Use of lime, limestone and kiln dust to stabilize reverse osmosis treated water

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ABSTRACT

The City of Pembroke Pines is embarking on an alternative water supply (AWS) project that includes the potential of using treated wastewater for aquifer recharge. The concept includes the use of reverse osmosis membranes, ultraviolet disinfection and advanced oxidation processes downstream of activated sludge and microfiltration. One of the problems is that the permeate leaves the process grossly under-saturated, because with respect to minerals, virtually everything in the water is removed by the reverse osmosis membranes. The practical natural minimum hardness level for water is 40 mg L^{-1} as CaCO$_3$, while the permeate water was <7 mg L^{-1}. As a result, a post-treatment system needed to be designed to restore minerals to the water to achieve stability so the water does not dissolve metals, other piping and treatment tank materials. Traditionally reverse osmosis plants for potable water systems use caustic soda, polyphosphates, orthophosphates and other chemicals to address the stability issue. These are costly and for an aquifer recharge project, the costs seemed high. For this project, the research focused on alternative solutions to restore hardness, alkalinity and pH using lime, limestone and kiln dust. All three resolved the pH and stability issues for the pilot process.

Key words | indirect potable reuse, reverse osmosis, water stability

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INTRODUCTION

The State of Florida is the fourth most populous state in the USA. The US Census population in 2010 for South Florida was approximately 5.5 million and it is expected to increase to approximately 7.4 million by year 2030 (Broward-by-the-Numbers 2006). Considering the projected population growth in the area, it can be anticipated that water demand will increase approximately 45% to 1,110 MGD for the same years, assuming an average water use of 150 gallons per capita per day (Whitcomb 2006). Water supply is a serious issue for South Florida as a result of weather patterns and climate variations. While the area receives nearly 60 inches of rainfall per year, water resources in South Florida are limited as a result of distinct wet and dry seasons. The dry season occurs concurrently with the period of highest population, while the wet season rainfall cannot be stored due to a lack of topographic relief.

The Biscayne Aquifer is the only source of freshwater in this area since the Floridan Aquifer is a source of brackish water 1,000 ft below the surface. As a result of it being a brackish water source, the costs for operations are significantly higher, and the sustainability of drawing large amounts of water from a confined aquifer is questionable. Desalination is far more costly, which creates concerns regarding the ability of the area to meet future water demand while maintaining the stability of the natural systems. In addition, wastewater production is also expected to increase, creating an impaired water source that has no obvious disposal option (Hudkins & Fox 2006). However, for Southeast Florida utilities, the reuse option is fraught with difficulties due to the volume of reuse generated, the lack of open space, and the small size of lots. As a result, large-scale reuse is not feasible. Five utilities have looked at aquifer recharge with reverse osmosis (RO)

treated wastewater, although none has moved ahead with full-scale projects.

The raw water supplies of the City of Pembroke Pines are limited as are reuse disposal options, so the City is considering the use of reclaimed wastewater to offset raw water supply needs. Because aquifer recharge requires much more treatment than reuse, it could provide a source of supply to meet increasing demands. In addition, aquifer recharge would permit the continuation of use of current water treatment processes (and many plants have capacity that is unused due to raw water supply limitations). However, the reclaimed wastewater is considered to be an 'impaired water'. Impaired waters are defined as waters containing constituents whose concentrations exceed regulatory limits of primary and secondary drinking water standards or which cannot be treated to evolving drinking water standards. Treating for recharge standards requires membranes to treat the water to acceptable standards. The standard-bearer for such recharge projects is Water Factory 21 in Orange County, CA. Water Factory 21 has been operating for over 30 years and was part of one of the most important epidemiological studies on the health impacts of recharging the aquifer with reclaimed wastewater using the treatment protocol at Water Factory 21. A 1996 study found no measurable differences in the incidence of diseases between Orange County and the Los Angeles basin where the water supply is not recharged with reclaimed water (Sloss *et al.* 1996). The City pilot tested the Water Factory 21 process for nine months. While the membrane treatment results are described elsewhere (Bloetscher *et al.* 2011), one of the concerns generated during the pilot testing was about loss of water stability resulting from the reverse osmosis treatment, including the potential to dissolve the aquifer formation, and to leach metals into the raw water. Neither is a desirable. As a result, significant effort was put toward the post treatment stabilization, required as a result of the reverse osmosis process.

