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Improving water quality for human and livestock consumption on cattle ranches in Lincoln and Socorro Counties, New Mexico

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EXECUTIVE SUMMARY

This report summarizes the assistance provided to Shafer Ranches, Inc., Hightower Ranch, and Western Environmental by Sandia National Laboratories under a Leveraged New Mexico Small Business Assistance grant. The work was conducted between April to November, 2014.

Cattle ranchers in Lincoln and Socorro Counties, New Mexico require assistance to engineer low cost solutions for the treatment of local water sources. The salt content of the well water varies, and a representative well has 2096 milligrams per liter (mg/L) total dissolved solids (TDS). This water is unfit for human consumption and at the high end of water quality limits deemed appropriate for maintaining a healthy livestock population (1000-2999 mg/L).[1] Additionally, some wells have elevated dissolved sulfur content and the poor water quality may cause health problems in cattle.

The cattle ranchers, as a result of the poor water quality, incur a significant economic penalty. Drinking water must be imported to meet human needs costing time and money. Unfortunately, there is no alternative water source for the livestock, and there is evidence that poor water quality affects cattle health. Additionally, at the Shafer Ranch there is a secondary problem that the fast scaling of water delivery pipes and pumps results in the frequent replacement of these components. The labor, transportation, and equipment costs associated with these issues combines for a significant economic impact to the ranches.

To date, the ranchers have been unable to find a solution to this issue. They have installed commercially available water treatment solutions to provide drinking water for human consumption. Unfortunately, these solutions have proven uneconomic due to their operating costs and inefficiencies resulting in a large percentage of wasted water. Therefore, Sandia National Laboratories has been asked to investigate and develop a water treatment system that would result in reduced cost associated with infrastructure, maintenance, elimination of importing water, and improved cattle health.

To address these issues, Sandia National Laboratories has conducted a detailed study of water chemistry at the ranches including analysis of the water from the Shafer and Hightower Ranches and soil and pipe scales from the Shafer Ranch. The results were used to construct a geochemical model to help understand the water chemistry and guide the selection of the most efficient water treatment options.

Multiple water treatment options were investigated including off-the-grid water treatment, solar-powered nano-filtration and distillation, reverse osmosis, and water softening systems. Potential solutions would be capable of i) producing drinking water from existing wells that meets EPA quality standards and ii) improving water quality for cattle to limit the negative impacts on animal health. Additionally, the economic impact of these solutions is evaluated by comparing capital costs against cost reduction gained by eliminating the need to import drinking water, reducing water waste, and prolonging the life of the water distribution systems.

Based on our findings we recommend Shafer and Hightower ranchers pursue two technologies to treat their water. The first technology is a reverse osmosis (RO) system commercially available from Western Environmental while the second technology is Zero Discharge Desalination

(ZDD) that could be piloted with assistance of the University of Texas El Paso. Both technologies would provide water suitable for both human and livestock consumption and eliminate the pipe scaling at the Shafer Ranch.

For both the RO and ZDD technologies to be used, a pretreatment step is necessary to remove the iron from the water at both the Shafer and Hightower ranches. Unfortunately, we were not able to determine a commercially available solution to remove the iron. We recommend future effort be focused on the issue of iron removal from the well water.

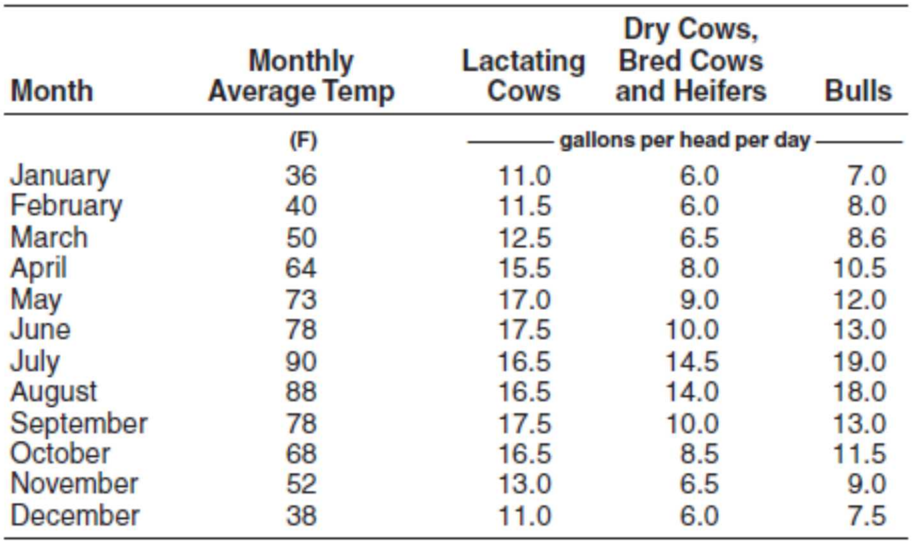
Finally, if no suitable method for iron removal is determined, we propose an experimental option that would help mitigate the issue of pipe scaling at the Shafer Ranch but not provide water for human consumption. This option centers on the installation of a granular filter just down stream of tank 1 at Shafer Ranch, and would require testing to validate its effectiveness and optimize design. Additionally, a tank cover could be added to prevent dirt from entering the pipes by way of the open-air tank.

INTRODUCTION

Water is an essential nutrient for livestock that is often overlooked. The water required by livestock is influenced by several factors, including rate of gain, pregnancy, lactation, activity, type of diet, feed intake and environmental temperature.[2] Generally in New Mexico when sufficient precipitation occurs, the cattle drink surface water captured in ponds; however, when precipitation is so low that the ponds dry up, they must be supplemented with groundwater. Ranchers in Central New Mexico, more specifically, the Shafer and Hightower Ranches in Socorro County, are affected by the recent drought conditions; the grasses and surface water are lacking so they rely more on groundwater to water cattle.

Table 1, Table 2, and Table 3 provide general estimates for cattle water consumption.[3] Table 1 estimates are for lactating beef cows, dry beef cows and bulls. Table 2 is for growing and finishing beef cattle, and Table 3 incorporates ambient temperature effects.[2] The summer months in New Mexico have been very dry and hot increasing the demand for water by the rancher’s cattle. Lack of water and/or poor water quality can depress animal performance more quickly and drastically than any other nutrient deficiency.

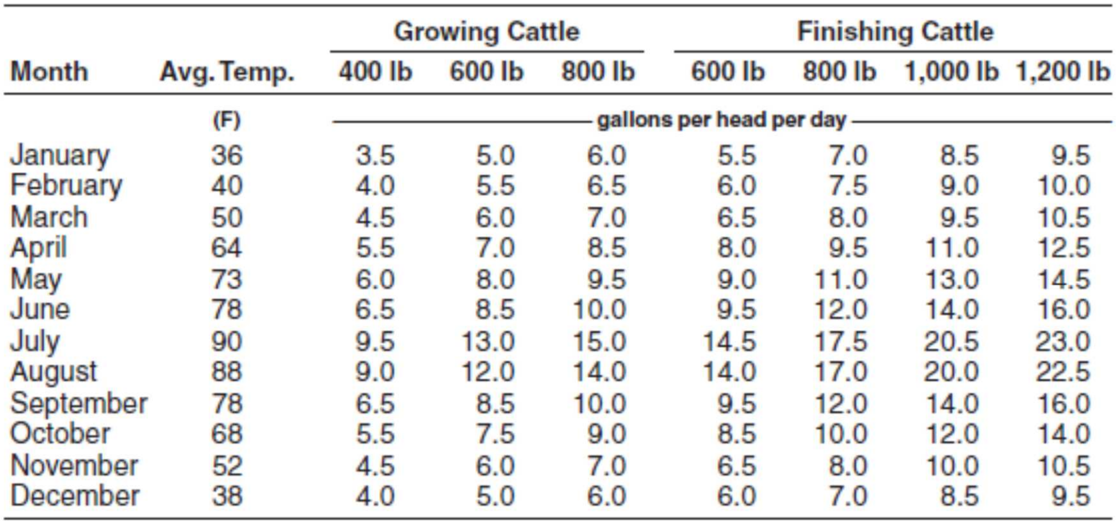
Table 1 Estimated daily water intakes (gallons per head per day) for lactating beef cows, bred cows, dry cows and bulls.[3]



Month	Monthly Average Temp	Lactating Cows	Dry Cows, Bred Cows and Heifers	Bulls
	(F)	gallons per head per day		
January	36	11.0	6.0	7.0
February	40	11.5	6.0	8.0
March	50	12.5	6.5	8.6
April	64	15.5	8.0	10.5
May	73	17.0	9.0	12.0
June	78	17.5	10.0	13.0
July	90	16.5	14.5	19.0
August	88	16.5	14.0	18.0
September	78	17.5	10.0	13.0
October	68	16.5	8.5	11.5
November	52	13.0	6.5	9.0
December	38	11.0	6.0	7.5

Adapted from GPE-1400, Water Requirements for Beef Cattle.

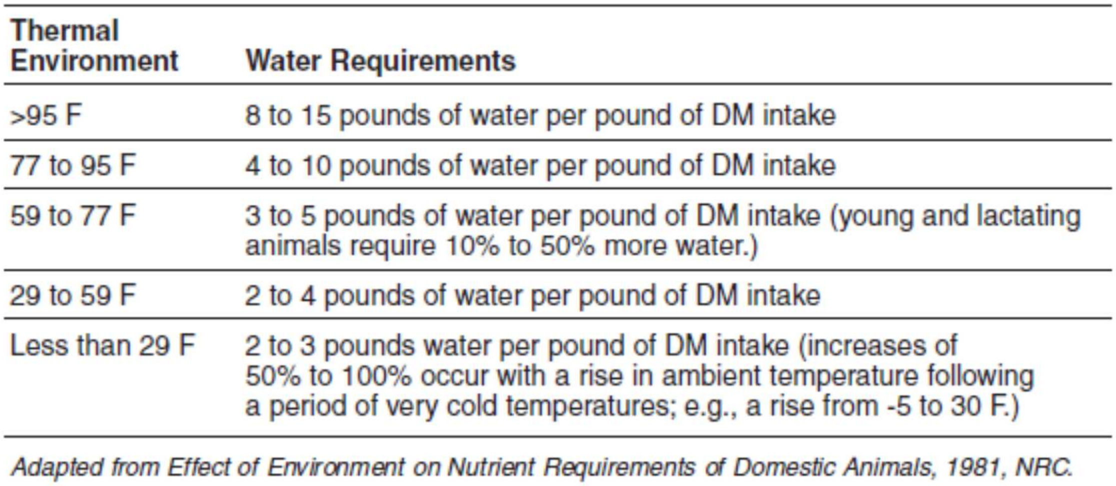
Table 2 Water requirements of growing and finishing beef cattle (gallons per head per day).[3]



		Growing Cattle			Finishing Cattle			
Month	Avg. Temp.	400 lb	600 lb	800 lb	600 lb	800 lb	1,000 lb	1,200 lb
	(F)	gallons per head per day						
January	36	3.5	5.0	6.0	5.5	7.0	8.5	9.5
February	40	4.0	5.5	6.5	6.0	7.5	9.0	10.0
March	50	4.5	6.0	7.0	6.5	8.0	9.5	10.5
April	64	5.5	7.0	8.5	8.0	9.5	11.0	12.5
May	73	6.0	8.0	9.5	9.0	11.0	13.0	14.5
June	78	6.5	8.5	10.0	9.5	12.0	14.0	16.0
July	90	9.5	13.0	15.0	14.5	17.5	20.5	23.0
August	88	9.0	12.0	14.0	14.0	17.0	20.0	22.5
September	78	6.5	8.5	10.0	9.5	12.0	14.0	16.0
October	68	5.5	7.5	9.0	8.5	10.0	12.0	14.0
November	52	4.5	6.0	7.0	6.5	8.0	10.0	10.5
December	38	4.0	5.0	6.0	6.0	7.0	8.5	9.5

Adapted from GPE-1400, Water Requirements for Beef Cattle.

Table 3 Water consumption estimates for beef cattle based on thermal environment and dry-matter (DM) intake.[3]



Thermal Environment	Water Requirements
>95 F	8 to 15 pounds of water per pound of DM intake
77 to 95 F	4 to 10 pounds of water per pound of DM intake
59 to 77 F	3 to 5 pounds of water per pound of DM intake (young and lactating animals require 10% to 50% more water.)
29 to 59 F	2 to 4 pounds of water per pound of DM intake
Less than 29 F	2 to 3 pounds water per pound of DM intake (increases of 50% to 100% occur with a rise in ambient temperature following a period of very cold temperatures; e.g., a rise from -5 to 30 F.)

Adapted from Effect of Environment on Nutrient Requirements of Domestic Animals, 1981, NRC.

Limited data are available regarding water quality and its influence on beef cattle performance.[4, 5] Reduction in weight gain has been observed and may be due to metabolic disorders, or may be related to the reduction in water intake. In some cases, a high level of one particular mineral can cause a reduction in performance. This notion is substantiated by work, where relatively high increases in dietary sulfur intake did not impact growth performance but did reduce water intake; additionally, above a certain threshold, clinical signs of sulfur toxicity were also observed.[6]

Currently, no differences between the effects of high TDS and high sulfur have been reported; however, in natural waters, high sulfur is usually observed in waters with high TDS. Additionally, high salinity (TDS) in water may affect bioavailability of nutrients to the cattle due to formation of aqueous complexes. For example, if the concentration of sulfur in water is sufficiently high, it will complex (bind) with copper and make it unavailable to the animal. The reduction in dietary copper availability is a cause for concern, since copper deficiency manifests as lower immunocompetence and reduced fertility. This often requires increased inclusion rates of dietary copper, which is an expensive supplement.

In order to truly assess water intake, one needs to predict the amount of water that should be consumed if water were of good quality. Becket and Oltjen, developed Eq (1), which uses body weight and ambient temperature to predict water intake in cattle.[7] Using data from Patterson et al. and Loneragan et al.,[4, 5] Corona Ranch Research Station researchers developed Eq (2) and (3) to predict water intake depression from TDS or sulfur. Concentration of TDS/sulfur can negatively impact cattle average daily gain (ADG). Specifically, Patterson et al. reported an increase in TDS/sulfur from 1226/441 to 7268/4654 mg/L decreased ADG from 1.8 to 0.6 lbs per day, respectively.[5] However, to date no information is available to rectify water quality issues. This is of great importance to livestock producers who have no alternative water sources.

$$\textit{Water intake, gal} = -0.28 + (\textit{Body weight} \cdot 0.034) + (-0.034 \cdot T) + (0.03 \cdot \textit{temp}^2) \tag{1}$$

TDS (ppm) influence on water intake $y = -0.0009x + 16.115$ **(2)**

S influence on Water intake $y = -0.0032x + 9.7$ **(3)**

WATER QUALITY ASSESSMENT AND GEOCHEMICAL MODELING

Shafer Ranch

The groundwater in Central and Eastern New Mexico is of poor quality due to high dissolved solids, and particularly, high sulfate content. Figure 1 and Figure 2 provide schematic representation of the water distribution systems on the Shafer Ranch, and locations of the water, tank sludge, pipe scale, and soil sampling. Water samples were analyzed by Hall Environmental for major anions and cations, TDS, conductivity, hardness, and alkalinity, and the results are presented in Table 4. Soil samples were analyzed for their mineral content using X-ray diffraction techniques. The composition of the collected solid phases (soil, sludge, and pipe scale) is shown in Table 6. Full X-ray diffraction spectra are presented in Appendix C: X-RAY DIFFRACTION DATA, while all raw analytical results are presented in Appendix B: WATER ANALYSIS REPORTS.

From this analysis it was determined there are several key issues with the Shafer Ranch water that must be addressed in any proposed solution. These include high dissolved solids content, scaling of water delivery system, and high sulfate content.

High TDS found in the well water negatively impacts both cattle health and the water delivery system. Table 5 summarized the effects of TDS levels on livestock health. Generally, dissolved solids in the 2000-4000 mg/L range are rated as fair quality for cattle. The Shafer Ranch groundwater has a TDS level in the 3000 mg/L range.

It should be noted that TDS is a nonspecific indicator of water quality and the components of TDS should be evaluated to determine the suitability of the water for animal consumption. In the Shafer well water chemistry, the high sulfate content, 1700-1800 mg/L, is the most concerning component of TDS affecting the performance of cattle. Sulfate in this range can adversely affect cattle health, especially, pregnant females and calves. The recommended levels of sulfate for cattle consumption are under 1000 mg/L, Table 7, while the sulfate recommendation for calves is less than 500 mg/L.

In addition to affecting cattle health, the water delivery piping (Schedule 40 PVC, 1-1/4 inch diameter) consistently plugs as a result of high TDS. Within relatively short time periods (~ 6 months) scale builds up on the interior of the pipes preventing water flow. This leads to a significant, negative economic impact at the Shafer Ranch.

