Comparative Operating Costs of Conventional Water Treatment versus Whole-House Reverse Osmosis

By Gary Battenberg

Introduction

The purpose of this comparative study is to find and recommend the best treatment process for this challenge water based on the laboratory results of the water sample collected from well # 15 of Diamond Tail Estates in Placitas, NM. Because of the geologic and geographic variability of the aquifers, a complete water analysis is the first step in determining with certainty the treatability of this water supply. From the perspectives of chemistry, available daily volume and maximum recovery of useable water, the goal is to minimize the waste stream in converting this water to a suitable quality for domestic household use. Two options will be evaluated for treating this challenge water and estimating the operating costs with regard to consumables, water usage and power consumption. The numbers are conservative due to the higher levels of TDS in the raw water. Above a certain level, the available capacity through a resin bed is diminished. This information is provided in the resin manufacturers application bulletins.

Results

The laboratory report in Figure 1 indicates the parameters that were tested pursuant to the New Mexico Environment Department/Drinking Water Bureau (NMED/DWB) requirements, and include the reporting standards. Constituents that comprise the primary indicators of concern for our comparative operating costs for the two treatment options are total dissolved solids (1,900); sulfate (1,200) and hardness (1,200 or 70 grains per gallon).

Interpretation

The three constituents are problematic in this regard because of the negative effects they have on the overall performance of a conventional water treatment system. They exceed the US EPA maximum contaminant level (MCL) for drinking water standards. Let's look at each constituent.

First, TDS at 1,900 mg/L is unsuitable for domestic use and is considered non-potable. The level indicates the total weight of the solids that are dissolved in a given volume of water: in this case,

Figure 1. Laboratory report from study installation site

		NMED/DWB
Date collected	**Dec. 3, 2008**	**MCL**
Parameters	**Concentration, mg/L**	
pH	7.53	6.5 - 8.5[a]
Total dissolved solids	**1,900**	**500**[a]
Alkalinity as $CaCO_3$	240	ns
Chloride	12	250[a]
Fluoride	0.44	2.0[a]
Nitrate-N	0.18	10.0
Nitrite-N	< 0.10	1.0
sulfate	**1,200**	**250**[a]
Aluminum	< 0.10	0.05 - 0.2[a]
Antimony	< 0.0010	0.006
Arsenic, dissolved	0.0020	0.01
Arsenic, total	< 0.0010	0.01
Barium	0.016	2.0
Beryllium	< 0.0020	0.004
Cadmium	< 0.0050	0.005
Calcium	320	ns
Chromium	< 0.010	0.1
Copper	< 0.020	1.0[a]
Iron	< 0.10	0.3[a]
Lead	< 0.0050	0.015
Magnesium	130	ns
Manganese	< 0.010	0.05[a]
Mercury	< 0.00020	0.002
Nickel	< 0.020	0.1
Selenium	< 0.0010	0.05
Silver	< 0.010	0.1[a]
Sodium	74	ns
Thallium	< 0.0010	0.002
Zinc	< 0.030	5.0[a]
Odor	no odor	ns
Cyanide, total	< 0.0050	0.2
Hardness	**1,200**	**ns**
Color	no color	15 cu[a]
Turbidity	no turbidity	ns
Surfactants/foaming agents	< 0.03	ns

a = secondary aesthetic standard (non-enforceable guideline)
Concentrations in bold meet or exceed the NMED/DWB, EPA standards, or aesthetic standards.
pH measurements in standard units.
Turbidity measured in nephelometric turbidity units.
Color reported as alpha color units.
Metals reported as total concentrations.
ns = no standard
NMED/DWB = New Mexico Environment Department/Drinking Water Bureau
MCL = maximum contaminant level

one liter in volume. Levels above 1,000 mg/L are considered brackish and impart a somewhat salty, distasteful quality. The US EPA secondary limit for TDS in drinking water is 500 mg/L. Levels above this amount may contain extreme levels of other contaminants that would impart undesirable tastes and odors to the water, prompting homeowners to buy bottled water or other alternative beverages.

Secondly, the sulfate level is 1,200 mg/L, which exceeds a US EPA primary drinking water standard of 500 mg/L, and a secondary drinking water standard of 250 mg/L. Sulfate in concentration greater than 250 mg/L may have a laxative effect on those not accustomed to sulfate above 500 mg/L; 1,200 mg/L would have an extreme cathartic affect on the bowels, not unlike taking a large dose of a commercial laxative.