Most designs suggest the solution to the stability problem is caustic soda, with little additional design information. The goal of this project is to determine if a low cost solution to restabilization of the water could be developed for the recharge water, and the parameters that would make such a system viable at a treatment facility. Solutions used water distribution solutions include the use of polyphosphates, orthophosphates and silicates, but these were not viewed positively due to costs for this application. Prior efforts dealing with chemical stability in low pH, unstable water include stabilization with lime in addition to lime softening in Collier County, Florida (Walker *et al.* 2007) and upflow limestone contactors in the Canary Islands (Hernandez 2005). However the water treatment industry is not the industry with low alkaline, low pH water as an ongoing problem, the mining industry is. Acid mine waste is a centuries old problem as a result of tailings on on-site processes. To remediate acid mine waste, there are a number of potentially useful technologies. Lime addition has been utilized in conjunction with organics and other properties to neutralize acidity (Gazea *et al.* 1996; Feng *et al.* 2000; Foucher *et al.* 2001; Johnson & Hallberg 2005; Ata & Koldas 2006; Kalin *et al.* 2006; Birnhack *et al.* 2011) and heavy metal release in to the environment is generally avoided by lime neutralization (Birnhack *et al.* 2011). Limestone is a proven technology where the acid mine water is run across limestone beds, channels or contactors to raise the pH (Hedin *et al.* 1994; Ziemkiewicz *et al.* 1994; Skousen *et al.* 2000; Ziemkiewicz *et al.* 2003). More recent experiments have used kiln dust, a high pH, highly alkaline waste product of the cement industry as a potential option (Doye & Duchesne 2003; Duchesne & Doye 2005). Given that South Florida has significant amounts of inexpensive limestone, significant amounts of kiln dust to dispose of and extensive experience with lime, these were determined to be potential options to resolve the pH, saturation problem. Specifically, the concepts of exposure time and pH/conductivity change, and sizing of such a reactor were to be investigated. Field testing of laboratory results was also undertaken.

MATERIALS AND METHODS

A comprehensive analysis of substances found in the wastewater treatment plant was performed by Calvin, Giordano and Associates (CGA) with the purpose of evaluating the plant's readiness to manage micro-pollutants present in feedwater (see Table 1). There were a number of issues of concern including phosphorus, which has a regulatory limit of 0.01 mg L^{-1} in Broward County (BC), metals, and emerging substances of concern like endocrine disruptors, pharmaceuticals, and the like that citizens had inquired about. To meet regulatory requirements, the project team