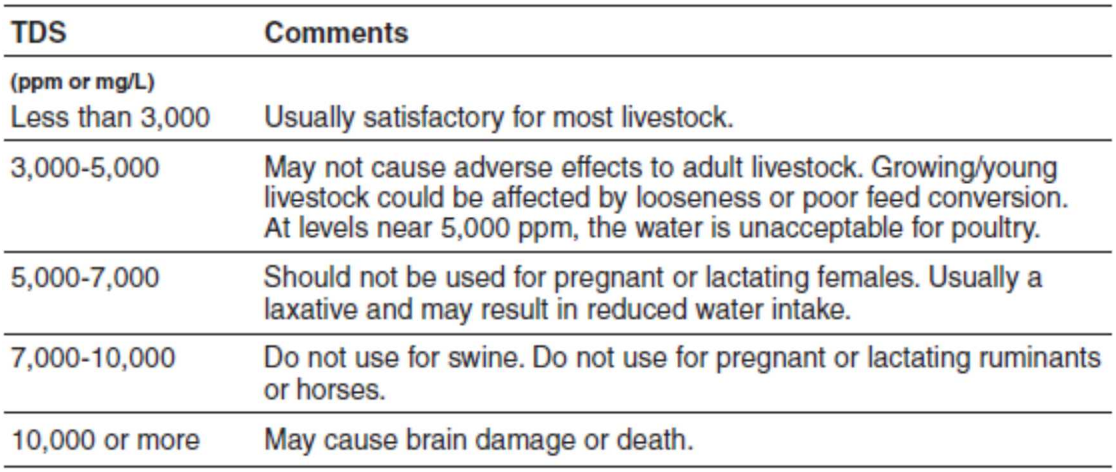
As pipe scaling is such an important part of this study, component analysis of the pipe scale was performed. X-ray diffraction (XRD) is used to identify the different solid components contributing to the pipe scale. Our findings indicated calcite ($CaCO_3$) is the primary component of the scale, while there were some minor amounts of quartz (SiO_2). Shafer ranch indicated that the location of plugged piping is consistently near the entrance and exit of tanks. This is most likely a result of a pressure drop (slowing of water flow rate) in the piping that facilitates the initiation of scale formation. The ranchers noted that removal of the scale is nearly impossible because it is so well bonded to the PVC pipe. Quartz does not form at ambient temperatures and pressures. Therefore, detectable amounts of this mineral in pipe scale is indicative of fine soil particles being wind-blown into the water storage tanks before being dispersed in water and deposited in the pipes. Covering the tanks could mitigate this issue, APPENDIX F: ESTIMATE FOR TANK COVER.

Based on additional water analysis done by Western Environmental, Appendix B: WATER ANALYSIS REPORTS, there is concern that the Shafer well water has a high level of iron present, 9 ppm and 0.57 ppm at wells 1 and 2 respectively. In house testing of iron levels at Sandia National Labs supports the findings of Western Environmental for tank 2. For tank 1, the iron levels were lower than those reported by Western Environmental, but still high enough to prevent RO from working effectively. The issue of iron levels is an important issue to rectify as high iron levels complicate the treatment options. For instance, with membrane filtration such as RO or nanofiltration, the iron must be removed prior to contact with the membranes or it will foul (plug) the membranes. This requires a pre-treatment step for iron removal. At present, there is not an easy commercially available technique for removing the iron, especially at the desired flowrates.

Table 4 Shafer Ranch well water quality values. Complete water analysis results are provided in Appendix B: WATER ANALYSIS REPORTS.

		Well #1	Well #2 (Belio)
	Water flow rate (gals per min)	1.12 – 1.85	1.04 – 2.22
Water Quality Parameters	Ph	7.2	7.9
	TDS (mg/L)	3000	3230
	Conductivity (*u*mhos)	2600	2700
	Hardness (As $CaCO_3$)	2000	2100
	Ca (mg/L)	600	570
	Sulfate (mg/L)	1700	1800
	Total Alkalinity (As $CaCO_3$)	430	340
	Bicarbonate (As $CaCO_3$)	430	340
	Iron (Fe) (ppm)	9.2	0.57
	Manganese (Mn) (ppm)	0.43	<0.01
	Silica (ppm)	51	52

Table 5 Recommendations for livestock water use based on total dissolved solids (TDS).[2]



TDS (ppm or mg/L)	Comments
Less than 3,000	Usually satisfactory for most livestock.
3,000-5,000	May not cause adverse effects to adult livestock. Growing/young livestock could be affected by looseness or poor feed conversion. At levels near 5,000 ppm, the water is unacceptable for poultry.
5,000-7,000	Should not be used for pregnant or lactating females. Usually a laxative and may result in reduced water intake.
7,000-10,000	Do not use for swine. Do not use for pregnant or lactating ruminants or horses.
10,000 or more	May cause brain damage or death.

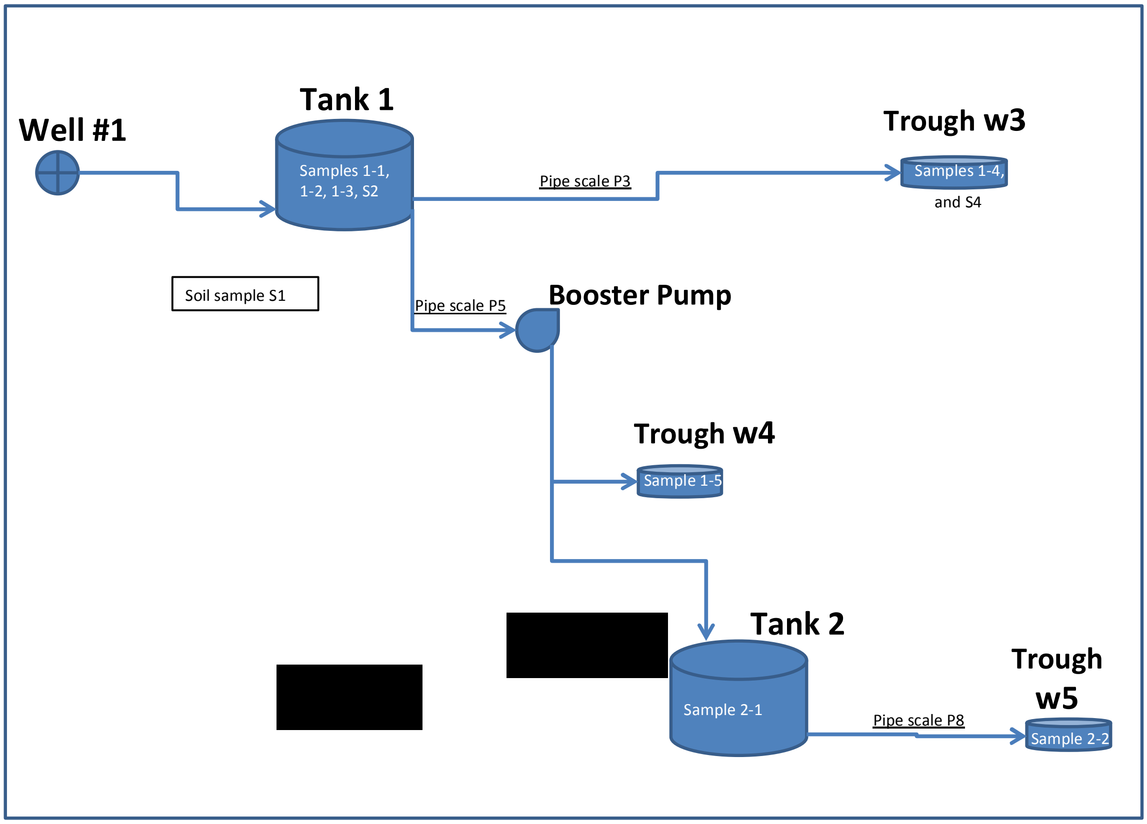


Figure 1 Shafer Ranch water distribution piping network schematic for well 1, and water, soil, and sludge sampling locations

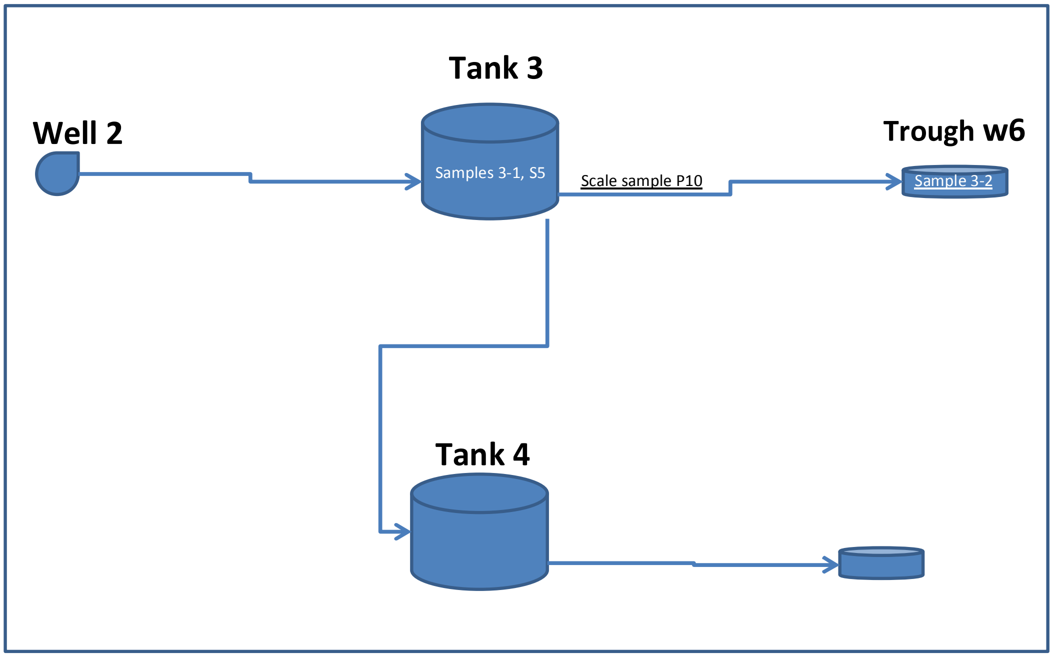


Figure 2 Shafer Ranch water distribution piping network schematic for well 2, and water, soil, and sludge sampling locations

Table 6 Composition of the solids (soil, sludge in the tank, and pipe scale) at Shafer Ranch

Soils near Tanks	Calcite, quartz, iron*
Tank 1 Sediment	Calcite, quartz (fine particles)
Tank 3 Sediment	Calcite, quartz, gypsum, aragonite
Pipe Scale (Tank1 outflow)	Calcite, quartz, iron*
Pipe Scale (from Tank1, near booster pump)	Calcite
Pipe Scale (Tank 2 outflow)	Calcite, gypsum
Pipe Scale (Tank 3 outflow)	Calcite, quartz, gypsum, aragonite

Note: * we found evidence that some iron flakes are present, likely due to deterioration of metal components of pipes.

Table 7 Sulfate effects in livestock drinking water. [3]

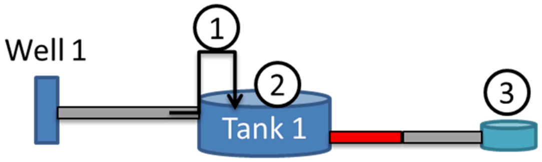
Sulfate concentration (mg/L)	Effect
< 1000	Generally safe
1000 – 2000	May result in diarrhea. Performance may be reduced, particularly in confined cattle on dry feed. Grazing cattle not likely affected. May cause slight reduction in copper availability
2000 – 3000	Likely to result in diarrhea. Performance will likely be reduced, particularly in confined cattle on dry feed. Sporadic cases of sulfur-associated PEM are possible. Grazing cattle may be affected. May cause substantial

	reduction in copper availability.
3000 – 4000	Likely to result in diarrhea. Performance will likely be reduced in all classes of cattle. Sporadic cases of sulfur-associated PEM are likely. May cause substantial reduction in copper availability
> 4000	Potentially toxic. Should be avoided.

We used geochemical modeling to interpret chemical changes observed in water samples collected at different points of the water distribution system at Shafer Ranch. This modeling allows us to predict mineral saturation (what minerals are expected to precipitate), their amounts, and associated changes in the water chemistry. We are also able to test simple water treatment scenarios to predict changes in the expected mineral precipitation. In this case, we have explored to what degree a slight acidification of water will decrease the amount of scale. The Geochemist Workbench (GWB) software was used with the standard thermodynamic database (*thermo.dat*). All modeling runs were done at room temperature (25 °C), and in equilibrium with the atmosphere.

We used water chemistry data, Appendix B: WATER ANALYSIS REPORTS, as input for our models. Each sample was modeled separately, to track the formation of scale in the pipes. Models were constructed to predict the identity and amount of minerals contributing to the pipe scale formation and were compared with the actual X-ray diffraction analyses results of these scales, Table 6 and Appendix C: X-RAY DIFFRACTION DATA. We also used changes in the chemical composition of water to estimate the amount of water lost due to evaporation.

Water analysis results indicate that there is a significant water loss due to evaporation. This is established based on the changes in concentrations of some of the conservative ions - chloride, sodium, and sulfate – these ions are not expected to precipitate or escape in the form of gas; therefore if their concentration is increasing, it means that some water has evaporated. Figure 3 illustrates the changes in the concentrations of these ions as water moves from well 1 (sample 1) to the tank (sample 2) to the trough (sample 3). These ions become more concentrated, and based on the concentration change we estimated that 25-30 % of pumped water volumes are lost due to evaporation in the open air tanks.



Sample	1	2	3
Na^+ (mg/L)	34	35	49
Cl^- (mg/L)	7.5	7.9	13
SO_4^{2-} (mg/L)	1600	1700	2100

Figure 3 Increasing concentrations of sodium, chloride and sulfate indicate water loss.

Additionally, we estimated water losses due to evaporation, based on the tabulated values for Alamogordo, NM. The tabulated height of the water column loss is 7.35 inches per month, in the month of October [8]. This value is based on a 10-year average of evaporation rates, measured prior to 1982. Shafer ranch estimated that tank 1 is ~ 30 feet in diameter, and has a depth of ~ 5 feet, which corresponds to the volume of 26,500 gallons. If 7.35 inches of water column is evaporated every month, this would correspond to 12 % water loss. Due to the sustained drought conditions that persist in New Mexico, the actual evaporation rates are higher, as evidenced by the increase of the concentration of sodium, chloride, and sulfate discussed above.

To predict the amount of mineral scale expected to form in the tanks and pipes, we have incorporated three simultaneous processes into our models:

1. Water loss due to evaporation in the holding tanks. The loss is time-dependent, and we chose a conservative value of 15 %;
2. Oxidation of iron. There is a significant amount of dissolved iron measured in water from well 1 (9.2 mg/L). This iron is originally in the reduced +2 state, and is expected to oxidize after water is exposed to the atmosphere. Accounting for the oxidation of iron is important, since iron 2+ is soluble, while the oxidized form iron 3+ is expected to precipitate and fall out of solution; and
3. Based on the pH value increase between well 1, tank water, and trough samples, accompanied by a significant decrease in the bicarbonate ion (HCO_3^-), we have concluded that these observations are best explained by some off-gassing of carbon dioxide (CO_2) as water is stored in the tanks. The amount of CO_2 gas lost was selected to match the recorded pH values, and was set at 130 mg.

The results of the geochemical modeling are summarized in Table 8. The sampling diagram is shown in Figure 1 and Figure 2. Geochemical models calculate mineral saturation states for all known minerals; and we have excluded all non-ambient phases from the results. These results predict the mass of the over-saturated mineral phases (calcite and hematite) expected to precipitate. By comparing the expected precipitate mass in the tank water samples, and samples collected downstream, we have calculated the mass of precipitate expected to be deposited in the pipes. Mass of hematite (iron oxide) is roughly an order of magnitude lower than the predicted mass of calcite. For the tank 1 distribution system, the calculated scale (calcite) mass is 0.26 grams per each liter of water (0.97 grams per each gallon of water) which passes from tank 1 to the trough (sample 3), and 0.18 grams per liter (0.68 grams per gallon) for the pipe going from tank 1 to the corral (sample 4). For tank 2, the calculated mass of scale is 0.026 grams per liter (0.10 g per gallon) for the pipe between tank 2 and trough (sample 5). For tank 3, the amount of scale is 0.17 grams per liter (0.66 grams per gallon) for the pipe going from tank 3 to the trough (sample 6).

Table 8 Summary of the geochemical modeling results.

Sample	Description	SI (1) (calcite)	SI (1) (hematite)	Mass, g (calcite)	Mass, g (hematite)
1-1	Well 1, Tank 1 Inflow	0.74	8.01	0.1	0.005
1-2, 1-3	Tank 1 middle (2)	1.45	8.14	0.27	0.013
1-4	Trough w3	0.92	n/a (3)	0.014	n/a (3)
1-5	Trough w4	1.33	n/a (3)	0.09	n/a (3)
2-1	Tank 2 middle (2)	1.51	10	0.1	0.001
2-2	Trough w5	1.46	n/a (3)	0.074	n/a (3)
3-1	Well 2, Tank 3 middle (2)	1.51	n/a (3)	0.22	n/a (3)
3-2	Trough w6	1.37	n/a (3)	0.046	n/a (3)

(1) SI – saturation index, positive value reflects the degree of over-saturation with respect to the listed mineral (calcite or hematite)
(2) Evaporation and CO_2 off-gassing in taken into account for water samples collected from the storage tanks only, since no evaporation is expected in the pipes
(3) n/a – not available. Iron concentration was only measured for samples collected from wells 1 and 2.

A graphical illustration of the mineral precipitation in tank 1 is shown in Figure 4. Reaction progress represents relative time required to evaporate 15 % of water.

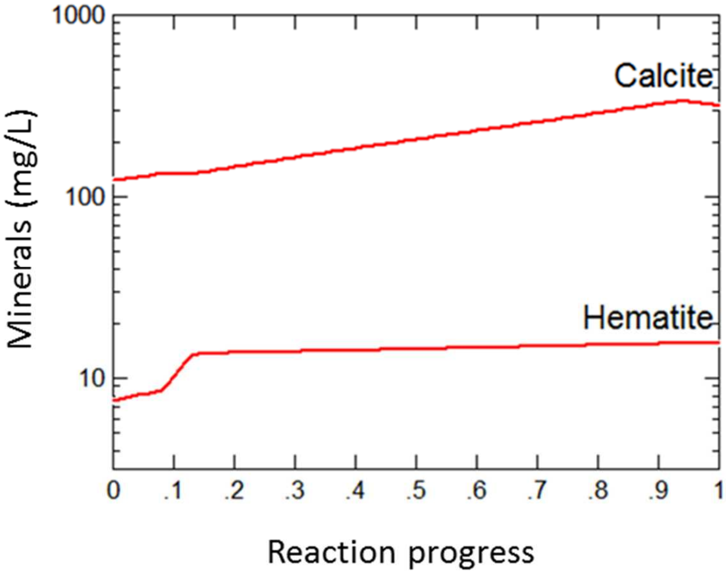


Figure 4 Formation of scale (calcite and hematite) in tank 1.