Finally, the hardness of the water is 1,200 mg/L or 70 grains per gallon. The term 'hard water' originates with the early pioneers who settled in the west and applied the term to waters that made laundering and cleaning chores difficult. Some water supplies contained so much calcium and magnesium that soap would not lather, so the term hard water was coined and has been the term used in the water treatment industry to describe difficult-to-use water.

Figure 2.
WQA/ASAE hardness standard

Term	grains/ gallon	mg/liter (ppm)
Soft	< 1.0	< 17.1
Slightly hard	1.0 – 3.5	17.1 – 60
Moderately hard	3.5 – 7.0	60 – 120
Hard	7.0 – 10.5	120 – 180
Very hard	10.5+	180+

Option 1

The degree of hardness standard was established by the American Society of Agricultural Engineers and the Water Quality Association (see Figure 2). At 70 grains per gallon of hardness, it is no exaggeration to say that this water would be extremely hard to work with. Although it can be softened, the cost to operate a softener would be prohibitive, especially when the cost to remove the sulfates is factored in. Water softening is the removal of calcium and magnesium (exchangeable cations) with a cation exchange resin regenerated with common salt (sodium chloride). The resin replaces the calcium and magnesium (the hardness minerals) with sodium.

Study example

This challenge water contains 1,200 mg/L of hardness. To convert this measurement to grains per gallon, divide 1,200 by 17.1 and the result is 70 grains per gallon. The sodium content of the challenge water supply is 74 mg/L. To find the additional amount of sodium that will be added to the water, multiply the grains per gallon of hardness by 7.86 and the result of the softening process will add an additional 550 milligrams of sodium per liter of water. Therefore, the total sodium in the softened water will be 624 mg/L (74 + 550). Because of this additional sodium, it will be necessary to convert it to total dissolved solids (TDS). To adjust the TDS, multiply the total sodium of 624 mg/L by 0.64: this yields the equivalent in TDS of 400 mg/L. Added to the challenge water, the adjusted TDS is now 2,300 mg/L (see study example).

After the water is softened, the sulfate, nitrate and alkalinity (exchangeable anions) can be reduced with a chloride anion dealkalizer. A dealkalizer works much the same as the softener, in that it is regenerated with common salt (sodium chloride) and converts the exchangeable anions to chloride using anion resin. To find the total additional chloride that will be contributed to the treated water after reducing the exchangeable anions, a multiplier is used to convert the anions to their calcium carbonate equivalent.

Sulfate...........1,200 mg/L x 1.04 = 1,248
Nitrate ....18 mg/L x 3.57 = 0.64
Alkalinity ....240 mg/L x 1.0 = 240
Naturally occurring chloride................ 12
Total adjusted chloride 1,500.64

Figure 3. Water usage summaries

Summary of estimated indoor water demand for domestic residence*

Item	Assumptions	Water demand estimate, GPCD	Water demand estimate, gal/day	Water demand estimate, ac-ft/yr
Toilets	1.6 gal/flush x 6 flush/capita day	9.6	25.9	0.03
Toilet leakage	0.17 x 24 gal/capita day	4.1	11.1	0.01
Showers	2.5 gpm x 4.8 minutes	12.0	32.4	0.04
Faucets	estimated	9.0	24.3	0.03
Dishwasher	7 gal/load x 0.17 load/capita day	1.2	3.2	0.004
Washing machine	43 gal/load x 0.30 load/capita day	12.9	34.8	0.04
Water softening	estimated	5.0	13.5	0.02
Drinking water treatment	estimated	1.0	2.7	0.003
Subtotal without evaporative cooling		54.8	148.0	0.17
Evaporative cooling	Based on Wilson, *et al.*, 2003 maximum estimate of 25 gpcd	20	54	0.06
Subtotal with evaporative cooling		74.8	202	0.23

Source: Wilson, *et al.*, 2003
gal/load = gallons per load; gal/flush = gallons per flush; ac-ft/yr = acre feet per year; gpcd = gallons per capita day; gpm = gallons per minute; gal/day = gallons per day
*Assuming an occupancy rate per dwelling of 2.7 with water conserving plumbing fixtures and appliances, Diamond Tail Subdivision, Southern Sandoval County, New Mexico

Summary of estimated outdoor water demand for a domestic residence*

Item	Water method	Area, ft^2	Water demand estimate, $gal/ft^2/yr$	Water demand estimate, ac-ft/yr
Turf grass area	sprinkler	300	32.71	0.04
Tree and shrub area	drip	300	14.22	0.013
Total irrigation requirement estimate				0.053

Source: Wilson, 1996
ft^2 = square feet; $gal/ft^2/yr$ = gallons per square foot per year; ac-ft/yr = acre feet per year
*Assuming sprinkler irrigation for turf grass and drip irrigation for trees and shrubs in the Diamond Tail Subdivision, Southern Sandoval County, New Mexico

Using the same formula to determine the final total dissolved solids the final adjusted TDS from the chloride contribution is 3,260 mg/L, a 42-percent increase in total dissolved solids. This water will now be very salty to the taste and may also be very corrosive due to the high level of chloride in the effluent water. Though the water is soft and significantly free of sulfate, nitrate and alkalinity, and exhibits a more neutral pH, it is still unsuitable for domestic household use.