Table 1 │ Summary of permeate samples

Analyte	Units	BC limit	FAC[a] limit	Post secondary	Pre-RO	Post RO filmtec	Post RO hydranautics	Post RO Koch
Sodium	µg L^{-1}	160,000	160,000	62,333				
Antimony	µg L^{-1}	6	6	0.74		U	U	U
Arsenic	µg L^{-1}	50	10	0.88		U	U	U
Barium	µg L^{-1}	2,000	2,000	11.33		U	U	U
Beryllium	µg L^{-1}	4	4	0.15		U	U	U
Cadmium	µg L^{-1}	5	5	0.07		U	U	U
Chromium	µg L^{-1}	100	100	1.10		U	U	U
Lead	µg L^{-1}	15	15	1.18		I	I	I
Mercury	µg L^{-1}	2	2	0.06		U	U	U
Nickel	µg L^{-1}	100	100	2.37		U	U	U
Selenium	µg L^{-1}	50	50	0.62		U	I	U
Thallium	µg L^{-1}	2	2	0.10		U	U	U
Cyanide, total	mg L^{-1}	0.2	0.2	0.01		U	U	U
Fluoride	mg L^{-1}	2	4	0.65		U	U	U
Nitrate as N	mg L^{-1}	10	10	15.7				
Nitrate nitrite as N	mg L^{-1}	10	10	15.7				
Nitrite as N	mg L^{-1}	1	1	0.32		I	U	U
Biochemical oxygen demand	mg L^{-1}	5	NS	18		U	U	U
Chemical oxygen demand	mg L^{-1}	10	NS	82		U	U	U
Oil & grease	mg L^{-1}	10	4	1.4		U	U	U
Phenolics	mg L^{-1}	0.0001	NS	U		U	U	U
Total organic carbon	mg L^{-1}	NS	3	13		U	U	U
Avg phosphorus	µg L^{-1}	0.01	NS	4	4	U	U	U
Avg turbidity	NTU	10	NS	4	0.15	U	U	U
Avg total coliforms	CFU/100 mL	1,000	4	589,000		U	U	U
Avg fecal coliforms	CFU/100 mL	800	1	67,000		U	U	U
Total suspended solids	µg L^{-1}	NS	NS	47		U	U	U
NH$_4$	mg L^{-1}	NS	NS	13.9		0.43	0.166	0.57
K	mg L^{-1}	NS	NS	12.7		0.37	0.152	0.18
Na	mg L^{-1}	NS	NS	18		0.5	0.173	0.25
Mg	mg L^{-1}	NS	NS	6.1		0.08	0.012	0
Ca	mg L^{-1}	NS	NS	48		0.58	0.096	0.03
Sr	mg L^{-1}	NS	NS	0.44		0.01	U	U
Ba	mg L^{-1}	NS	NS	0.2		U	U	U
CO$_3$	mg L^{-1}	NS	NS	0.05		U	U	U
HCO$_3$	mg L^{-1}	NS	NS	136.75		4.07	1.213	2.9
NO$_3$	mg L^{-1}	NS	NS	n/a		U	n/a	n/a
Cl	mg L^{-1}	NS	NS	29.94		0.45	0.148	0.27
F	mg L^{-1}	NS	NS	0.7		0.02	U	U

(*continued*)

Table 1 | continued

Analyte	Units	BC limit	FAC[a] limit	Post secondary	Pre-RO	Post RO filmtec	Post RO hydranautics	Post RO Koch
SO$_4$	mg L^{-1}	NS	NS	79.85		0.74	0.099	0.06
SiO$_2$	mg L^{-1}	NS	NS	11		0.29	0.05	0.12
Boron	mg L^{-1}	NS	NS	0.27		0.22	n/a	n/a
pH		NS	NS	6.8		5.1	5.01	5.1
CO$_2$	mg L^{-1}	NS	NS	37.48		37.27	27.19	32.89
Total dissolved solids	mg L^{-1}	NS	NS	390		8.83	2.1	4.39

[a]FAC: Florida Administrative Code.

developed a series of treatment processes after the current secondary treatment that included sand filters, microfiltration, reverse osmosis membranes and ultraviolet light/advanced oxidation (UV/AOP). For the latter, the concern was the potential for endocrine disrupting compounds, and pharmaceuticals and personal care products (EDCs/PPCPs), to contaminate the Biscayne aquifer as a result of injection with treated wastewater effluent.

The pre-treatment phase of the study concluded that Dynasand media filters and Pall Microfiltration skids could accomplish adequate removal of particulates and foulants to permit the development of the polishing phase of the study. In the polishing phase, major testing was conducted using a two-stage, three-element per vessel Osmonics RO pilot skid and a two-vessel, one-stage RO skid connected as a third stage. Supplementary testing was performed to determine the efficiency of recovering additional water from the first and second stage concentrate streams. The concentrate has two options: return to the headworks or disposal in the on-site deep injection well. A hydrogen peroxide feed system and Trojan UV light unit concluded the permeate treatment. The resulting water was virtually distilled, meaning it was severely corrosive and needed some form of stabilization.

For the life of the project, the following water quality parameters were collected on a daily basis, along with the averages for the membranes tested: pH, specific conductivity, temperature, dissolved oxygen (DO) and oxygen reduction potential (ORP).