Calcite is the main component in the scale, and its solubility is controlled by the acidity of water (solubility increases as pH decrease). Therefore, we modeled how adjusting pH value (acidifying the water) would change the amount of pipe scaling. We only consider semi-neutral pH values (above 6.5), and assume 15 % evaporation in tank 1.

The results of this modeling are summarized in Table 9. By adjusting pH value from 8 (measured in tank 1) to 7.5, the amount of scale would be decreased by only 0.02 grams per liter (0.076 grams per gallon), if pH is adjusted to 7.0 – decreased by almost 50 % (from 0.27 grams per liter to 0.15 grams per liter), and further acidification to pH of 6.5 is expected to prevent the precipitation of calcite scale. Therefore, utilizing an acidification treatment to prevent pipe scaling would eliminate the need to replace piping. However, it would not improve the overall water quality for human or animal consumption.

Table 9 Predicted mass of calcite to precipitate at various pH values calculated for tank 1 water and assuming an evaporation rate of 15%

	pH = 8.0	pH = 7.5	pH = 7.0	pH = 6.5
Calcite mass, grams	0.27	0.25	0.15	0

Hightower Ranch

We analyzed 2 water samples collected at Hightower Ranch and present the results in Table 10 Hightower Ranch Water Compositions.

Table 10 Hightower Ranch Water Compositions.

Water Sample	Hightower 1	Hightower 2
Ca^{2+} mg/L	514	654
Mg^{2+} mg/L	258	171
Na^{+} mg/L	4820	4060
K^{+} mg/L	44.2	44
P(total) mg/L	1.25	0.87
Cl^{-} mg/L	193	227
$S0_4^{2-}$ mg/L	2100	1900
Fe (total) mg/L	9.94	10.76
pH	6.88	6.87
Cond. mS/cm	3.4	3.37
Total Alk mEq/L	188	280
Hardness as mg/L $CaCO_3$	2170	2120
TDS g/L	4.89	4.29

Overall, the water quality (hardness) is somewhat similar to the water collected at Shafer Ranch. The difference is an even higher TDS – 4.3-4.9 g/L, Table 10, and significantly higher concentration of dissolved sodium chloride. The concentration of iron is similar to the Shafer Ranch water; however, the Hightower samples were not preserved prior to the analysis, which could potentially lead to under-estimation of the amount of iron (if some iron fell out of solution as iron oxide prior to our analysis).

Geochemical modeling of the Hightower 1 water sample indicates that calcite is over-saturated (SI = 0.14), and due to the higher dissolved sodium (4820 mg/L vs. 34 mg/L), and slightly lower pH (6.88 vs. 7.1) the amount of calcite scale expected to precipitate is a lot lower than at Shafer Ranch. The model predicts that only 0.007 g/L of calcite is expected to precipitate. This is consistent with the fact that at Hightower Ranch no problems with scale clogging water distribution system have been reported.

Even though Hightower Ranch does not have the same issues with pipe replacement as the Shafer Ranch, the water treatment options will be similar for the two ranches. This is because the amount of TDS in the water at both the Hightower and Shafer ranches is detrimental to both cattle and human health.

COMMERCIALLY AVAILABLE WATER TREATMENT SYSTEM REVIEW

There are a number of possible solutions to consider for improving water quality for cattle. The easiest and least costly solutions are to capture as much surface water as possible and manage grazing locations. Unfortunately, with the sustained drought conditions that persist in New Mexico, this is not an option. Another solution is to develop new water sources if possible. This could be a new well or connection to another water source of higher quality. The ranchers have already considered this possibility and determined that they are not feasible. The final option is treating the water to remove the undesirable constituents.

The optimum water treatment solution is based on the initial and final desired water chemistries and flowrates. There are several scenarios that could be considered when evaluating water treatment technologies for the ranch waters:

a) treat all well water to a target TDS level needed to protect cattle health and distribution piping (~ 2000-5000 gal/day) but not to a level required for human consumption
b) treat the portion of the well water that goes to the home only (~500 gal/day) to a target level TDS needed for human consumption
c) treat the well water to a target level to protect cattle health and piping (1500 – 4500 gal/day) and further treat a small side-stream to potable water levels for household/human use (500 gal/day).
d) treat all well water to a target level needed to protect human health and distribution piping (~ 2000-5000 gal/day)

To begin our analysis, we discussed our scenarios with Scott Bierle, President of Western Environmental Management. Scott, who is a participant in this NMSBA project, has decades of experience treating groundwater with similar chemistries in New Mexico for the Dairy and Ranch Industries. Based on our conversations, we have concluded that there is no significant cost savings in scenarios *a-d.* Specifically, the capital investment is identical whether one treats 500 or 5000 gal/day. Additionally, for a conventional technology such as reverse osmosis (RO), there is only a very small savings in the operating costs between 500 or 5000 gal/day. This is regardless whether the system is set up to treat water to cattle or human water quality standards. Moreover, there is a reduction in water consumption during the treatment process if larger volumes of water are treated.

The commercially available water treatment solutions that could apply to the Shafer & Hightower Ranch water supplies are listed below. Additionally, we have included a general description of the technology and our assessment of feasibility for the ranch waters. Our assessment takes into account initial water chemistry, capital costs, and operational costs. A list of vendors contacted during this study and a summary of relevant information collected can be found in Appendix C: VENDOR INFORMATION.

Water softening

A water softener is a technology that would exchange the magnesium or calcium sulfate for sodium sulfate, and thereby reduce pipe scaling. However, it would not improve the water quality, because a water softener, carbon filter, or sediment filter does not remove the sulfate which is the most concerning constituent of the TDS at the Shafer Ranch for the cattle's heath. This treatment option also does not produce water appropriate for human consumption. Therefore, this standard technique is not recommended for the Shafer or Hightower Ranch waters.

Distillation

Distillation is a water treatment process where water is boiled, and the resulting steam is then cooled, condensed, and captured in a separate vessel. Dissolved minerals such as calcite (calcium carbonate), magnesite (magnesium carbonate), and gypsum (calcium sulfate) are left behind in the boiling vessel. Conventional distillation technologies would work well for the ranch waters; however, they are so energy intensive they are far too costly.

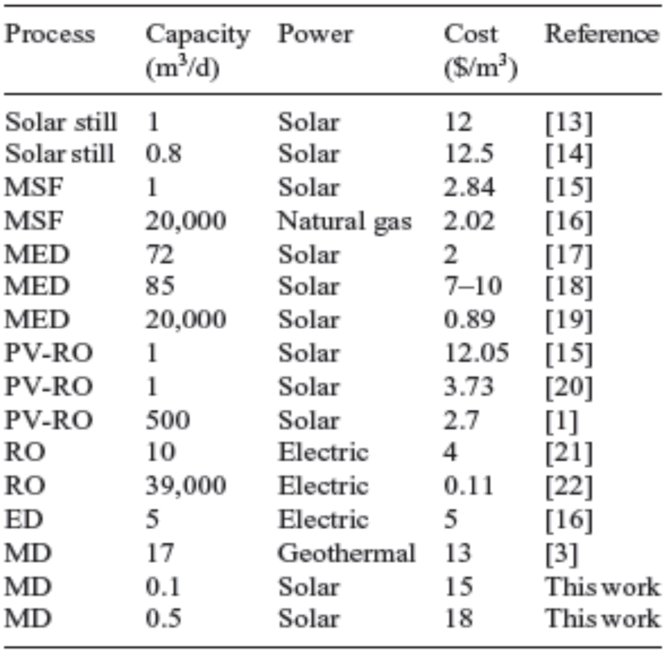
Recently, research combining the distillation process with solar technology has shown promise of lowering the overall cost by using the sun's energy. Research has focused on the equipment (thermal and electrical) required to convert the free solar energy into a useful form. Of the numerous variations of solar water purification, only two are potentially appropriate to treat the relatively small water volumes at the Shafer and Hightower Ranches. They are: (a) autonomous solar powered membrane distillation and (b) solar stills.

Solar-powered membrane distillation is a process that heats water using solar energy. This results in water vapor passing through a membrane that screens out minerals. The vapor is then condensed on the opposite side of the membrane as clean water.

Solar stills are the oldest known method of water desalination. Solar stills operate using the greenhouse effect. The heat of the sun causes the water to evaporate leaving behind any dissolved minerals. The distilled water vapor then condenses and is collected for use.[9]

Both solar-powered membrane distillation and solar stills are capable of treating the ranch water; however, the costs are likely prohibitive. An economic assessment was done by Banat and Jwaied to estimate the expected cost of these two technologies.[10] Based on the calculations, the estimated cost of potable water produced by a solar powered membrane distillation unit is $\$18/m^3$, which is at least 4 times greater than the operating costs for a RO system using electricity, Table 11. Considering the relative high cost of solar distillation technologies, we do not recommend them as a feasible solution.

Table 11 Unit production costs of selected desalination units taken from Banat and Jwaied, 2008.[10]



Process	Capacity (m^3/d)	Power	Cost ($\$/m^3$)	Reference
Solar still	1	Solar	12	[13]
Solar still	0.8	Solar	12.5	[14]
MSF	1	Solar	2.84	[15]
MSF	20,000	Natural gas	2.02	[16]
MED	72	Solar	2	[17]
MED	85	Solar	7–10	[18]
MED	20,000	Solar	0.89	[19]
PV-RO	1	Solar	12.05	[15]
PV-RO	1	Solar	3.73	[20]
PV-RO	500	Solar	2.7	[1]
RO	10	Electric	4	[21]
RO	39,000	Electric	0.11	[22]
ED	5	Electric	5	[16]
MD	17	Geothermal	13	[3]
MD	0.1	Solar	15	This work
MD	0.5	Solar	18	This work

Ion exchange (IX)

Ion exchange (IX) is a common method for removing sulfate from water for commercial, livestock, and public supplies. Ion exchange works by passing water containing an ion of interest (e.g. sulfate) through a resin that is specifically designed for its removal. As water passes through the resin, the ion of interest is exchanged for an ion on the resin. For example, in resins designed for sulfate removal the sulfate ions are exchanged for chloride ions. Strong base resins are usually employed, and the resins may be regenerated using a brine solution.

Some commercial resins are reported to be effective at removing essentially 100% of the sulfate in a water sample with sulfate concentrations up to 2,500 mg/L. Factors such as high levels of dissolved organic carbon or high particulate load, however, can impact the efficiency of these resins by adsorbing to the resin and preventing exchange of ions. At the Shafer Ranch - relatively low organic carbon and particulate loading indicate these parameters will not interfere with sulfate removal.

Water chemistry analysis data was sent to several of the leading vendors of ion exchange units for evaluation of the Shafer water. All vendors stated that the water could probably be cleaned using IX; however, the cost would be prohibitive due the very poor water quality. All vendors suggested reverse osmosis as the optimal choice.

Some experts feel that ion exchange is likely to be more reliable than nanofiltration because of the sensitivity of the nanofiltration process to total dissolved solids and bio fouling discussed above. For example, a representative from Purolite wrote:

"Unfortunately, ion exchange will not be a good solution. There are two options for ion exchange - brine regenerated SBA and demineralization. The former will result in solving one problem and creating another (i.e. high chloride). The latter is likely uneconomical and impractical for the location indicated."

Chemical precipitation (coagulation followed by filtration)

Another class of treatment approaches involves chemical precipitation of an insoluble form of sulfate by adding another salt. Various industries such as mining, battery manufacturing, and metal galvanizing have each developed reliable chemical precipitation methods for removing sulfate from their waters. Typically a chemical precipitation process is a multi-stage process requiring addition of a precipitating agent such as hydrated lime, calcium chloride, or barium salts to the water. A settling (clarification) process is then used followed by removal of the precipitated sulfate-salt complex with filtration. This is a reliable, well-understood method for sulfate removal; however, the process complexity and associated cost generally make this technology economical only at large scale and where technicians are available to maintain the process. This process is not feasible for a ranch setting unless a simplified adaptation can be formulated/designed.

Membrane filtration

Membrane filtration employs semi-permeable membranes that are selectively permeable to water and certain solutes. Membrane separation processes differ based on separation mechanisms and size of the separated particles. The widely used membrane processes include microfiltration, nanofiltration, reverse osmosis, electrolysis, dialysis, electro dialysis, vapor permeation, membrane distillation and membrane contactors.[11] Filter membranes are divided into four classes according to pore size and the material that needs to be removed.

Table 12 Classification of membrane filtration methods are based on pore size

Pore Size	Process	Removal of
0.1 *u*m	Microfiltration	Larger bacteria, yeast, particles
100-2 nm	Ultrafiltration	Bacteria, macromolecules, proteins, larger viruses
2-1 nm	Nanofiltration	Viruses, 2-valent ions[5]
< 1nm	Reverse Osmosis	Salts, small organic molecules

Zero Discharge Desalination (ZDD)

Recent research conducted at the University of Texas El Paso (UTEP) combines two membrane filtration technologies, nanofiltration or reverse osmosis and electro-dialysis, into a single unit called ZDD (Zero Discharge Desalination). This technology has been designed with emphasis on treating ground waters in the Tularosa Basin - the location of the Shafer and Hightower ranches. ZDD technology is being tested at the Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, NM to evaluate the economics of a ZDD solution for the city of Alamogordo. The groundwater in Alamogordo is very similar to the ranch waters with the exception of the high iron content. Malynda Cappelle, Associate Director of the UTEP Center for Inland Desalination, has indicated a strong interest in conducting a pilot test at one of the ranches. UTEP already has a ZDD pilot system that would match the ranch well water flowrates. Malynda stated that a pilot could readily be deployed but that a pre-filtration step to remove the iron would have to be added. We recommend pursuing this option as a possible water treatment solution.

Reverse osmosis (RO)

RO systems are a subset of membrane filtration that removes minerals from water by pushing the water through a membrane that does not allow minerals to pass. Clean water (permeate stream) exits the membrane leaving the minerals behind on the opposite side of the membrane (concentrate stream). The primary cost associated with RO is the pumping power required to overcome the osmotic pressure of water when pushing it through the membrane. A specific section on RO is included as this technology is one of the more promising solutions for the issue of water quality at the Shafer and Hightower ranches. Multiple vendors, including Western Environmental, indicated that RO was the best commercially available solution they had to offer for this application. However, the issue of high iron must still be addressed before an RO system could be used to treat the well water.

Related Previous Sandia National Labs Work

In 2010, Sandia National Labs conducted work on treating well water in Guadalupe County, NM for cattle consumption. The work was conducted as the overall health, longevity, and reproduction rates for the cattle on several ranches in Guadalupe County, NM have consistently been 15-20% below industry standard. Through years of observation, the ranchers have noticed that the numbers are significantly higher in drought years when the cattle drink groundwater from the ranch wells instead of collected rainwater. Therefore, Sandia National Labs conducted a chemistry analysis of the well water and determined the supplemental well water contained high levels of sulfates (>2300 mg/L) and magnesium (>1000 mg/L). Water treatment options were evaluated for multiple wells located on ranches near in Guadalupe County, NM. It was determined that several commercially available technologies would work well for TDS and sulfate removal at concentrations slightly higher than those at the Shafer Ranch.

During this project, the McKenzie Ranch was chosen for further evaluation and testing of a water treatment system. Commercially available technologies capable of removing the high sulfate and magnesium were identified and then assessed based on anticipated cost. Cost assessment included capital outlay and annual operational costs. The technologies investigated are listed below in order of lowest to highest cost.

Lowest	(1) Membrane technology (specifically low pressure Reverse Osmosis)
	(2) Ion exchange

(3) Coagulation/filtration
Highest (4) Distillation

The information was presented to Kenneth McKenzie of McKenzie Ranch, and RO was selected due to the relatively low maintenance requirement. In addition, the simplicity of the system appealed to Mr. McKenzie because he felt that he could conduct the maintenance operations without having to contract an outside company.

As part of the current study, Sandia National Labs contacted Mr. McKenzie to interview him on his RO system. Mr. McKenzie stated that he is pleased with this system. His cattle appear healthy and his calf survival rates have gone up.

Economics of a RO Solution for the Shafer & Hightower Ranches

Unit production cost numbers exist for all the technologies discussed above; however, the costs are based on 500,000 gal/day or larger systems. Cost data for small-scale systems needed for this project are absent in the literature. For that reason, an economic analysis for treatment of the well water at the Shafer and Hightower Ranches is not provided. Instead a look at a similar project previously conducted by Sandia National Laboratories at the McKenzie Ranch in Guadalupe County can provide some insight into approximate costs for such a small system.

The groundwater treatment issues faced by the Shafer and Hightower Ranches are similar to McKenzie's water with one significant difference – the higher iron levels at the former. McKenzie installed a low pressure RO system to remove sulfate and other minerals from his well water. Results have shown 70-80% recovery of very high quality water without significant operational issues.

A general rule of thought regarding RO treated water is that it may require blending with the untreated water or adjustment of pH or mineral content to please the cows. McKenzie has been supplying his cows RO treated water for over a year without any adjustment or adverse health effects. In fact, McKenzie has stated that he has seen general improvement in cattle health, and tremendous improvement in calf survival rates; in the year prior to the RO system installation he lost 30 calves but has not lost a single calf since. The weather and other factors have remained relatively constant, so McKenzie attributes the improvement to the improved water quality.

The McKenzie RO system produces roughly 2 times more water (~ 8gpm) than a single well at the Shafer or Hightower ranches. Based on the capital and operating costs for the McKenzie system, it is anticipated that a similar system sized for a Shafer or Hightower wellhead Flowrate would be between $7,000 – $12,000 for initial investment capital costs and annual operating costs of between $3,000 and $6,000. These rough cost estimates do not include removal of the iron.