In reference to the indoor water demand indicated in Figure 3, it is possible to estimate the operating cost to treat this water using conventional methods.

Because of the high level of TDS (1,900) in the untreated water, calculating the available capacity of a cubic foot of cation resin regenerated with 10 pounds of salt (sodium chloride) must be determined. High TDS limits the exchange capacity of a softener, thus reducing its efficiency. Under normal TDS levels of 200 to 400 mg/L, and a hardness level of 10 grains per gallon, the exchange capacity of a softener would be 27,000 grains exchange capacity per cubic foot of resin.

Using industry-standard calculations adjusting for 70-grain hard water and 1,900 mg/L of TDS, the adjusted capacity of the softener is now 18,000 grains per cubic foot. A 1.5-cubic-foot softener salted at 10 lbs. of salt per foot equals 27,000 grains or 15 pounds of salt per regeneration. Looking at the water demand estimate per day, divide the available capacity of the softener by the daily subtotal water usage without evaporative cooling, and that will yield the available gallons of soft water.

Example

Total softener capacity: 27,000 grains
Divide by: 70 grains per gallon
Equals: 385 gallons soft water
Divided by: 148 estimated gallons/day
Equals: 2.6 days/regeneration

Since there is not a full three-day volume available, the softener will regenerate every other day at 15 lb. salt. Using 30 days for the average month, the softener will regenerate 15 times per month. Multiplying the salt pounds (15) per regeneration by 15 days per month, the salt usage is estimated at 225 pounds per month. At 40 lbs. per sack, that is equal to 5.6 sacks (six sacks nominally) per month at seven dollars per sack or $42 per month. Total water volume per regeneration is 64 gallons multiplied by 15 regenerations equals 960 gallons of wastewater per month.

The soft water must be treated to reduce the sulfate and other exchangeable anions. Using the same daily water consumption estimates, the operating cost may be calculated accordingly. Add the sulfate (1,248) and the nitrate (0.64 = 1,248.64 mg/L) and divide by 17.1 = 73 grains per gallon. A minimum of 296 gallons for two-day-demand estimate (Figure 3) would require a dealkalizer capacity of 21,608 grains capacity. One cubic foot of anion resin regenerated with 10 lbs. of salt has a rated capacity of 16,500 grains. Calculating the required capacity of the dealkalizer by multiplying 296 (the two-day-demand estimate) by the equivalent hardness of the anion load (73 grains) will determine the size of the dealkalizer.

At 16,500 grains capacity per cubic foot, a 1.3-cubic-foot dealkalizer will be needed to yield the required exchange capacity. However, because of the high total dissolved solids, the dealkalizer must be de-rated for the same reason as the softener. This would yield an actual capacity of 11,055 grains. Therefore, a two-cubic-foot dealkalizer would be necessary to yield the required two-day capacity for this application. The available capacity would now be 22,110 grains at 20 lbs. of salt per regeneration.

The dealkalizer will regenerate every other day at 20 lbs. salt. Using 30 days for the average month, the dealkalizer will regenerate 15 times per month. Multiplying the pounds of salt (20) per regeneration by 15 days per month, the salt usage will be 300 pounds per month. That equates to eight sacks of salt at seven dollars or $56 dollars per month to operate the dealkalizer. The regeneration frequency is two days, just the same as the softener. The volume of water for regeneration is 70 gallons multiplied by 15 regenerations equals 1,050 gallons of wastewater per month. Since the delkalizer regenerates with soft water, add the total regeneration volume of 70 gallons to the soft water volume from the softener to ensure that no hard water enters the dealkalizer to prevent calcium carbonate precipitation, which would permanently damage the dealkalizer.

Soft water with significantly reduced sulfate is still not suitable for drinking and cooking because of the elevated sodium and chloride levels in the treated water. This makes it necessary to refine the water quality with a pressure-boosted RO system properly configured to produce high-quality drinking water. This type of product is very compact and is designed to install under the kitchen sink cabinet where water, power and drainage are readily available. It will provide up to 12 gallons of premium, quality water for drinking. For every gallon of drinking water produced, this product will typically reject six gallons to drain. This type of RO typically operates at a 16-percent recovery ratio. The higher waste ratio is necessary to maintain the concentration polarization at the membrane surface to prevent premature fouling of the membrane. Therefore, it would require 72 gallons of wastewater to produce the 12 gallons it is rated for.