All data were gathered in the field by hand. Measurements of conductivity, resistivity, total dissolved solids (TDS), ORP and pH were taken using a Hach MP-6 portable meter. Calibration was conducted once per month with

conductivity standards appropriate to the solution matrix. Calibration checks were performed with pH solution twice per month. pH was calibrated using three points (4.01, 7.00, and 10.01).

For conductivity and TDS measurements, the sensor cup was rinsed with test solution three times to condition the temperature compensation sensor and prepare the cell. Then the cup was refilled making sure that no air bubbles clung to the cell wall, and the final measurement was recorded. For resistivity, the pH/ORP sensor cap was secured to avoid contamination. Holding the meter at a 30° angle, the sample was added to the conductivity cup continuously to avoid air bubbles, and the value was recorded if above 10 kΩ. For pH/ORP, the protective pH/ORP sensor cap was removed by squeezing the sides and pulling up. The pH/ORP sensor cup is rinsed three times with the sample to be measured. The meter was shaken to remove all residual liquid after each rinse. Then both sensor cups were filled with sample, and both values were recorded. After testing, the pH/ORP sensor cup was filled with pH storage solution and the protective cap was replaced so that the sensor cup did not dry out. All calibrations were compensated for temperature at 25 °C. In between testing, sensor cups were rinsed with deionized water. Table 1 summarizes the results for the daily samples by membrane.

These data are required for calculating corrosion indices that measure the potential for corrosion or deposition of material on pipe walls. The common indices are: Langelier Saturation Index (LSI) greater than zero (0); calcium carbonate precipitation potential (CCPP) between 4 and 10 mg L^{-1}; Ryznar Stability Index (RSI) between 6.2 and 6.8; and alkalinity divided by the sum of the concentrations for chloride and sulfate (Alk/(Cl + SO$_4$)) greater than 5.0.

In addition, water quality testing indicated that the calcium concentration was $0\ \text{mg L}^{-1}$ in two March samples and alkalinity evaluated at $0\ \text{mg L}^{-1}$. Additional results are noted in Table 2. Note that zeros for alkalinity and calcium cannot be used in the calculations, so $0.01\ \text{mg L}^{-1}$ was used.

Using data gathered, the permeate has an LSI of -9.67, which is extremely corrosive. The permeate has a CCPP of $-12\ \text{mg L}^{-1}$, which indicates a significant potential for corrosion caused by under-saturation. The permeate has an RSI exceeding 25.1, which indicates that severe corrosion is a problem. The Carrier Indicator also suggested scale will be an issue. Alkalinity divided by the sum of chlorides and sulfates is zero, which indicates a potential for corrosion due to lack of buffering capacity. The silt density index was zero. All indices indicated a high potential for corrosion.

Potential treatment methodologies for resolving stability concerns

Corrosion of water conduits can cause significant economic loss. As a result, several methods have been developed to slow or prevent corrosion. The methods include pH adjustment, use of chemical inhibitors, electrochemical measures, and designing the system so that conditions that encourage corrosion are avoided.

The goal of pH adjustment is to form a protective layer on the pipe. This is usually the first method attempted to achieve a positive LSI. In addition to affecting the carbonate system, pH is the key variable in the solubility of pipe materials such as lead, copper, and zinc. pH adjustment can play a major role in the stabilizing of a pipe material. pH can be adjusted with NaOH. NaOH quickly adjusts the pH, but adds no buffering or hardness to the water. As a result the pH adjustment is not completely useful for the City.

Water treatment practices used to adjust pH and achieve a positive LSI have typically involved the addition of calcium oxide or sodium hydroxide. These chemicals increase the alkalinity of the water, which then tends to decrease the solubility of the corrosion products. In waters of high alkalinity, however, it becomes more difficult to adjust the pH to above 8 because of the more rapid precipitation of calcium carbonate in the distribution system. This reaction could create deposition that leads to plugging of the pipe over a period of time. Other commonly used water distribution solutions include the use of polyphosphates, orthophosphates and silicates. All were rejected due to costs.