Conclusions and recommendations

In conclusion, we have investigated water treatment solutions to address the water quality issue at the Shafer and Hightower ranches. Analysis of water chemistry, soil samples, and pipe scale samples were performed, and high levels of total dissolved solids, sulfate, and iron were found in the water. These results were then used in a geochemical model to show that the primary component of scale at Shafer Ranch is the calcium carbonate in the water.

To investigate commercially available water treatment technologies, several water treatment companies were contacted as well as the University of Texas at El Paso Center for Inland Desalination and a rancher that Sandia National Laboratories had previously assisted with a similar water treatment project. Water softening, distillation (including off-the-grid options such as solar distillation), ion exchange, chemical precipitation, membrane filtration, reverse osmosis, and zero discharge desalination technologies were included in this study. Only the final two solutions – reverse osmosis and zero discharge desalination – were determined to be potential candidates for treating the water at the Shafer and Hightower Ranches.

Unfortunately, the high iron content of the well water at both the Shafer and Hightower Ranches poses a problem for both the reverse osmosis and zero discharge desalination systems. A pretreatment system to remove the iron will need to be installed. This is a nontrivial issue and no commercially available options can be recommended. Further study will be needed to address removal of iron. We recommend that both Shafer and Hightower Ranches contact the University of Texas, El Paso regarding the zero discharge desalination. We also recommend that they further investigate the possibilities for iron removal as a pretreatment step for either reverse osmosis or zero discharge desalination systems.

Finally, we have proposed three additional options to address only the issue of pipe scaling at the Shafer Ranch. First, we have proposed a do-it-yourself design to trap the scale in a filter system that can be more easily maintained than the ranch's current underground piping network. This system would need to be tested and perfected through trial and error at the ranch. Second, we have proposed that covering the open-air water holding tanks would both reduce evaporation rates and prevent dirt from entering the pipes by way of the tanks, and thereby reducing that rate at which the pipes clog. We have provided price estimates for this option.

Appendices

Appendix A : SCOPE OF WORK DOCUMENT

Sandia National Laboratories will provide technical consulting to the Requestor in the following manner:

1. Water quality assessment and geochemical modeling to predict the best water treatment methods
    a. Sampling and chemical analysis of well water and mineral scales
    b. Gechemical modeling to identify chemical treatments capable of preventing scaling
2. Research and down selection of commercially available water treatment systems
    a. Research off-the-grid water treatment systems
    b. Research solar-powered nano-filtration and distillation systems
    c. Research reverse osmosis and water softening systems
    d. Analysis of efficiency (water and energy), and cost (capital vs. operating), and down selection of available options
3. Report: recommendation of the optimum water treatment steps to improve water quality for livestock and people

Appendix B: WATER ANALYSIS REPORTS

Multiple water analyses were performed in this study. The raw results from these analyses are presented in this appendix, including the following:

1. Water samples from wells 1 and 2 were collected by Western Environmental Management, Carlesbad, NM, and analyzed by General Electric (GE) Power & Water – Water & Process Technologies.
2. Water samples collected at the Shafer Ranch were analyzed by Hall Environmental Analysis Laboratory, Albuquerque, NM. In addition to the report sheets, we also provide a compilation of all results in Table A1.
3. Samples collected at the Hightower Ranch were analyzed at the geochemistry laboratory, Sandia National Labs, Albuquerque, NM.

Table A1. Chemical composition of water samples collected at the Shafer Ranch, October 2014 (Compilation of the analysis performed by the Hall Environmental).

Sample *	Sample Description	Ca^{+} mg/L	Mg^{2+} mg/L	Na^{+} mg/L	K^{+} mg/L	HCO$_3^{-}$ mg/L	SO$_4^{2-}$ mg/L	Cl^{-} mg/L	pH	Cond. mS/cm	Total Alk mEq/L	Hardness as mg/L CaCO$_3$	TDS g/L
1-1	**Sacate Tank 1 Inflow. Filtered on site**	610	110	34	3.9	440	1600	7.5	7.1	2600	440	2000	2950
1-2	**Tank 1 inflow. Duplicates 1-1 but filtered in lab**	620	110	33	3.9	430	1700	7.5	7.25	2600	430	2000	3000
1-3	**Sacate Tank 1 Mid-Depth**	590	120	35	4	370	1700	7.9	7.87	2600	370	2000	2990
1-4	**"W3 1st Trough" fed from Tank 1**	620	150	49	4.2	78	2100	13	8.02	2800	78	2100	3480
1-5	**Corral Trough (W4) with water pumped from Tank 1**	610	130	39	6.6	280	1800	10	7.86	2600	280	2000	3100
2-1	**Tank 2 Mid-Depth**	610	130	39	6.5	270	1700	8.2	8.06	2600	270	2100	3020
2-2	**"W5" Trough supplied from Tank 2**	580	130	39	4.4	230	1800	9.5	8.1	2600	230	2000	3080
3-1	**Tank 3 Mid-Depth, fed from Belio well**	570	170	59	5	340	1800	7.9	7.99	2700	340	2100	3230
3-2	**"W6" Trough supplied from Tank 3**	610	210	73	6.1	160	2200	11	8.19	3000	160	2400	3790

Note: *Sampling locations are shown in Figures 1 and 2.

GE Power & Water

Water & Process Technologies

WATER ANALYSIS REPORT

4000101850
WESTERN ENVIRONMENTAL MANAGEMENT
3106 EAST GREENE STREET
Carlsbad, NM
UNITED STATES 88221

Sampled: 17-OCT-2014
Reported: 31-OCT-2014
Field Rep: Laird, Kelly
GED071

	SHAFER RNCH WELL1 Y1024018	SHATER RNCH WELL2 Y1024019
pH	6.9	7.8
Specific Conductance, at 25°C, µmhos	4470	4750
Alkalinity, "P" as $CaCO_3$, ppm	0	0
Alkalinity, "M" as $CaCO_3$, ppm	448	363
Sulfur, Total, as SO_4, ppm	1710	2000
Chloride, as Cl, ppm	7.9	8.1
Hardness, Total, as $CaCO_3$, ppm	2080	2250
Calcium Hardness, Total, as $CaCO_3$, ppm	1600	1480
Magnesium Hardness, Total, as $CaCO_3$, ppm	477	759
Barium, Total, as Ba, ppm	< 0.1	< 0.1
Strontium, Total, as Sr, ppm	7.8	8.6
Copper, Total, as Cu, ppm	< 0.05	< 0.05
Iron, Total, as Fe, ppm	9.2	0.57
Sodium, as Na, ppm	34	62
Potassium, as K, ppm	4.3	5.5
Aluminum, Total, as Al, ppm	< 0.1	< 0.1

WATER ANALYSIS REPORT

4000101850
WESTERN ENVIRONMENTAL MANAGEMENT
3106 EAST GREENE STREET
Carlsbad, NM
UNITED STATES 88221

Sampled: 17-OCT-2014
Reported: 31-OCT-2014
Field Rep: Laird, Kelly
GED071

Result Legend

I - A chemical or physical interference prevented the labs ability to perform this test.

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-001
Matrix: AQUEOUS
Client Sample ID: W3 1st Trough
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS							Analyst: **LGP**
Chloride	13	0.50		mg/L	1	10/17/2014 6:02:43 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 6:02:43 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 6:39:57 PM	R21997
Sulfate	2100	50	*	mg/L	100	10/23/2014 3:32:38 AM	R22092
SM2340B: HARDNESS							Analyst: **ELS**
Hardness (As CaCO3)	2100	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS							Analyst: **ELS**
Calcium	620	10		mg/L	10	10/22/2014 1:17:49 PM	R22081
Magnesium	150	10		mg/L	10	10/22/2014 1:17:49 PM	R22081
Potassium	4.2	1.0		mg/L	1	10/22/2014 1:16:19 PM	R22081
Sodium	49	1.0		mg/L	1	10/22/2014 1:16:19 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE							Analyst: **JRR**
Conductivity	2800	0.010		µmhos/cm	1	10/20/2014 6:36:03 PM	R22035
SM4500-H+B: PH							Analyst: **JRR**
pH	8.02	1.68	H	pH units	1	10/20/2014 6:36:03 PM	R22035
SM2320B: ALKALINITY							Analyst: **JRR**
Bicarbonate (As CaCO3)	78	20		mg/L CaCO3	1	10/20/2014 6:36:03 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 6:36:03 PM	R22035
Total Alkalinity (as CaCO3)	78	20		mg/L CaCO3	1	10/20/2014 6:36:03 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS							Analyst: **KS**
Total Dissolved Solids	3480	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-002
Matrix: AQUEOUS

Client Sample ID: Sacate Tank 1 A Inflow
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst: **LGP**	
Chloride	7.5	0.50		mg/L	1	10/17/2014 6:52:21 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 6:52:21 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 7:04:46 PM	R21997
Sulfate	1600	25	*	mg/L	50	10/23/2014 3:45:02 AM	R22092
SM2340B: HARDNESS						Analyst: **ELS**	
Hardness (As CaCO3)	2000	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst: **ELS**	
Calcium	610	10		mg/L	10	10/22/2014 1:20:33 PM	R22081
Magnesium	110	10		mg/L	10	10/22/2014 1:20:33 PM	R22081
Potassium	3.9	1.0		mg/L	1	10/22/2014 1:19:06 PM	R22081
Sodium	34	1.0		mg/L	1	10/22/2014 1:19:06 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst: **JRR**	
Conductivity	2600	0.010		µmhos/cm	1	10/20/2014 6:44:45 PM	R22035
SM4500-H+B: PH						Analyst: **JRR**	
pH	7.10	1.68	H	pH units	1	10/20/2014 6:44:45 PM	R22035
SM2320B: ALKALINITY						Analyst: **JRR**	
Bicarbonate (As CaCO3)	440	20		mg/L CaCO3	1	10/20/2014 6:44:45 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 6:44:45 PM	R22035
Total Alkalinity (as CaCO3)	440	20		mg/L CaCO3	1	10/20/2014 6:44:45 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: **KS**	
Total Dissolved Solids	2950	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-004
Matrix: AQUEOUS

Client Sample ID: Tank 2b Middle
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst: **LGP**	
Chloride	8.2	0.50		mg/L	1	10/17/2014 7:42:01 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 7:42:01 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 7:54:26 PM	R21997
Sulfate	1700	50	*	mg/L	100	10/23/2014 4:09:51 AM	R22092
SM2340B: HARDNESS						Analyst: **ELS**	
Hardness (As CaCO3)	2100	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst: **ELS**	
Calcium	610	10		mg/L	10	10/22/2014 1:26:01 PM	R22081
Magnesium	130	10		mg/L	10	10/22/2014 1:26:01 PM	R22081
Potassium	6.5	1.0		mg/L	1	10/22/2014 1:24:35 PM	R22081
Sodium	39	1.0		mg/L	1	10/22/2014 1:24:35 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst: **JRR**	
Conductivity	2600	0.010		µmhos/cm	1	10/20/2014 7:20:26 PM	R22035
SM4500-H+B: PH						Analyst: **JRR**	
pH	8.06	1.68	H	pH units	1	10/20/2014 7:20:26 PM	R22035
SM2320B: ALKALINITY						Analyst: **JRR**	
Bicarbonate (As CaCO3)	270	20		mg/L CaCO3	1	10/20/2014 7:20:26 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 7:20:26 PM	R22035
Total Alkalinity (as CaCO3)	270	20		mg/L CaCO3	1	10/20/2014 7:20:26 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: **KS**	
Total Dissolved Solids	3020	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-005
Matrix: AQUEOUS
Client Sample ID: W4 Corral
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst:	**LGP**
Chloride	10	0.50		mg/L	1	10/17/2014 8:31:39 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 8:31:39 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 8:44:03 PM	R21997
Sulfate	1800	50	*	mg/L	100	10/29/2014 2:38:10 AM	R22200
SM2340B: HARDNESS						Analyst:	**ELS**
Hardness (As CaCO3)	2000	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst:	**ELS**
Calcium	610	10		mg/L	10	10/22/2014 1:33:24 PM	R22081
Magnesium	130	10		mg/L	10	10/22/2014 1:33:24 PM	R22081
Potassium	6.6	1.0		mg/L	1	10/22/2014 1:27:21 PM	R22081
Sodium	39	1.0		mg/L	1	10/22/2014 1:27:21 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst:	**JRR**
Conductivity	2600	0.010		µmhos/cm	1	10/20/2014 7:33:45 PM	R22035
SM4500-H+B: PH						Analyst:	**JRR**
pH	7.86	1.68	H	pH units	1	10/20/2014 7:33:45 PM	R22035
SM2320B: ALKALINITY						Analyst:	**JRR**
Bicarbonate (As CaCO3)	280	20		mg/L CaCO3	1	10/20/2014 7:33:45 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 7:33:45 PM	R22035
Total Alkalinity (as CaCO3)	280	20		mg/L CaCO3	1	10/20/2014 7:33:45 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst:	**KS**
Total Dissolved Solids	3100	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-007
Matrix: AQUEOUS

Client Sample ID: W6
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst: **LGP**	
Chloride	11	10		mg/L	20	10/17/2014 9:33:41 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 9:21:16 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 9:33:41 PM	R21997
Sulfate	2200	50	*	mg/L	100	10/23/2014 5:11:53 AM	R22092
SM2340B: HARDNESS						Analyst: **ELS**	
Hardness (As CaCO3)	2400	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst: **ELS**	
Calcium	610	10		mg/L	10	10/22/2014 1:38:56 PM	R22081
Magnesium	210	10		mg/L	10	10/22/2014 1:38:56 PM	R22081
Potassium	6.1	1.0		mg/L	1	10/22/2014 1:37:30 PM	R22081
Sodium	73	1.0		mg/L	1	10/22/2014 1:37:30 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst: **JRR**	
Conductivity	3000	0.010		µmhos/cm	1	10/20/2014 8:01:01 PM	R22035
SM4500-H+B: PH						Analyst: **JRR**	
pH	8.19	1.68	H	pH units	1	10/20/2014 8:01:01 PM	R22035
SM2320B: ALKALINITY						Analyst: **JRR**	
Bicarbonate (As CaCO3)	160	20		mg/L CaCO3	1	10/20/2014 8:01:01 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 8:01:01 PM	R22035
Total Alkalinity (as CaCO3)	160	20		mg/L CaCO3	1	10/20/2014 8:01:01 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: **KS**	
Total Dissolved Solids	3790	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs			**Client Sample ID:** Tank 3 Middle
Project: Thirsty Cattle			**Collection Date:** 10/16/2014 4:00:00 PM
Lab ID: 1410829-008		**Matrix:** AQUEOUS	**Received Date:** 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst:	**LGP**
Chloride	7.9	0.50		mg/L	1	10/17/2014 9:46:05 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 9:46:05 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 9:58:29 PM	R21997
Sulfate	1800	50	*	mg/L	100	10/23/2014 5:24:18 AM	R22092
SM2340B: HARDNESS						Analyst:	**ELS**
Hardness (As CaCO3)	2100	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst:	**ELS**
Calcium	570	10		mg/L	10	10/22/2014 1:41:42 PM	R22081
Magnesium	170	10		mg/L	10	10/22/2014 1:41:42 PM	R22081
Potassium	5.0	1.0		mg/L	1	10/22/2014 1:40:15 PM	R22081
Sodium	59	1.0		mg/L	1	10/22/2014 1:40:15 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst:	**JRR**
Conductivity	2700	0.010		µmhos/cm	1	10/20/2014 8:11:16 PM	R22035
SM4500-H+B: PH						Analyst:	**JRR**
pH	7.99	1.68	H	pH units	1	10/20/2014 8:11:16 PM	R22035
SM2320B: ALKALINITY						Analyst:	**JRR**
Bicarbonate (As CaCO3)	340	20		mg/L CaCO3	1	10/20/2014 8:11:16 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 8:11:16 PM	R22035
Total Alkalinity (as CaCO3)	340	20		mg/L CaCO3	1	10/20/2014 8:11:16 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst:	**KS**
Total Dissolved Solids	3230	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:				
	*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
	E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
	J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
	O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
	R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
	S	Spike Recovery outside accepted recovery limits		

CLIENT: Sandia Natl. Labs
Project: Thirsty Cattle
Lab ID: 1410829-009
Matrix: AQUEOUS
Client Sample ID: tank 1 Inlet D
Collection Date: 10/16/2014 4:00:00 PM
Received Date: 10/16/2014 5:08:00 PM

Analyses	Result	RL	Qual	Units	DF	Date Analyzed	Batch
EPA METHOD 300.0: ANIONS						Analyst: **LGP**	
Chloride	7.5	0.50		mg/L	1	10/17/2014 11:00:32 PM	R21997
Nitrogen, Nitrate (As N)	ND	0.10		mg/L	1	10/17/2014 11:00:32 PM	R21997
Phosphorus, Orthophosphate (As P)	ND	10		mg/L	20	10/17/2014 11:12:57 PM	R21997
Sulfate	1700	25	*	mg/L	50	10/23/2014 5:36:42 AM	R22092
SM2340B: HARDNESS						Analyst: **ELS**	
Hardness (As CaCO3)	2000	6.6		mg/L	1	10/22/2014 12:19:00 PM	R22081
EPA METHOD 6010B: DISSOLVED METALS						Analyst: **ELS**	
Calcium	620	10		mg/L	10	10/22/2014 1:44:29 PM	R22081
Magnesium	110	10		mg/L	10	10/22/2014 1:44:29 PM	R22081
Potassium	3.9	1.0		mg/L	1	10/22/2014 1:42:59 PM	R22081
Sodium	33	1.0		mg/L	1	10/22/2014 1:42:59 PM	R22081
SM2510B: SPECIFIC CONDUCTANCE						Analyst: **JRR**	
Conductivity	2600	0.010		µmhos/cm	1	10/20/2014 8:26:43 PM	R22035
SM4500-H+B: PH						Analyst: **JRR**	
pH	7.25	1.68	H	pH units	1	10/20/2014 8:26:43 PM	R22035
SM2320B: ALKALINITY						Analyst: **JRR**	
Bicarbonate (As CaCO3)	430	20		mg/L CaCO3	1	10/20/2014 8:26:43 PM	R22035
Carbonate (As CaCO3)	ND	2.0		mg/L CaCO3	1	10/20/2014 8:26:43 PM	R22035
Total Alkalinity (as CaCO3)	430	20		mg/L CaCO3	1	10/20/2014 8:26:43 PM	R22035
SM2540C MOD: TOTAL DISSOLVED SOLIDS						Analyst: **KS**	
Total Dissolved Solids	3000	40.0	*	mg/L	1	10/21/2014 4:54:00 PM	15999

Refer to the QC Summary report and sample login checklist for flagged QC data and preservation information.