Example

Product: 12 gallons per day
Reject: 72 gallons per day
72 divided by 12 = 6 to 1 ratio
100% divided by 6 = 16.6%

Calculations for the total cost of producing water with this conventional method:

	Softener	Dealkalizer	RO
Model	5418-48K-2T	7820-60K-2T	RV-SS-001
Gal. per regen	64	70	72
Regens per mo.	15	15	6 –12 per day
Total gals. per mo.	960	1,050	180 – 360
Total combined gals.	960	1,050	180 = 2,190 – 2,370
+ daily demand (gals.)	148 x 30 (days)		= 4,440
= monthly volume (gals.)			6,630 – 6,810

(***Author note:*** *This chart explains the amount of water needed to operate a conventional treatment process. These numbers are in addition to the daily estimated water usage to manage household needs. This is not RO water. Refer to Figure 3 and see Option 2.)*

This drives up the estimated daily water demand from 148 to between 221 – 227 gallons per day, or approximately 50 percent more water than is projected for this residence. The water bill would increase by approximately 50 percent as well, based on the available 0.34 acre-feet (the volume of water that is not to be exceeded by order of the state engineer) per household per year. Each home is allowed 11.4 gallons per hour, 274 gallons per day or 100,010 gallons per year, based on currently supplied information.

Option 2

Taking another approach to this water quality for remediation, to make it suitable for domestic use, is advanced technology utilizing reverse osmosis. With this process, the water is separated at the molecular level, whereby the offending constituents of sulfate, TDS and hardness are separated from the water and flushed to drain. Food-grade, FDA-approved antiscalant is dosed into the feed water to the system to prevent fouling of the membrane array.

This system is fully integrated for completely automatic operation and will only require routine pre-filter replacement and periodic replenishment of FDA-approved antiscalant. The entire system, including the specific location of the system components, is carefully designed for easy service and maximum efficiency.

Of the 274 daily allowable gallons per home, 80 percent (or 219 gallons) will be converted to high-quality water for domestic use and stored in an FDA-approved water tank for repressurization and delivery to the service plumbing in the home. The quality of this water will be equivalent to having bottled water at every tap in the home. The advantages with of system are ultra-low maintenance, no salt usage and minimal water waste.

Another value-added feature with this system is the low energy consumption to produce this high-quality water. It only requires 3.56 kilowatt hours per 1,000 gallons produced (or 3,560 watts of energy) to produce water for one week at 148 gallons per day (see Figure 3).

The water quality produced will reduce the three primary contaminants of TDS, sulfate and hardness to the following approximate levels, with the membrane design of this system:

TDS: …………..53 mg/L
Sulfate: ……….25 mg/L
Hardness: ……10 mg/L
pH: ……………7.0 – 7.2

Conclusions

From the interpretation of the water chemistry, available daily volume and maximum recovery of useable water, it is clear that our goal of minimizing the waste water volume and reduced pumping and consumables costs has been achieved.

Recommendations

In order to prove the efficacy of this technology, a prototype system specially prepared for Diamond Tail Estates was recommended. This system would be one-third scale model assembled on a skid-mounted inertia base to facilitate transport to a test site for demonstration. (An inertia base protects a portable system that is preassembled for transport. The skid base includes seismic snubbers that act like shock absorbers on a truck to dampen shock loads during transit.) Real-time function of the system performance, complete with quality monitoring of the feed water and product water streams, will clearly prove that the system represents a considerable advantage over a field-engineered system.

An actual full-scale model could then be manufactured for stationary placement at a model home in Diamond Tail Estates to confirm the reliability and consistent performance of this product. Prospective home buyers would observe the performance and see for themselves what their water processing system would look like in an installed configuration in their new home.

This customer has approved the pilot-scale system for evaluation and is currently preparing the proper environment for this system. Stay tuned for a field report on the project to learn more about this expanding arena of whole-house RO water treatment and purveyance.

About the author

Gary Battenberg is Managing Director of Santa Fe, NM-based Good Water Company, Inc. He has over 26 years experience in the field of domestic, commercial and high purity water treatment processes. Battenberg has worked in the areas of sales, service, design and manufacturing, utilizing filtration, ion exchange, UV sterilization, RO and ozone technologies. Contact him at gary@goodwatercompany.com or (505) 471-9036.