Alternative treatment methods for resolving stability concerns

With the Pembroke Pines project, the only parameter that failed to meet the regulatory requirements during testing was pH (due to the RO process). The low pH of 5.3–5.8 needed to be adjusted to 7, so a solution was required. The goals were to adjust pH, alkalinity and hardness simultaneously to address pH and saturation concerns. The following were evaluated: lime, limestone filters, and kiln dust filter.

Option 1 – Adding lime as a means to raise pH and resolve saturation

The concept behind the addition of lime at the plant was to add hardness and saturate the water. Lime is commonly used at lime softening water plants to raise pH and reduce hardness through precipitation. For this project, the pH was far too low for precipitation, and moderate amounts

Table 2 | Summary of water quality parameters by membrane

Membrane	DOW filmtec BW 30-4040	Hydranautics ESPA2 4040HR	Koch TFC-4040HR
Koch			
pH	5.62	5.57	5.87
Specific conductivity (mS cm^{-2})	0.014	0.017	0.017
DO (mg L^{-1})	5.07	3.9	2.43
ORP (mV)	534	522	469
Temp. (°C)	27.3	29.4	30.2
Rejection (%)	98	97.6	97.5
Recovery (%)	66.4	72.8	70.5
Concentration factor	3.1	3.7	3.4
Flux (gpd sf^{-1})	15.7	16.7	21.5
Normalized specific flux (gpd/sf/psi)	0.072	0.072	0.103
Change in flux (peak to end after start up) (%)	17	21	0
Crossflow velocity (ft/d)	19.3	21.1	20
Pressure (psi)	220	220	220

Figure 1 | Lime slurry feed pump and bucker (white on left).

of lime could significantly reduce corrosivity of the water. A minimum dose of 40 mg L^{-1} of lime was assumed to create 40 mg L^{-1} of hardness and alkalinity in the water, the practical minimum of lime softening and a point where corrosion appears to be reduced. In addition, lime needed to be added to increase the pH to over 7. Figure 1 shows the flow pacing pump and bucket used to mix the lime. A fish tank motor was used to mix the lime in the solution bucket. Measures of 1,000 mL of lime was added each day

to 5 gallons of water. While this is not the optimal solution, it worked effectively for the 30 d of testing.

Option 2 – Using a limestone filter as a means to raise pH and resolve saturation

Initial tests were undertaken to determine how fast the pH changed in the permeate after exposure to limestone. The major concern was to predict how much contact time would be needed to get the pH and corrosion index issues resolved. A series of tests indicated that the contact time was in the order of a minute, and that the limestone also contributed hardness and alkalinity to the water. Figure 2 outlines the bench results used to figure out contact time and flow rates to use the limestone to obtain, pH, hardness and alkalinity. The initial curves indicate that the pH rises rapidly with contact time. Within minutes the pH will exceed the pH threshold of 6.5. However, time is not really the issue since the limestone is dissolving. Flow spread over the top surface area, so it does not address volume contact time. The contact coefficient addresses both contact volume and contact time concern. The contact coefficient was calculated based
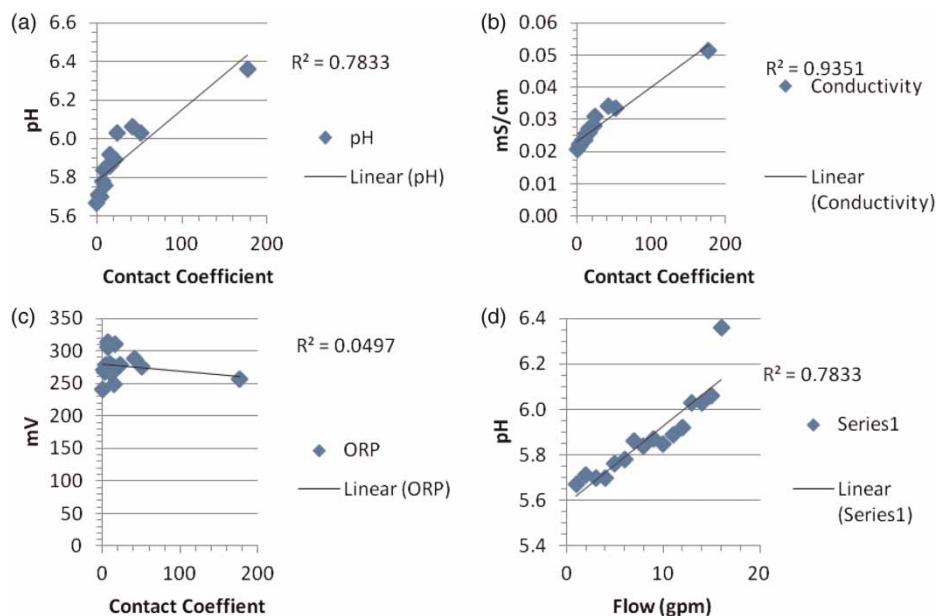

