate tube and brine seal were all intact and in good condition. Orange deposition was found on the fiberglass wrap and both ATD's of the element. Dissection of the element revealed a coating of a crystalline foulant and orange discoloration on the membrane surface. The integrity of the glue lines and channel spacer netting material was good. Samples of foulant were removed for Loss on Ignition (LOI), Scanning Electron Microscopy (SEM), Targeted- Energy Dispersive X-Ray Analysis (T-EDXA) and Fourier Transform Infrared Spectroscopy (FTIR).

LOI testing indicated the foulant from element F5375511 was composed of 1.4% volatile organic material and 98.6% inorganic material.

SEM and T-EDXA analyses determined the largest inorganic constituent of the foulant from element F5375511 to be calcium at 91.96%. The remaining inorganic constituents were a combination of manganese (3.16%), iron (3.10%), sulfur (1.20%), and silicon (0.56%).

FTIR analysis of the foulant removed from element F5375511 indicated it was mostly CaCO3 with small amounts of alumio-silicate clays.

Charles Wardle

Technical Support Engineer

Appendix G. Responses to TWDB and TDA Comments

City of Seminole
An Integrated Wind-Water Desalination Demonstration Plant for an Inland Municipality
TWDB Contract No. 0804830832
Comments from TWDB Staff

General Comments:

Please include the contract number on title page and the header of the report.

The contract number has been added.

Please include the geology report as Appendix A, the driller's log as Appendix B, and the two membrane autopsy reports as Appendixes C and D.

The Cirrus (2011) report (includes the geophysical log) is Appendix A, the driller's log is Appendix B, and Dr. Lehman's geologic log is Appendix C. There were actually three autopsy reports, one each for the cartridge filter, the lead element, and the tail element. They are now attached as Appendixes D, E, and F, respectively.

Please refer to the USEPA as the U.S. Environmental Protection Agency wherever it is used in the report.

The references were corrected.

Please uppercase aquifer wherever it is used after the name of the aquifer (for example, Ogallala Aquifer) but lowercase it if more than one aquifer is mentioned (for example, Ogallala and Dockum aquifers).

The capitalization changes were made.

The total cost (capital and operations and maintenance) to treat a unit of water using electricity generated by the wind turbine and that obtained from the grid should be determined using, for example, the approach taken by Shirazi and Arroyo (2010). An attempt should also be made to clearly present the financial impact of the electricity generated from the wind turbine on the total cost of treating the brackish water. The potential cost savings (if any) from using this renewable resource should be highlighted.

The following paragraph was added to the executive summary and conclusions sections.

This demonstration project did not lend itself to scalable economic analyses for several reasons. First, most of the funds came from grants, so no capital costs were covered by amortizable debt. Second, the sizes of the well pump, RO system, and wind turbine were set by grant funding limitations, and as such their costs per unit of production were relatively high compared to full-scale, larger capacity systems. Third, concentrate management, which is usually a large fraction of the overall costs, was done by simply combining the permeate and concentrate flows for disposal through the city's sanitary sewer system, a choice that would not likely be recommended for a full-scale system. Fourth, the costs of providing drinking water from this conceptual combination of wind-assisted brackish water desalination must be greater than the current City of Seminole water costs based on treatment and distribution of chlorinated groundwater, so we are not promoting savings relative to current practice. Finally, we did estimate the value of the wind-generated electricity at $0.33/1000 gal of permeate. As the wind turbine was purchased with grant funds, the water pumped and treated when the electricity came from the wind essentially cost $0.33/1000 gal less than similar water pumped and treated when the electricity came from the grid.

Specific Comments:

Page 1, first paragraph, second to last sentence: Please consider indicating that there were interruptions throughout the year. Please indicate the longest uninterrupted operational period.

Page 2, first bullet, line 2: Please delete the word "for" before "about" in the sentence.

The change was made.

Page 2, second bullet, last sentence: This is an incomplete sentence. Please complete.

The missing word was replaced.

Page 2, fourth bullet, last sentence: Please add the word "generated" between "energy" and "was".

The change was made.

Page 2, bullets: Please add a bullet stating the concentrate disposal method selected for and used in the project.

The change was made.

Page 4, second paragraph, line 2: Please change Texas Commission for Environmental Quality to Texas Commission on Environmental Quality.

The change was made.

Page 4, second paragraph, middle of paragraph: Please spell out MGD if this is the first use of the acronym.

A list of abbreviations has been added on page iii.

Page 4, third paragraph, line 4: Please delete “or Santa Rosa”. The Santa Rosa is not a designated aquifer: the Dockum Aquifer is.

The change was made. Santa Rosa is used regionally for the producing zone.

Page 5, Table 1: Please define MGD, mg/L, and pCi/L in the footnote.

A list of abbreviations has been added on page iii.

Page 6, Table 2: Please consider adding Texas High Plains after Exceedances in the table caption.