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

Anatek Labs, Inc.

1282 Alturas Drive • Moscow, ID 83843 • (208) 883-2839 • Fax (208) 882-9246 • email moscow@anateklabs.com ·
504 E Sprague Ste. D • Spokane WA 99202 • (509) 838-3999 • Fax (509) 838-4433 • email spokane@anateklabs.com

Client:	HALL ENVIRONMENTAL ANALYSIS LAB	**Batch #:**	141021021
Address:	4901 HAWKINS NE SUITE D ALBUQUERQUE, NM 87109	**Project Name:**	1410829
Attn:	ANDY FREEMAN		

Analytical Results Report

Sample Number 141021021-001 **Sampling Date** 10/16/2014 **Date/Time Received** 10/21/2014 10:35 AM
Client Sample ID 1410829-001C / W3 1ST TROUGH **Sampling Time** 4:00 PM
Matrix Water
Comments

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.62	10/31/2014	HSW	SM4500S2F	

Sample Number 141021021-002 **Sampling Date** 10/16/2014 **Date/Time Received** 10/21/2014 10:35 AM
Client Sample ID 1410829-002C / SACATE TANK 1 A INFLOW **Sampling Time** 4:00 PM
Matrix Water
Comments

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.4	10/31/2014	HSW	SM4500S2F	

Sample Number 141021021-003 **Sampling Date** 10/16/2014 **Date/Time Received** 10/21/2014 10:35 AM
Client Sample ID 1410829-003C / SACATE TANK 1B MID TANK **Sampling Time** 4:00 PM
Matrix Water
Comments

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.37	10/31/2014	HSW	SM4500S2F	

Sample Number 141021021-004 **Sampling Date** 10/16/2014 **Date/Time Received** 10/21/2014 10:35 AM
Client Sample ID 1410829-004C / TANK 2B MIDDLE **Sampling Time** 4:00 PM
Matrix Water
Comments

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.46	10/31/2014	HSW	SM4500S2F	

Client:	HALL ENVIRONMENTAL ANALYSIS LAB	**Batch #:**	141021021
Address:	4901 HAWKINS NE SUITE D ALBUQUERQUE, NM 87109	**Project Name:**	1410829
Attn:	ANDY FREEMAN		

Analytical Results Report

Sample Number	141021021-005	**Sampling Date**	10/16/2014	**Date/Time Received**	10/21/2014 10:35 AM
Client Sample ID	1410829-005C / W4 CORRAL			**Sampling Time**	4:00 PM
Matrix	Water				
Comments					

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.59	10/31/2014	HSW	SM4500S2F	

Sample Number	141021021-006	**Sampling Date**	10/16/2014	**Date/Time Received**	10/21/2014 10:35 AM
Client Sample ID	1410829-006C / W5			**Sampling Time**	4:00 PM
Matrix	Water				
Comments					

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	0.510	mg/L	0.51	10/31/2014	HSW	SM4500S2F	

Sample Number	141021021-007	**Sampling Date**	10/16/2014	**Date/Time Received**	10/21/2014 10:35 AM
Client Sample ID	1410829-007C / W6			**Sampling Time**	4:00 PM
Matrix	Water				
Comments					

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.49	10/31/2014	HSW	SM4500S2F	

Sample Number	141021021-008	**Sampling Date**	10/16/2014	**Date/Time Received**	10/21/2014 10:35 AM
Client Sample ID	1410829-008C / TANK 3 MIDDLE			**Sampling Time**	4:00 PM
Matrix	Water				
Comments					

Parameter	Result	Units	PQL	Analysis Date	Analyst	Method	Qualifier
Sulfide	ND	mg/L	0.56	10/31/2014	HSW	SM4500S2F	

QC SUMMARY REPORT

'all Environmental Analysis Laboratory, Inc.

WO#: 1410829
03-Nov-14

Client: Sandia Natl. Labs
Project: Thirsty Cattle

Sample ID **MB** SampType: **MBLK** TestCode: **EPA Method 300.0: Anions**
Client ID: **PBW** Batch ID: **R21997** RunNo: **21997**
Prep Date: Analysis Date: **10/17/2014** SeqNo: **646536** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Chloride	ND	0.50								
Nitrogen, Nitrate (As N)	ND	0.10								
Phosphorus, Orthophosphate (As P	ND	0.50								

Sample ID **LCS** SampType: **LCS** TestCode: **EPA Method 300.0: Anions**
Client ID: **LCSW** Batch ID: **R21997** RunNo: **21997**
Prep Date: Analysis Date: **10/17/2014** SeqNo: **646537** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Chloride	4.6	0.50	5.000	0	92.3	90	110			
Nitrogen, Nitrate (As N)	2.4	0.10	2.500	0	96.8	90	110			
Phosphorus, Orthophosphate (As P	4.7	0.50	5.000	0	94.5	90	110			

Sample ID **MB** SampType: **MBLK** TestCode: **EPA Method 300.0: Anions**
Client ID: **PBW** Batch ID: **R21997** RunNo: **21997**
Prep Date: Analysis Date: **10/17/2014** SeqNo: **646591** Units: **mg/L**

nalyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Chloride	ND	0.50								
Nitrogen, Nitrate (As N)	ND	0.10								
Phosphorus, Orthophosphate (As P	ND	0.50								

Sample ID **LCS** SampType: **LCS** TestCode: **EPA Method 300.0: Anions**
Client ID: **LCSW** Batch ID: **R21997** RunNo: **21997**
Prep Date: Analysis Date: **10/17/2014** SeqNo: **646592** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Chloride	4.5	0.50	5.000	0	90.3	90	110			
Nitrogen, Nitrate (As N)	2.4	0.10	2.500	0	94.7	90	110			
Phosphorus, Orthophosphate (As P	4.7	0.50	5.000	0	93.1	90	110			

Sample ID **MB** SampType: **MBLK** TestCode: **EPA Method 300.0: Anions**
Client ID: **PBW** Batch ID: **R22092** RunNo: **22092**
Prep Date: Analysis Date: **10/22/2014** SeqNo: **649843** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Sulfate	ND	0.50								

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

QC SUMMARY REPORT

Hall Environmental Analysis Laboratory, Inc.

WO#: **1410829**

03-Nov-14

Client: Sandia Natl. Labs

Project: Thirsty Cattle

Sample ID **LCS**	SampType: **LCS**	TestCode: **EPA Method 300.0: Anions**	
Client ID: **LCSW**	Batch ID: **R22092**	RunNo: **22092**	
Prep Date:	Analysis Date: **10/22/2014**	SeqNo: **649844**	Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Sulfate	9.2	0.50	10.00	0	91.8	90	110			

Sample ID **MB**	SampType: **MBLK**	TestCode: **EPA Method 300.0: Anions**	
Client ID: **PBW**	Batch ID: **R22200**	RunNo: **22200**	
Prep Date:	Analysis Date: **10/28/2014**	SeqNo: **654010**	Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Sulfate	ND	0.50								

Sample ID **LCS**	SampType: **LCS**	TestCode: **EPA Method 300.0: Anions**	
Client ID: **LCSW**	Batch ID: **R22200**	RunNo: **22200**	
Prep Date:	Analysis Date: **10/28/2014**	SeqNo: **654011**	Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Sulfate	9.7	0.50	10.00	0	96.9	90	110			

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

QC SUMMARY REPORT

Hall Environmental Analysis Laboratory, Inc.

WO#: **1410829**

03-Nov-14

Client: Sandia Natl. Labs

Project: Thirsty Cattle

Sample ID **MB** SampType: **MBLK** TestCode: **EPA Method 6010B: Dissolved Metals**

Client ID: **PBW** Batch ID: **R22081** RunNo: **22081**

Prep Date: Analysis Date: **10/22/2014** SeqNo: **649469** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Calcium	ND	1.0								
Magnesium	ND	1.0								
Potassium	ND	1.0								
Sodium	ND	1.0								

Sample ID **LCS** SampType: **LCS** TestCode: **EPA Method 6010B: Dissolved Metals**

Client ID: **LCSW** Batch ID: **R22081** RunNo: **22081**

Prep Date: Analysis Date: **10/22/2014** SeqNo: **649470** Units: **mg/L**

Analyte	Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	%RPD	RPDLimit	Qual
Calcium	51	1.0	50.00	0	103	80	120			
Magnesium	52	1.0	50.00	0	104	80	120			
Potassium	51	1.0	50.00	0	101	80	120			
Sodium	51	1.0	50.00	0	103	80	120			

Qualifiers:

*	Value exceeds Maximum Contaminant Level.	B	Analyte detected in the associated Method Blank
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
O	RSD is greater than RSDlimit	P	Sample pH greater than 2.
R	RPD outside accepted recovery limits	RL	Reporting Detection Limit
S	Spike Recovery outside accepted recovery limits		

HALL ENVIRONMENTAL ANALYSIS LABORATORY

Hall Environmental Analysis Laboratory
4901 Hawkins NE
Albuquerque, NM 87109
TEL: 505-345-3975 FAX: 505-345-4107
Website: www.hallenvironmental.com

Sample Log-In Check List

Client Name: **Sandia Natl. Labs** Work Order Number: **1410829** RcptNo: **1**

Received by/date:	KMS	10/16/14	
Logged By:	**Ashley Gallegos**	**10/16/2014 5:08:00 PM**	
Completed By:	**Ashley Gallegos**	**10/17/2014 8:06:58 AM**	
Reviewed By:		10/17/14	

Chain of Custody

1. Custody seals intact on sample bottles? Yes ☐ No ☐ Not Present ☑
2. Is Chain of Custody complete? Yes ☑ No ☐ Not Present ☐
3. How was the sample delivered? Client

Log In

4. Was an attempt made to cool the samples? Yes ☐ No ☑ NA ☐

Samples were collected the same day.

5. Were all samples received at a temperature of >0° C to 6.0°C Yes ☐ No ☑ NA ☐

Samples were collected the same day.

6. Sample(s) in proper container(s)? Yes ☑ No ☐
7. Sufficient sample volume for indicated test(s)? Yes ☑ No ☐
8. Are samples (except VOA and ONG) properly preserved? Yes ☑ No ☐
9. Was preservative added to bottles? Yes ☐ No ☑ NA ☐
10. VOA vials have zero headspace? Yes ☐ No ☐ No VOA Vials ☑
11. Were any sample containers received broken? Yes ☐ No ☑
12. Does paperwork match bottle labels? Yes ☑ No ☐
    (Note discrepancies on chain of custody)
13. Are matrices correctly identified on Chain of Custody? Yes ☑ No ☐
14. Is it clear what analyses were requested? Yes ☑ No ☐
15. Were all holding times able to be met? Yes ☑ No ☐
    (If no, notify customer for authorization.)

# of preserved bottles checked for pH: 9, 9
(<2 or >12 unless noted)
Adjusted? NO
Checked by:

Special Handling (if applicable)

16. Was client notified of all discrepancies with this order? Yes ☐ No ☐ NA ☑

Person Notified: Date
By Whom: Via: ☐ eMail ☐ Phone ☐ Fax ☐ In Person
Regarding:
Client Instructions:

17. Additional remarks:

18. Cooler Information

Cooler No	Temp °C	Condition	Seal Intact	Seal No	Seal Date	Signed By
1	20.0	Good	Not Present			

Chain-of-Custody Record

Client: Brian Dwyer

SANDIA LABS

Mailing Address: 1515 E-bank, SE, Alb

bpdwyer@sandia.gov

Phone #: 505 - 845-9894

email or Fax#:

QA/QC Package:

☐ Standard ☐ Level 4 (Full Validation)

Accreditation

☐ NELAP ☐ Other

☐ EDD (Type)

Turn-Around Time:

☒ Standard ☐ Rush

Project Name: Thirsty Cattle

Project #:

Project Manager: Brian Dwyer

Sampler:

On Ice: ☐ Yes ☒ No

Sample Temperature: 20.0

HALL ENVIRONMENTAL ANALYSIS LABORATORY

www.hallenvironmental.com

4901 Hawkins NE - Albuquerque, NM 87109

Tel. 505-345-3975 Fax 505-345-4107

Date	Time	Matrix	Sample Request ID	Container Type and #	Preservative Type	HEAL No.
10/16/14	4pm	H2O	W3 1st trough	1	HNO3	HD829
↓	↓	↓	↓	1	H2SO4	-001
				1	zinc acetate	
			↓	1	none	
			~~Sacate~~ Tank 1A ~~input~~ inflow	1	HNO3	-002
			↓	1	H2SO4	
				1	zinc acetate	
			↓	1	~~H2SO4~~ none	
			Sa Cate tank 1B mid Tank	1	H2SO4	-003
			↓	1	none	
				1	HNO3	
			↓	1	zinc acetate	
↓	↓	↓				

Analysis Request

BTEX + MTBE + TMB's (8021)	BTEX + MTBE + TPH (Gas only)	TPH 8015B (GRO / DRO / MRO)	TPH (Method 418.1)	EDB (Method 504.1)	PAH's (8310 or 8270 SIMS)	RCRA 8 Metals	Anions (F, [✓ Cl], [✓ NO3], NO2, [✓ PO4], [✓ SO4])	8081 Pesticides / 8082 PCB's	8260B (VOA)	8270 (Semi-VOA)	Ca, Mg, Na, ~~A~~ K Diss	Hardness	Alk, pH, EC, TDS	Sulfide	Air Bubbles (Y or N)
							✓				✓	✓	✓	✓	

Date:	Time:	Relinquished by:	Received by:	Date	Time
10/16/14	5:08	Brian P Dwyer		10/16/14	5:08
Date:	Time:	Relinquished by:	Received by:	Date	Time

Remarks:

If necessary, samples submitted to Hall Environmental may be subcontracted to other accredited laboratories. This serves as notice of this possibility. Any sub-contracted data will be clearly notated on the analytical report.

Chain-of-Custody Record

Client: Brian Dwyer

Mailing Address:

Phone #: 505 - 845-9894

email or Fax#:

QA/QC Package:
☐ Standard ☐ Level 4 (Full Validation)

Accreditation
☐ NELAP ☐ Other

☐ EDD (Type)

Turn-Around Time:
☑ Standard ☐ Rush

Project Name: Thirsty Cattle

Project #:

Project Manager: Brian Dwyer

Sampler:

On Ice: ☐ Yes ☒ No

Sample Temperature: 20.0

HALL ENVIRONMENTAL ANALYSIS LABORATORY

www.hallenvironmental.com

4901 Hawkins NE - Albuquerque, NM 87109

Tel. 505-345-3975 Fax 505-345-4107

Date	Time	Matrix	Sample Request ID	Container Type and #	Preservative Type	HEAL No. 1410824
10/16/14	4pm	H_2O	Tank 2b middle		Zinc acetate	004
10/16/14	↓	↓	↓	1	H_2SO_4	↓
10/16/14				1	HNO_3	
10/16/14				1	NONE	
10/16/14						
10/16/14			W4 corral	1	Zinc acetate	-005
10/16/14			↓	1	H_2SO_4	↓
10/16/14				1	HNO_3	
10/16/14				1	None	
↓	↓		W5	1	none	-006
			W6	1	none	-007
			Tank 3 middle	1	none	-008
			Tank 1 inlet D	~~1~~ 2	none	-009

Analysis Request

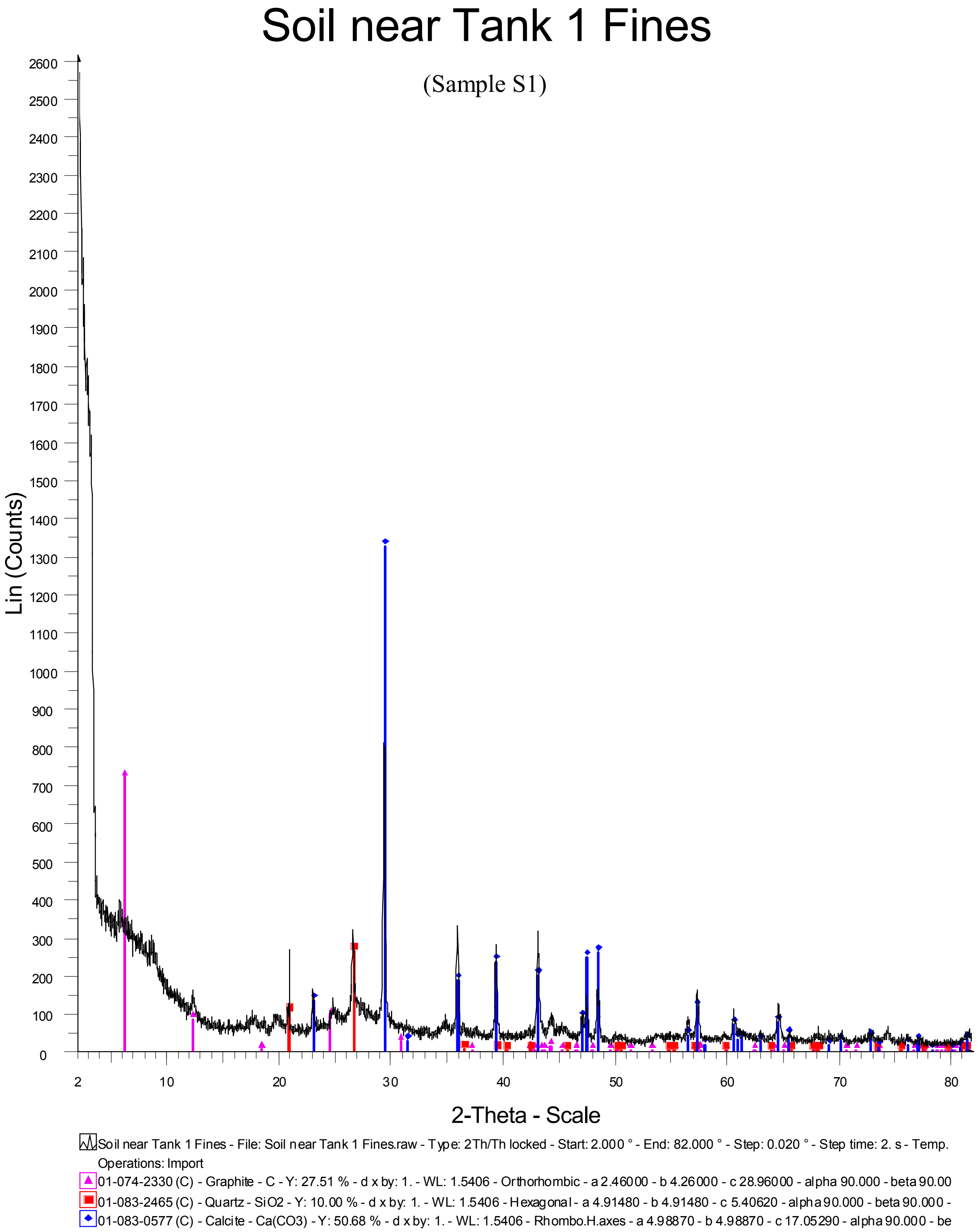
Sample Request ID	BTEX + MTBE + TMB's (8021)	BTEX + MTBE + TPH (Gas only)	TPH 8015B (GRO / DRO / MRO)	TPH (Method 418.1)	EDB (Method 504.1)	PAH's (8310 or 8270 SIMS)	RCRA 8 Metals	Anions (F, [✓ Cl], [✓ NO3], NO2, [✓ PO4], [✓ SO4])	8081 Pesticides / 8082 PCB's	8260B (VOA)	8270 (Semi-VOA)	Ca, Mg, Na, K, Diss	Hardness	Alk, pH, EC, TDS	Sulfide	Air Bubbles (Y or N)
Tank 2b middle								✓				✓	✓	✓	✓	
(following rows)								↓				↓	↓	↓	↓	

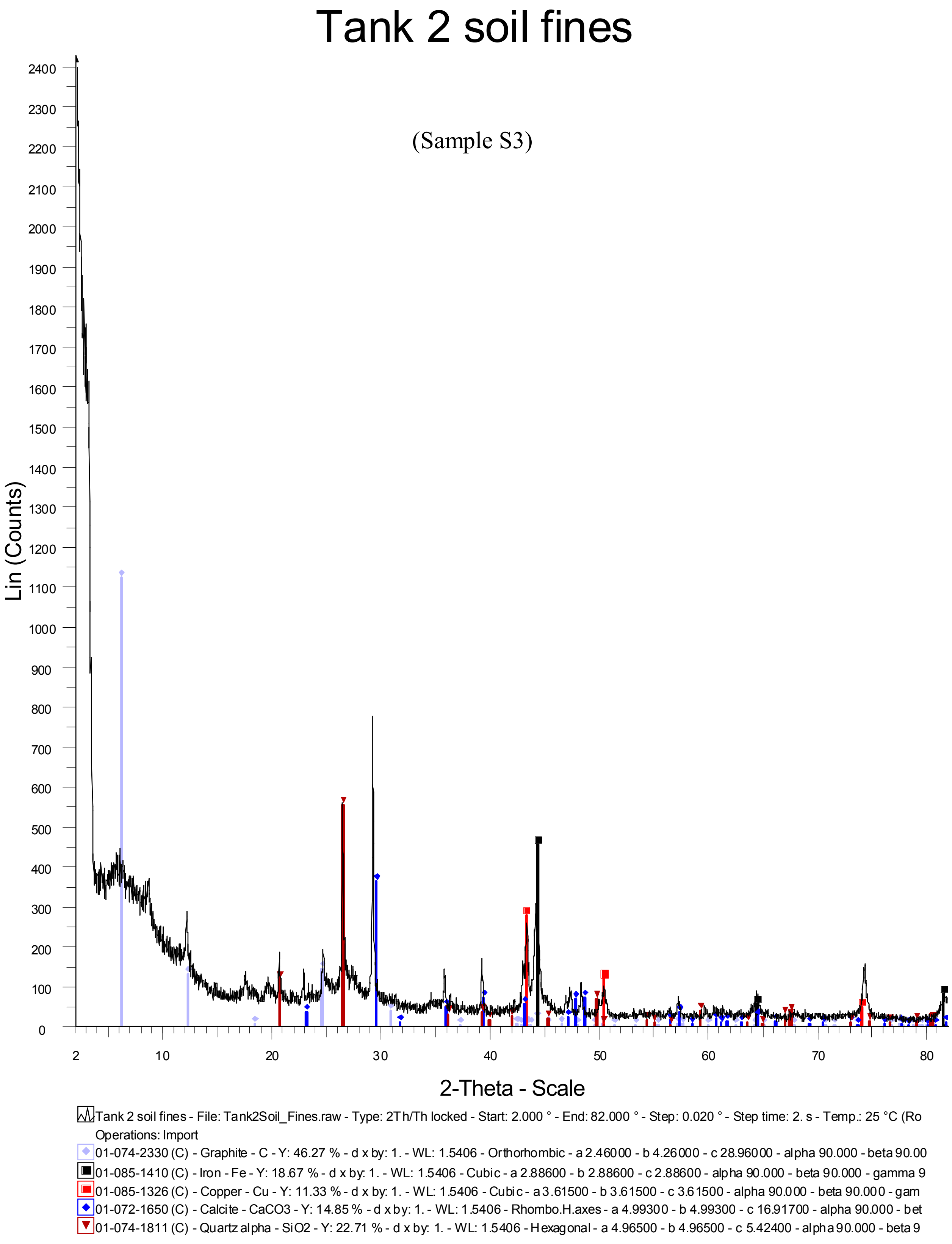
Date: 10/16/14	Time: 5:08	Relinquished by: Bri P. Dy	Received by:	Date 10/16/14	Time 5:08
Date:	Time:	Relinquished by:	Received by:	Date	Time

Remarks:

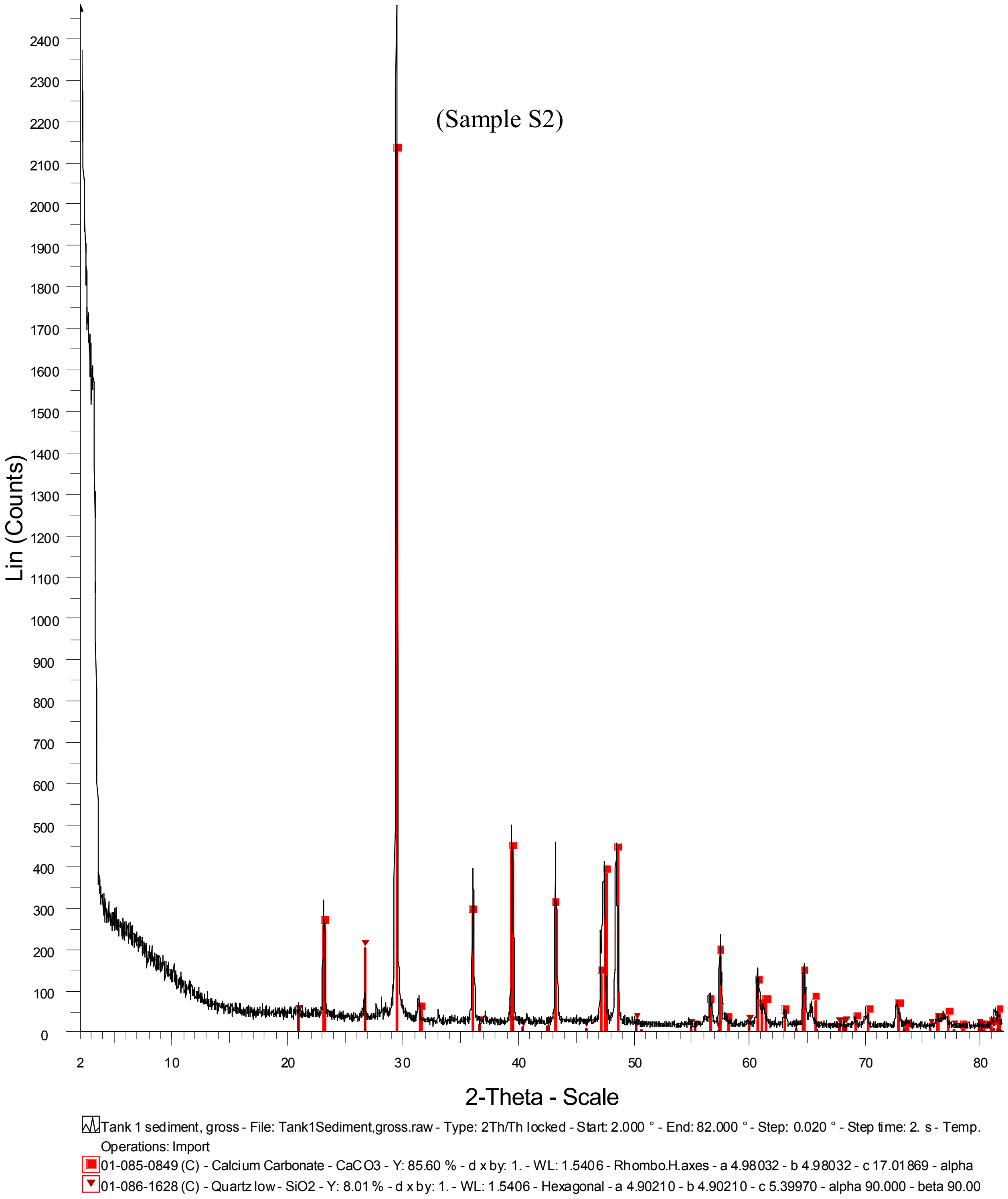
If necessary, samples submitted to Hall Environmental may be subcontracted to other accredited laboratories. This serves as notice of this possibility. Any sub-contracted data will be clearly notated on the analytical report.

Appendix C: X-RAY DIFFRACTION DATA

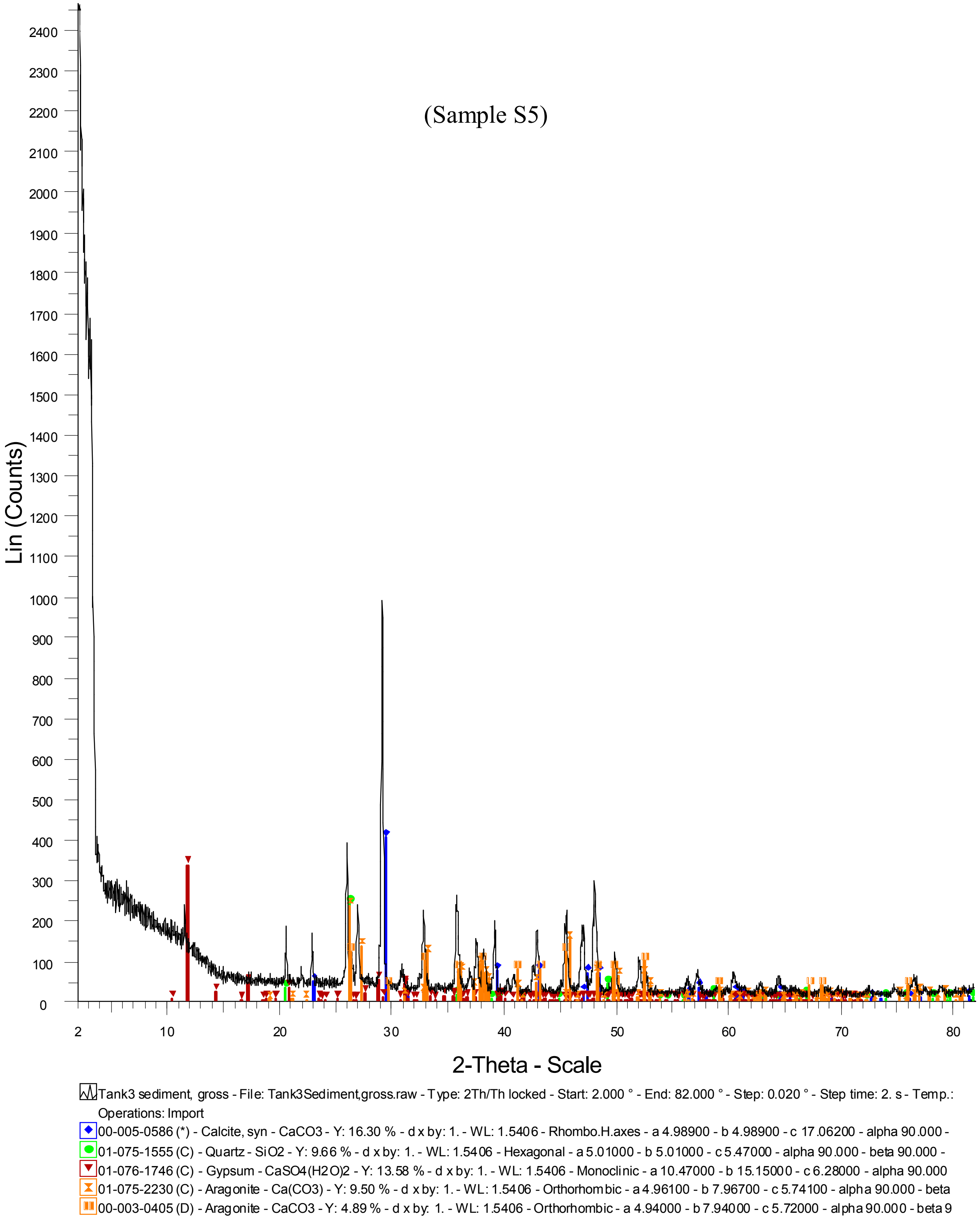



Tank 2 soil fines
(Sample S3)
Lin (Counts)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2
10
20
30
40
50
60
70
80
2-Theta - Scale
Tank 2 soil fines - File: Tank2Soil_Fines.raw - Type: 2Th/Th locked - Start: 2.000 ° - End: 82.000 ° - Step: 0.020 ° - Step time: 2. s - Temp.: 25 °C (Ro
Operations: Import
01-074-2330 (C) - Graphite - C - Y: 46.27 % - d x by: 1. - WL: 1.5406 - Orthorhombic - a 2.46000 - b 4.26000 - c 28.96000 - alpha 90.000 - beta 90.00
01-085-1410 (C) - Iron - Fe - Y: 18.67 % - d x by: 1. - WL: 1.5406 - Cubic - a 2.88600 - b 2.88600 - c 2.88600 - alpha 90.000 - beta 90.000 - gamma 9
01-085-1326 (C) - Copper - Cu - Y: 11.33 % - d x by: 1. - WL: 1.5406 - Cubic - a 3.61500 - b 3.61500 - c 3.61500 - alpha 90.000 - beta 90.000 - gam
01-072-1650 (C) - Calcite - CaCO3 - Y: 14.85 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99300 - b 4.99300 - c 16.91700 - alpha 90.000 - bet
01-074-1811 (C) - Quartz alpha - SiO2 - Y: 22.71 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.96500 - b 4.96500 - c 5.42400 - alpha 90.000 - beta 9