Some of the cities are in New Mexico, as explained in the text.

Page 6, second paragraph, line 9: Please consider splitting the sentence into two sentences by adding a period after the word “project”, deleting the word “and” and uppercasing the word “the” to start the next sentence.

The change was made.

Page 7, Figure 1: Please consider creating a process flow diagram for this project.

A figure was added as the new Figure 10, and other figure numbers were updated.

Page 8, Brackish Groundwater Well Section, paragraph 1, line 8: Please consider replacing the word “existed” with “were drilled”.

The change was made.

Page 8, Brackish Groundwater Well Section, paragraph 2, line 3: Please add “Appendix A” after “Cirrus [2011]”.

The change was made.

Page 8, Brackish Groundwater Well Section, paragraph 2, line 4: Please spell out “ac”.

“ac” is the normal abbreviation for acres, and the other units used in the report (such as ft, gpm, mg/L, µS/cm) follow normal usage. A list of abbreviations has been added on page iii.

Page 9, paragraph 1, line 3: Please spell out “bgs” at first use and abbreviate it thereafter.

The abbreviation was defined on the previous page.

Page 11, second paragraph, lines 7 and 9: Please replace “appendix” with “Appendix A”.

Page 13, first paragraph, line 5: Please replace “appendix” with “Appendix A”.

The change was made.

Page 13, first paragraph, line 6: Please delete the word “in” after “sand units”.

The change was made.

Page 13, second paragraph, line 7: Please consider replacing “rest of the test duration” with “duration of the test”.

The change was made.

Page 13, third paragraph, line 1: Please define or describe an unofficial water sample.

The word “unofficial” was replaced with “field grab”. This analysis was reported by WTWWS, and we did receive a lab report as backup.

Page 18, Section 3.1, line 1: please replace “the well” after the comma with “it”.

The change was made.

Page 18, Section 3.1: Please report Total Dissolved Solids (TDS) in milligrams per liter instead of gallons per liter. This parameter is most commonly reported in these units.

The units for TDS are grams per liter, not gallons per liter. This unit choice saved space in the tick mark labels and was also the same unit used reported by the Aqua Troll. The abbreviations for grams (such as in g/L) and gallons (such as in gpm and gpd, neither of which has the slash) unfortunately are both “g”, but gallons per liter would not be interpreted by readers familiar with this water quality context.

Page 18, Section 3.1, line 12: This is an incomplete sentence. Please complete.

The sentence was completed.

Page 20, Figure 12: Please consider reporting TDS in milligrams per liter instead of gallons per liter.

The units for TDS are grams per liter, not gallons per liter. This unit choice saved space in the tick mark labels and was also the same unit used reported by the Aqua Troll.

Page 21, third paragraph, last line: Please replace “depth to water” with “water level”.

The change was made.

Pages 22-25, Figures 13-20: Please add “below ground surface” after “ft” in the vertical axis label.

“bgs” was added after “ft”, as “below ground surface” made the axes labels too long, and the “bgs” acronym is now in the list of abbreviations.

Page 26, Section 3.2.1, first paragraph, line 1: Please consider replacing the word “was” with “became”.

The change was made.

Page 26, Section 3.2.1, first paragraph, line 8: Please explain what forms an official water sample.

The word official was deleted.

Page 26, Section 3.2.1, second paragraph, line 3: Please delete the word “drop”.

The word was deleted.

Page 26, Section 3.2.1, second paragraph, line 8: Please add a date when the wind turbine became operational.

The date was added.

Page 26, Section 3.2.1, third paragraph, line 3: Please consider replacing the word “watched” with “monitored”.

The change was made.

Page 29, Figure 21: Please consider using symbols to differentiate among more than two parameters. Using different colors for the parameters is difficult to see in black and white print.’

The change was made.

Page 30, Figure 23: Please consider changing the colors between the two parameters.

The change was made.

Page 30, Figure 24: Please consider using symbols to differentiate among more than two parameters. Using different colors for the parameters is difficult to see in black and white print.

The change was made.

Page 31, Figure 25-26: Please consider using symbols to differentiate among more than two parameters. Using different colors for the parameters is difficult to see in black and white print.

The change was made.

Page 31, paragraph 1, line 1: Please consider replacing “on January 13-15, 2014” with “between January 13 and 15, 2014”.

The change was made.

Page 32, Figure 27: Please consider using symbols to differentiate among more than two parameters. Using different colors for the parameters is difficult to see in black and white print.

The change was made.

Page 33, first paragraph: Please explain how storing the RO skid unit caused a disadvantage.

The explanation of the vendor concerns was added.

Page 36, third paragraph, line 1: Please consider replacing the word "see" with "conclude".

The replacement was made.

Page 36, third paragraph, last sentence: Please consider describing how the pH adjustment and antiscalant dosing was established in the first place for the project.