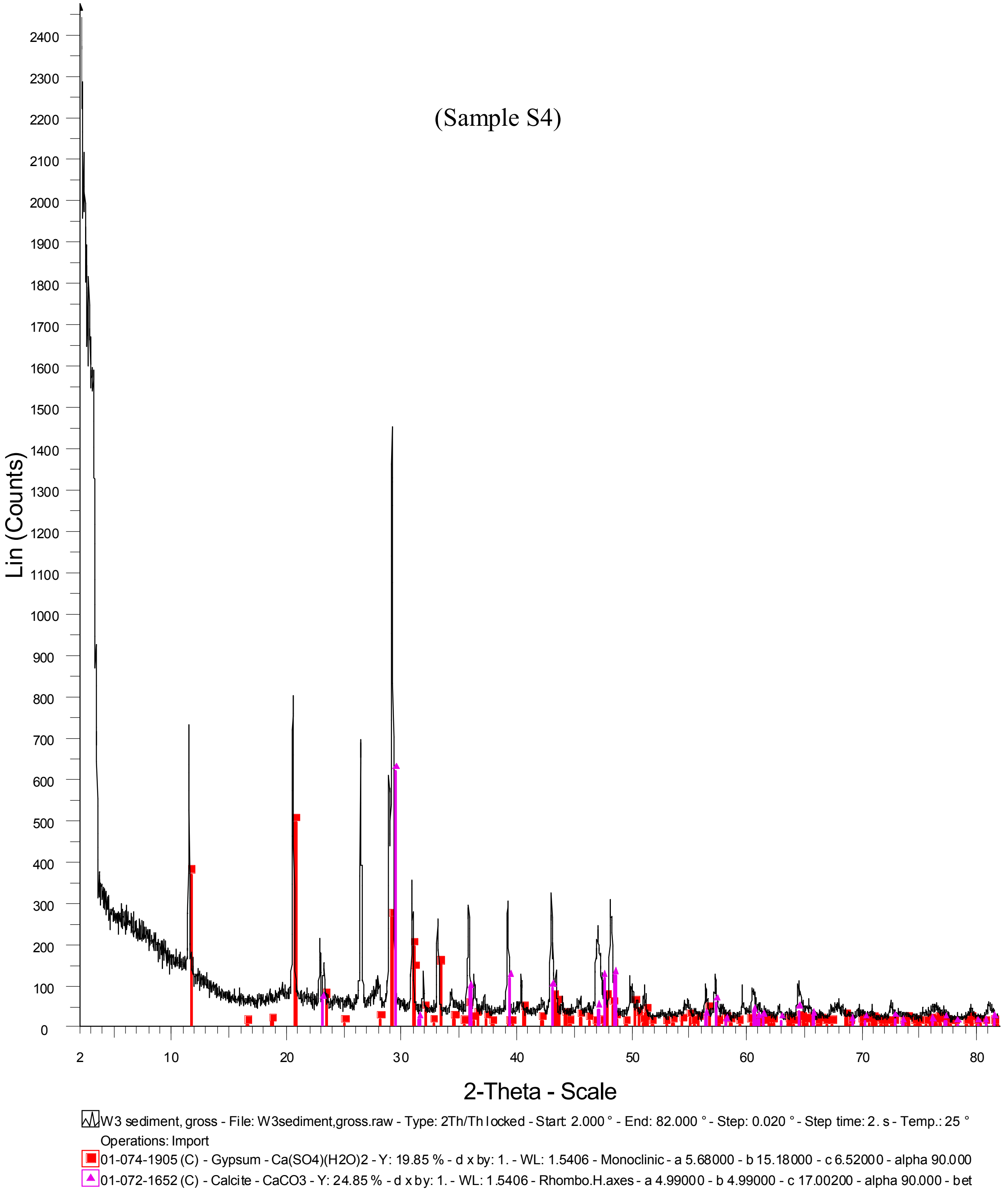
Tank 1 sediment, gross



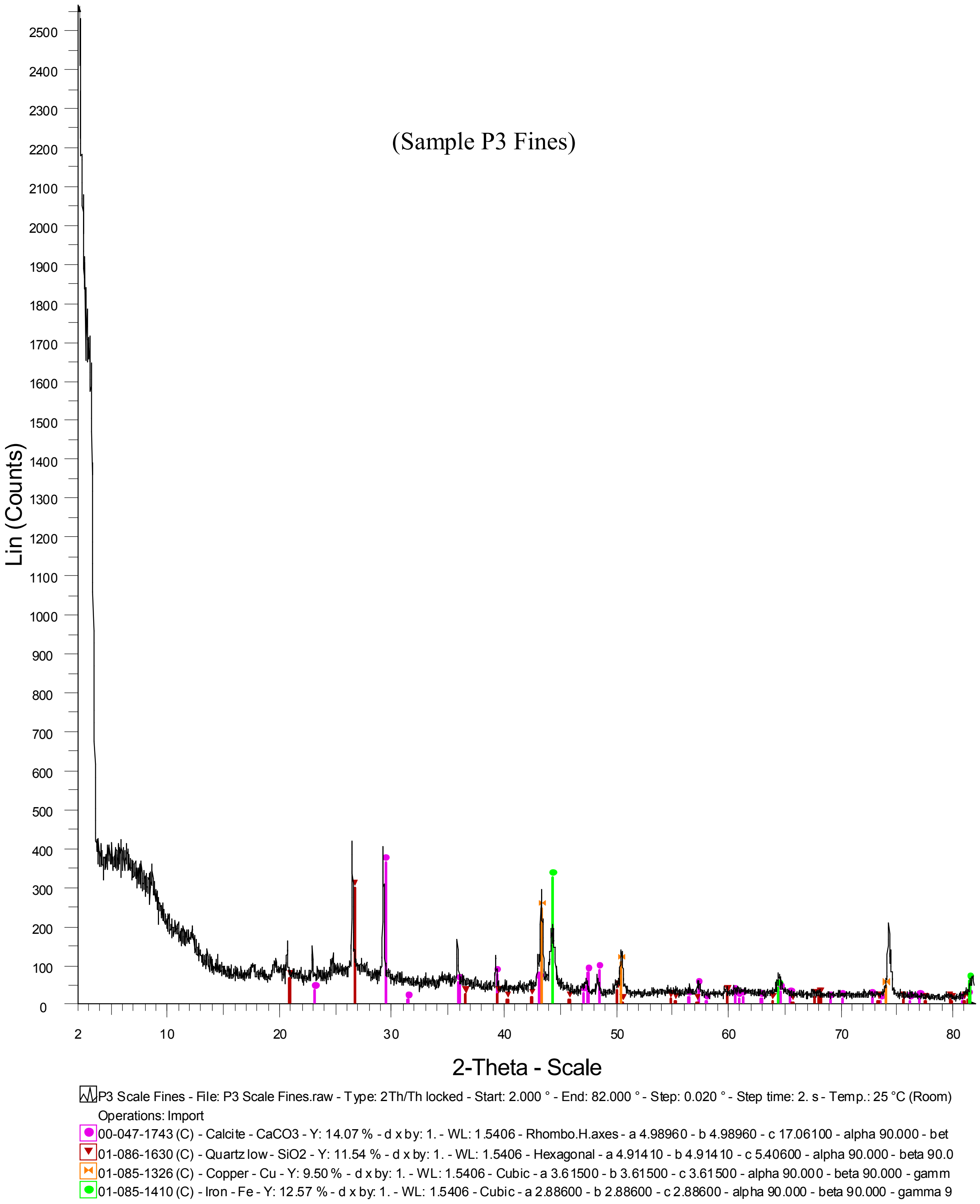
Tank3 sediment, gross

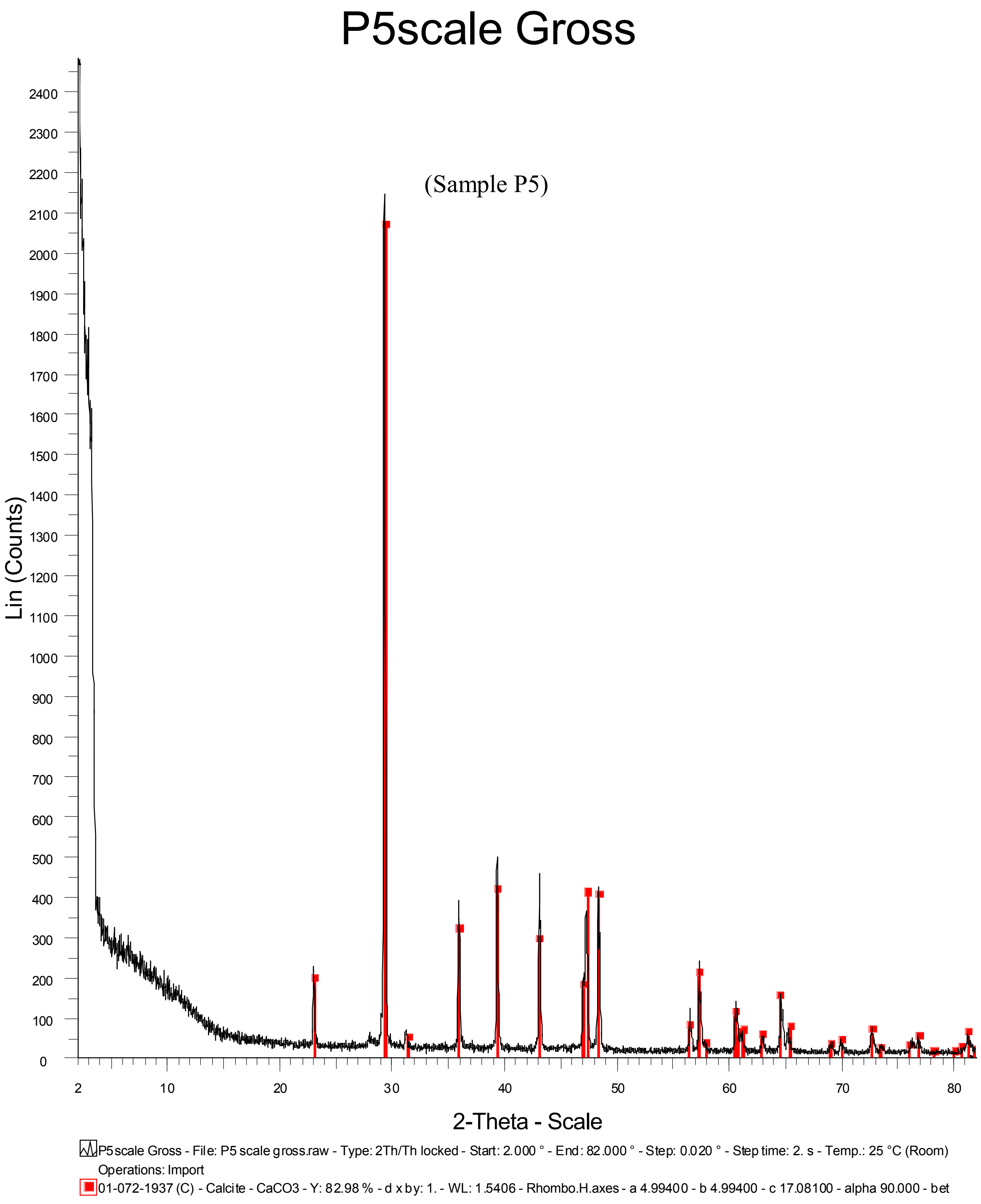


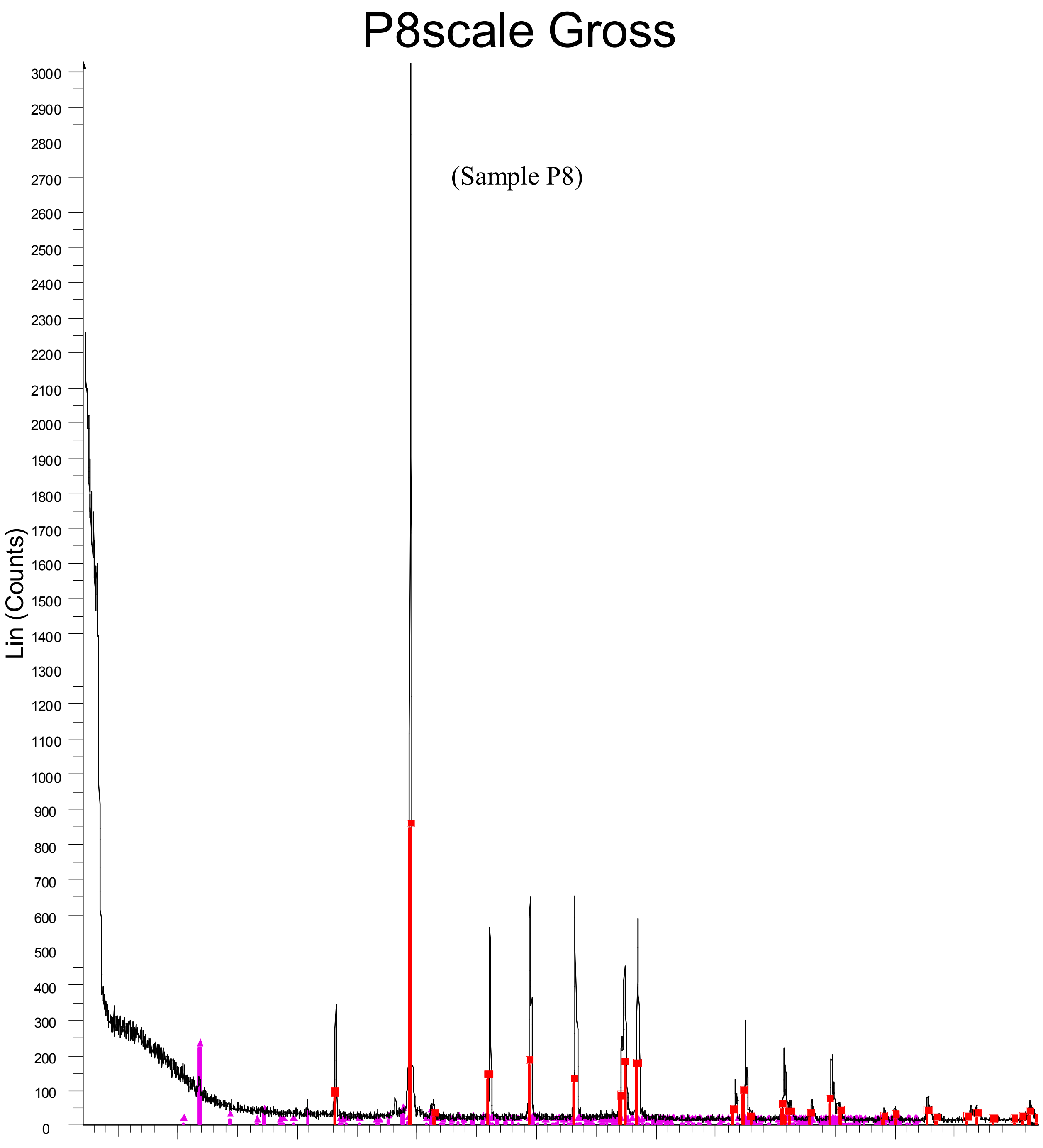
W3 sediment, gross



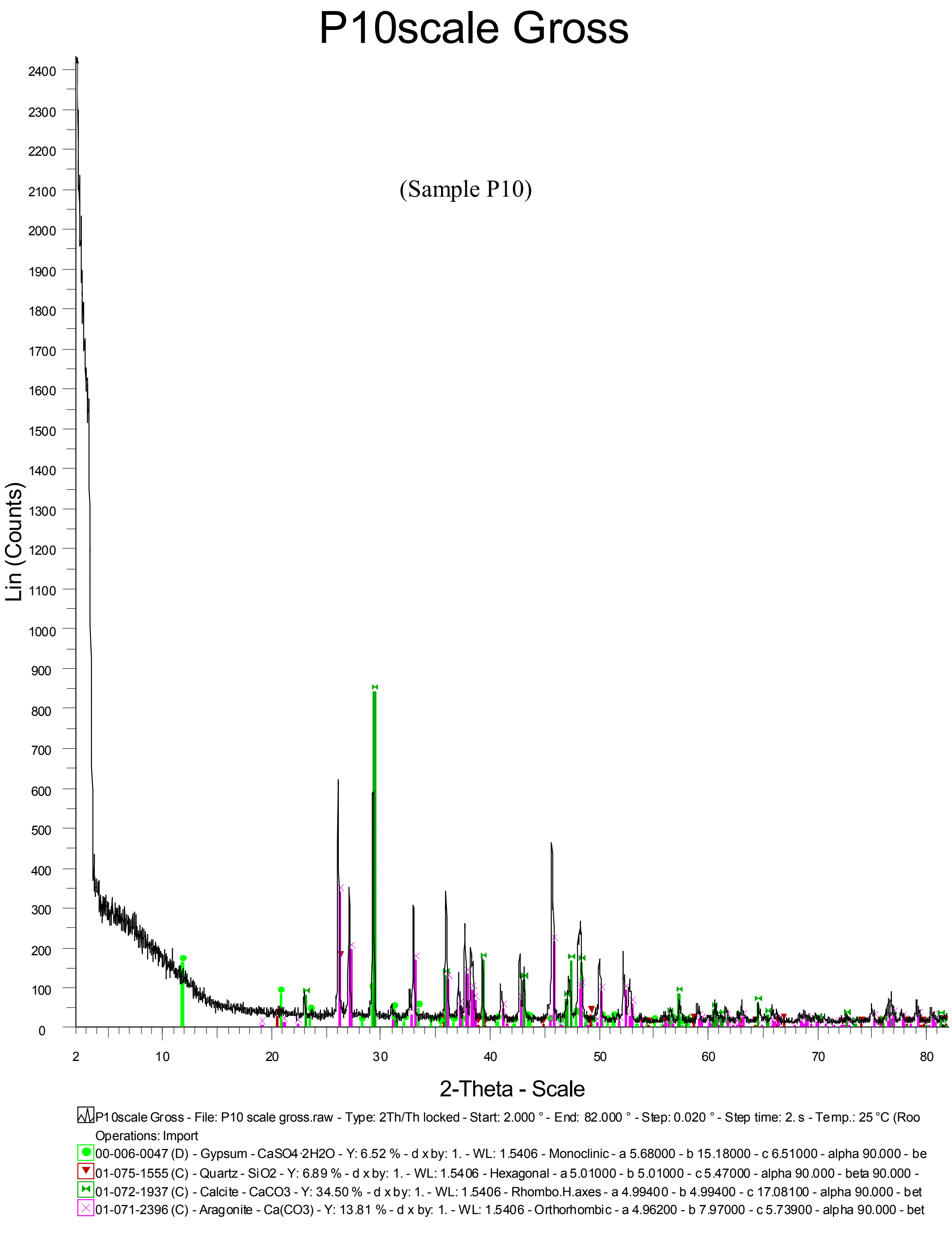
P3 Scale Fines




P5scale Gross
(Sample P5)
Lin (Counts)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2
10
20
30
40
50
60
70
80
2-Theta - Scale
P5scale Gross - File: P5 scale gross.raw - Type: 2Th/Th locked - Start: 2.000 ° - End: 82.000 ° - Step: 0.020 ° - Step time: 2. s - Temp.: 25 °C (Room)
Operations: Import
01-072-1937 (C) - Calcite - CaCO3 - Y: 82.98 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99400 - b 4.99400 - c 17.08100 - alpha 90.000 - bet



P8scale Gross - File: P8 scale gross.raw - Type: 2Th/Th locked - Start: 2.000 ° - End: 82.000 ° - Step: 0.020 ° - Step time: 2. s - Temp.: 25 °C (Room)
Operations: Import
🟥 01-072-1937 (C) - Calcite - $CaCO_3$ - Y: 27.88 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99400 - b 4.99400 - c 17.08100 - alpha 90.000 - bet
▲ 01-076-1746 (C) - Gypsum - $CaSO_4(H_2O)_2$ - Y: 7.18 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 10.47000 - b 15.15000 - c 6.28000 - alpha 90.000 -


P10scale Gross
(Sample P10)
Lin (Counts)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2
10
20
30
40
50
60
70
80
2-Theta - Scale
P10scale Gross - File: P10 scale gross.raw - Type: 2Th/Th locked - Start: 2.000 ° - End: 82.000 ° - Step: 0.020 ° - Step time: 2. s - Temp.: 25 °C (Roo
Operations: Import
● 00-006-0047 (D) - Gypsum - CaSO4·2H2O - Y: 6.52 % - d x by: 1. - WL: 1.5406 - Monoclinic - a 5.68000 - b 15.18000 - c 6.51000 - alpha 90.000 - be
▼ 01-075-1555 (C) - Quartz - SiO2 - Y: 6.89 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 5.01000 - b 5.01000 - c 5.47000 - alpha 90.000 - beta 90.000 -
⧓ 01-072-1937 (C) - Calcite - CaCO3 - Y: 34.50 % - d x by: 1. - WL: 1.5406 - Rhombo.H.axes - a 4.99400 - b 4.99400 - c 17.08100 - alpha 90.000 - bet
× 01-071-2396 (C) - Aragonite - Ca(CO3) - Y: 13.81 % - d x by: 1. - WL: 1.5406 - Orthorhombic - a 4.96200 - b 7.97000 - c 5.73900 - alpha 90.000 - bet

Appendix C: VENDOR INFORMATION

Several water treatment companies were contacted regarding a proposed solution to the water treatment issues at the Hightower & Shafer Ranches. Below is a list of the vendors followed by their recommendation:

- ResinTech

  Francis DeSilva
  National Sales Manager
  Los Angeles, CA
  Cell: (760) 809-4864
  LA Office: (323) 262-1600
  Fax: (323) 262-1615
  fdesilva@resintech.com

  Resin Tech is primarily offers IX water treatment and has stated that RO or NF would be more appropriate.

- Purolite

  Francis Boodoo
  Director of Applied Technologies
  150 Monument Road
  Bala Cynwyd, PA 19004
  T +1 800.343.1500
  T +1 610.668.9090
  F +1 610.668.8139
  M +1 610.203.1673
  francis.boodoo@purolite.com
  www.purolite.com

  Purolite primarily offers IX water treatment and has stated that RO or NF would be more appropriate.

- Safe Water Technologies

  Dale Nordick
  Safe Water Technologies, Inc.
  996 Bluff City Blvd.
  Elgin, IL 60120
  Ph: 847-888-6900
  Fax: 847-888-6924
  Email: info@swtwater.com
  web: www.swtwater.com

  Safe Water Technologies offers membrane and IX water treatment solutions. They have expressed concern about the high iron levels and do not have a proposed solution.

- Western Environmental Management, Inc.

  Scott Bierle, President
  (575) 885-5709
  scott_bierle@wemwater.com

  Scott Bierle has stated that RO would work well with water recovery rates in the 70-80% range; however, he feels that the iron has to be removed as a pre-treatment step. They have no economically viable solution for iron removal at this time.

Appendix E: GRANULAR MEDIA FILTER DESIGN

Objective

At the Shafer Ranch calcite (calcium carbonate) precipitates in the pipes when the velocity slows due to a pressure drop. This is evident because of the locations of plugged piping. In order to take advantage of this phenomenon, a filter design is presented here to provide controlled removal of calcium carbonate; thereby, protecting downstream piping. The filter should be installed immediately after the holding tanks, therefore removing scale prior to water entering the distribution system.

The purpose of these calculations is to provide design guidance for the installation of a filter (mineral precipitation zone) to remove calcium carbonate from well water prior to distribution. In our calculations below we used the current rates of calcite precipitation observed in the pipes (1/4” PVC pipe is sealed by calcite scale in 6 months period).

Granular media filtration theory

Granular media filtration is the most common type of filter process used for particulate removal from water. A granular filter consists of a bed of porous material or materials contained in a vessel. Often the vessel is designed to allow for backwashing to remove the captured solids; however, in this instance the objective is to remove particulates passively. Consequently, when the filter plugs the media will be removed and replaced. This will be initiated by unacceptable flow (due to increased head loss across the media). The proposed system is passive, i.e., water flow by gravity. Figure 5 below shows the general location of the proposed water treatment filter vessel.

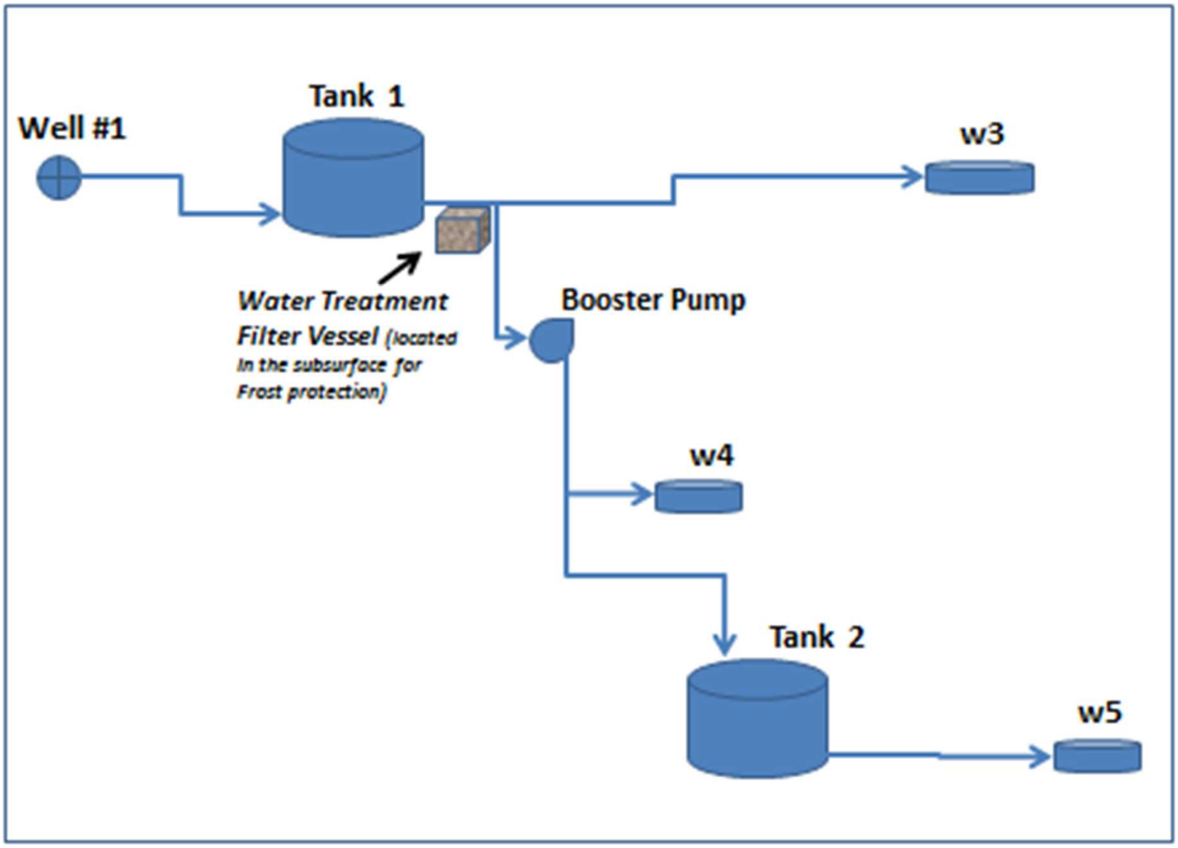


Figure 5 Proposed location of Water Treatment Filter Vessel.

Filter design/hydraulic flow calculations

Design Parameters

1. EBCT (empty bed contact time)
2. Hcr (critical bed depth)
    a. A critical depth (Hcr) of media and a corresponding minimum EBCT must be exceeded to ensure the MTZ (mass transfer zone) is large enough to eliminate immediate breakthrough
    b. Increase EBCT results in increase in Bed Life (service time), correspondingly the MUR (media usage rate) will decrease to a minimum value. Bed life and MUR must be simultaneously considered to optimize capital costs and maintenance costs (bed replacement frequency)
3. HLR (hydraulic loading rate), gpm/ft^2
4. Backwashing - not possible with our filter configuration
    a. System operates via gravity, i.e., passive operation

Design Assumptions

1. Well flow characteristics
2. Media Hydraulic conductivity (Ks) in filter vessel is TBD (cm/sec).

Methodology

Using Darcy's Law to calculate the cross sectional flowrate.

Darcy's Law: Q=Ks i A, where
Q = flowrate (cu. Ft./sec),
Ks = hydraulic conductivity (cm/sec),
i = hydraulic gradient (ft./ft.), and
A = filter vessel cross sectional area (ft^2)

(Freeze, 1979)

3. Filter will be located just down-gradient of Tank 1.
4. Filter will not have Regeneration or Backwash capability; instead the media will be replaced when spent (unacceptable pressure drop across filter bed).
5. $CaCO_3$ precipitation (deposition) rate = 0.97 g/gal.
6. Kinetic removal rate of calcium carbonate $CaCO_3$ TBD (must remove of 100% of $CaCO_3$ from water @ 0.97 g/gal exiting Tank 1 @ Q = 2 gpm).
7. Precipitation kinetic rates are not system flow rate limiting
8. Assume Q = 2.0 gpm
9. Hydraulic head (pressure head)
   Use 6 feet = 6 ft. (0.433 psi/ft.) = 2.6 psi
10. Media filtration capacity TBD
11. Filter media will consist of pumice, pea gravel or other. Final choice TBD upon conceptual design acceptance. **.
12. The primary filter removal mechanisms for $CaCO_3$ are (1) straining; and (2) sedimentation.
13. Assume HLR = 4 gpm/ft^2
14. If a multi-media filter is chosen, design will minimize intermixing of filter layers.
15. The head loss of the granular media filter is governed by three equations: (1) a macroscopic mass balance; (2) the kinetics of particulate removal; and (3) a general expression for increase of head loss across the media with time and accumulation of solids.
16. Density of $CaCO_3$ is 2.5 g/cc
17. $CaCO_3$ particle size is 0.1-50 *u*m, rounded in shape
18. Volume of $CaCO_3$ precipitate is estimated based 100% removal of 0.97 g/gal at Q = 2 gpm.
19. Media intial porosity (*n*) = 0.7
20. Media spent porosity (*n*) = 0.35

Estimate Filter Bed Loading Rate and Bed Life (Z)

Calculate

1. Filter vessel volume (V), ft^3

Precipitation rate = (0.97 g $CaCO_3$/gal) (2 gal/min) = 1.94 g $CaCO_3$/min

Filter Design Duration (time between media change-outs) = 6 months = 259,200 min.
1.94 g $CaCO_3$(259,200 min) = 502848 g $CaCO_3$

Assume filter volume initial = 0.7, final (when media is spent based on loss of flow) = 0.35, then precipitate volume = 0.35 of total vessel volume

p $CaCO_3$ = 2.5 g/cc

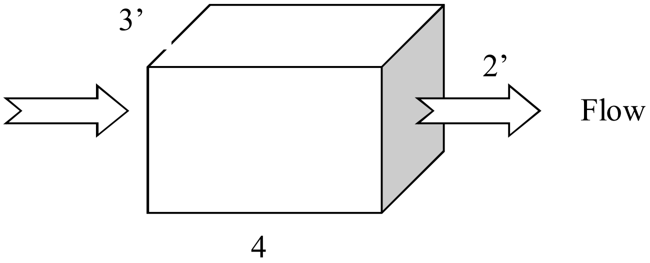
502,848 g $CaCO_3$ / 2.5 g/cc = 201139 cc (0.000035315 ft^3/cc) = 7.1032 ft^3

Size vessel

7.1032 ft^3/0.35 = 20.3 ft^3

Use: [L x W x H] of 4' x 3' 2'= 24 ft^3
Provides Factor of Safety (F.S.) = 24/20.3 = 1.2

Vessel dimensions are 4'x3'x2'= 24 ft^3



Vessel will have 2 internal baffles to minimize channeling and maximize residence time.

2. Check HLR
   HLR = Q/A = 2 gal/min (4'x3') = 0.167 gpm/ft^2 << 4 gpm/ft^2 OK√

3. Determine EBCT, for HLR = 0.167 gpm/ft^2
EBCT = V/Q = 24 ft^3/[(0.167 gal/min)(1 ft^3/7.48 gal)] = 1075 min = 17.9 hours

Check water flow velocity
v = Q/A = 0.167 gpm/ft^2 (1 ft^3/7.48 gal) = 0.0223 ft/sec.

Table 13 Shafer Ranch water flow rates.

SHAFER RANCH		
	Well #1	Well #2 (Belio)
Water Flowrate (gpm)	1.12 – 1.85	1.04 – 2.22
Design Flowrate (gpm)	2	2
Water Velocity (ft./sec)	0.29 – 0.49	0.27 – 0.59

.

Table 14 Shafer Ranch - Water Distribution System Flowrates

	Cross Section Area – A (ft^2)	Q (ft^3/day)	Q (gal/day)	* Q (gpm)	Velocity (ft.sec)	HLR (gpm/ft^2)
Well # 1 Original (1-1/4" PVC pipe)	0.00852 0.0100694 ft^2	0.25	2667	1.85	0.49	N/A
Well # 2 Original (1-1/4" PVC pipe)	0.00852	0.214	3200	2.22	0.59	N/A
Well #1 Filter Vessel	TBD	0.25	2667	1.85	TBD	TBD
Well #2 Filter Vessel	TBD	0.214 0.77 9.2	3200 70	2.22 0.05	TBD 2 0.1	TBD

*Used highest average 3 month flow rates for Well 1 & Well 2

Treatment media calculations

Table 15 includes the Design Basis for contaminants

.

Table 15 Design basis Ca^+ and CO_3^{2-} concentrations

Concentration (mg/L as $CaCO_3$))	Ca^+	CO_3^{2-}
Max.	620	440
Target Levels **	300	**

**CO_3 is buffered by the dissolution of carbon dioxide from the atmosphere so target is not relevant

In order to calculate the required volume of treatment media, the minimum required residence time to remove the Ca^+ to below the target level must be estimated.

Table 16 Contaminant removal residence time.

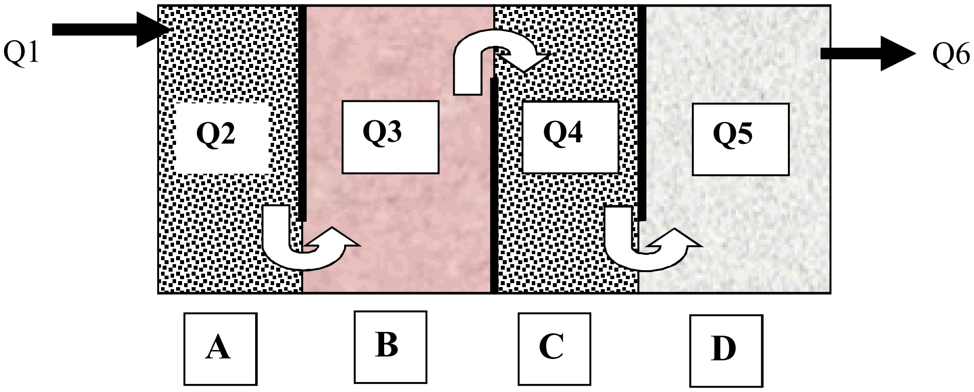
Contaminant	Max. Expected Conc. (mg/L as $CaCO_3$)	Treatment Goal (mg/L as $CaCO_3$)	Min. Residence Time (Tr), (hrs)	Factor of Safety (F.S.)	Design Residence Time - Tr (hrs.)
Ca	640	300		2	

Treatment media volume calculations

Assumptions

1. Gradient =
2. Saturated media cross sectional area (A) =
3. Flowrate (Q) across area (A) = 2.0 gpm

4. For conservation of flow – Q1 = Q2= Q3= Q4= Q5 = Q6



5. Proposed treatment media Hydraulic Conductivities (Ks). Each media zone is divided by internal baffles within a single treatment vessel, and is arranged in series as ordered below.

Zone	Order	Media	Ks (ft./day)
A	1		
B	2	3/8" pea gravel	250
C	3	3/8" pea gravel	250
D	4		

Solution

V = EBCT (Q) where EBCT (empty bed contact time) = Tr (residence time)
V = media volume

Calculation:
The cross sectional area of each zone will be the same. If multiple media are used - the volume (thickness) may vary; therefore, the lowest (slowest) Ks material dictates minimum cross section area A.

APPENDIX F: ESTIMATE FOR TANK COVER

Fabricate custom cattle tank cover with 30’ diameter, pricing does not include installation or NMgrt:

Since 1947
RADER
AWNING

Jill Mowery Litt
ALBUQUERQUE
4100 S. Paseo Del Norte Frtg. Rd. NE
Albuquerque, NM 87113
505.856.2000, 1.800.656.4523
Fax: 505.856.2002
jill@raderawning.com

18 oz Vinyl Coated Plastic - $2650.00
Ferrari 502 (8 year warranty) – $6010.00

REFERENCES

1. Committee on Water Quality Criteria, E.S.B., *Water Quality Criteria 1972*, 1972: Washington D.C.
2. Lardy, G., C. Stoltenow, and R. Johnson, *Livestock and Water*, 2008, NDSU Extension Service, North Dakota State University, Fargo, North Dakota 58105.
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