The description was added.

Page 37, paragraph 1, line 11: Please add in what year the technicians accessed the wind turbine. Only a month (May) has been mentioned.

The year 2014 was added.

Page 41, Section 4.1, paragraph 1, line 1: Please consider replacing "tend to work" with "are an established technology and will work".

The sentence was modified.

Page 42, bullet 6, line 2: Please delete the word "for" after the word "information".

The word was deleted.

Page 42, bullet 7, second sentence: This is an incomplete sentence. Please complete.

Actually, the third sentence was incomplete. The sentence is now complete.

Comments from Travis Brown, Texas Department of Agriculture

On page 36, the report states that the company that was paid to collect data on the wind turbine never did that work. How much was the company paid? Was it paid by the city or TTU? Did anyone pursue legal action to recover payment?

The company gave a quote of $1500 to provided data collection, storage, and access to data through the internet. The TTU WRC used its own funds to pay for that service. We did not pursue legal action, as the vendor has ongoing contract work with the City.

Page 2 mentions the "loss of access to the RO manufacturer." What does that mean? Who was the manufacturer? Was there another company contracted to work on the RO system? (The answer to this and some of my other questions are probably in the report somewhere, so if you can point me to those references….)

Crane Environmental has its corporate and manufacturing headquarters in Florida, and for some time they had sales representatives in Texas. What we learned during the project was that the technical support staff were only out of Florida, which greatly reduced their availability. Also, the technician who started up the RO system for left Crane during the project duration, so Crane had no employees to send to our site to help us.

The report states on page 37 that the turbine was down "for four months or more in total…" However, page 36 states "the wind turbine had generated 37,054 kWh over 4276 hr (178 day-equivalents) of operation." The report states the test period was April 2013 into August 2014, a 17-month period. So, was the entire facility (turbine plus RO unit) fully operational 13 months (17 months minus the four) or six months (the 178 days)?

This concept is hard to get across, but there were times that the wind turbine was up and the RO system, and vice versa. As we did not have the real-time data collection for the wind turbine that we had hoped for, we got only accumulated power generation data, not real-time generation. We just did not get the detailed data to answer when both system were running. In addition, we must remember that the wind turbine usually only generated power for parts of any given 24-hr day, so those 178 day-equivalents actually took place across many more days.

Page 2 also sets out the amount of power produced by the turbine and the amount used by the RO system. On page 41, the report estimates the cost for the city to provide power to the RO system during the 17-month test period was $4,836 and the estimated value of the power provided by the turbine during that period was $2,300. Were those dollar amounts for the 178 day period or what? Based on those dollar amounts, etc., would it be reasonable to estimate that the 50 kw turbine saved the city roughly 50 percent on the cost of treating the water from the well. (Also, I can't recall if the power from the turbine was just going to the RO unit or the well, too. Was it both?)

The $2,300 was for the 178-day equivalents. The wind turbine saved about half of the power cost of the well pumping and RO system operation.

Page two mentions the city's contract with BW Primoris to treat water from the city's existing Ogallala wells. Any idea how long those wells are expected to be ususable before depletion, etc.?

We did not look into the lives of the existing wells as part of the project.

Now that the project has ended, what is the status of the RO unit, the well and the turbine? Are any of these still being utilized by the city to produce potable water? It appears the city and/or Primoris might be using the well and the RO system at some point, but what about the turbine? Is it just going to sit there? Also, will the city continue to own all those, or is it turning over/selling any of these to Primoris?

We are happy to say that over the last several months, BW Primoris has begun negotiations with us to utilize our well, turbine, and treatment system in their future plans for serving the City. I am not sure who will end up owning which equipment. Our TTU view is that anything we purchased was intended to belong to Seminole, so we will see how that works out. We will be talking to you about TDA's requirements if any.

Were any tests on water quality in the well done early on that could have predicted the elements in the water that fouled the membranes?

The water quality tests emphasized dissolved chemicals, not the clay particles that caused the problems. It is true that the early need for the sand separator to extend the lives of the cartridge prefilters did indicate that the clay materials in the feed water were at high enough levels to warrant concern. The calcium carbonate that fouled the tail element is a normal problem with hard waters, and as was stated in the report, more aggressive pretreatment can prevent this type fouling.

How much potable water actually was produced during the test period? Can you give me a sentence or two in layman's terms as to the quality of the water produced? Would it have been potable alone, or was it potable only after being blended with water from the city's other wells? (This info may already be in the report. If so, just direct me to those sections.)

We produced almost 15,000,000 gal of very good quality water during this project. None of the major ions and trace metals analyzed in the permeate were above drinking water standards, and the average permeate total dissolved solids level of about 520 was very good. This water can be potable on its own if disinfection is added to the treatment train, and it could easily be blended with the local Ogallala water to lower arsenic and fluoride levels.