Figure 2 | (a) pH versus contact coefficient for limestone, (b) conductivity versus contact coefficient for limestone, (c) ORP versus contact coefficient for limestone, (d) pH versus flow for limestone.

on the height of limestone in a filter (maximum was 24 inches (0.7 m) in the laboratory, 6 ft (2 m) in the field) and volume of the bench scale filter vessel (media height/volume empty of vessel (ft/cu ft or $m\,m^{-3}$)). Contact coefficient was used for comparison to address contact time issues and measure the progression of stabilization in the permeate.

The results indicated that the higher the contact coefficient, the higher the pH, conductivity and lower the ORP. Through optimizing contact time in the laboratory, the taller the filter, the better results. The 24 inch filters were not high enough, but projecting out, the Florida Atlantic University (FAU) team decided that a 6 ft (2 m) deep filter would resolve the issues. pH was resolved at flow 1 gpm/sf ($0.2\,L\,min^{-1}\,m^{-2}$), although in a 1 inch (2.5 cm) tube. Upflow filters were used to control flow rates.

Based on the laboratory testing, a 'limestone filter system' was created using 4 inch (10 cm) PVC pipe 6 ft (2 m) long (area/depth ratio = 18:1 – see Figure 3). The

Figure 3 | Lime and kiln dust filters.

filter was designed as an upflow system, with a meter at the bottom and flow control gate valves at the top.

Option 3 – Using a filter filled with kiln dust to raise pH and resolve saturation

Figure 4 outline the bench results used to figure out contact time and flow rates to use the kiln dust to obtain, pH, hardness and alkalinity. The initial curves indicate that the pH rises more rapidly with contact time for kiln dust than for limestone. The change is at least twice as fast. This is no surprise since kiln dust has a pH of 12. Within minutes the pH will exceed the pH threshold of 6.5. For the same reasons as discussed above, the contact coefficient was used to address both contact volume and time issue. The taller the filter the better results because of contact time. The 24 inch (0.7 m) filters were not high enough, but projecting out, the FAU team suggested that a 6 ft (2 m) deep filter would resolve the issues. pH was resolved at flow over 2 gpm/sf ($0.2\,L\,min^{-1}\,m^{-2}$), meaning the deeper filter could take more flow and resolve stability faster.

RESULTS AND DISCUSSION

Option 1 – Stability results of the addition of lime

Among the issues noted during testing was that the flow pacing system did not result in the optimal conductivity or pH in the initial testing (see Figures 5 and 6). In part this was a limitation of the system (plugging) and the flow speed versus the injection of lime. To remedy the issue, the flow pacing was increased in the latter part of the experiment. Figure 7 shows that to meet both requirements, conductivity needed to be over $65\,\mu M\,cm^{-2}$, just as suggested with bench scale the testing. A concentration of $65\,\mu M\,cm^{-2}$ results in the addition of $40\,mg\,L^{-1}$ of lime. For the Pembroke Pines plant, this amounts to 1 ton per day at a cost of US \$225/ton (900 kg). A slaker and lime silo is likely needed to accomplish this solution.

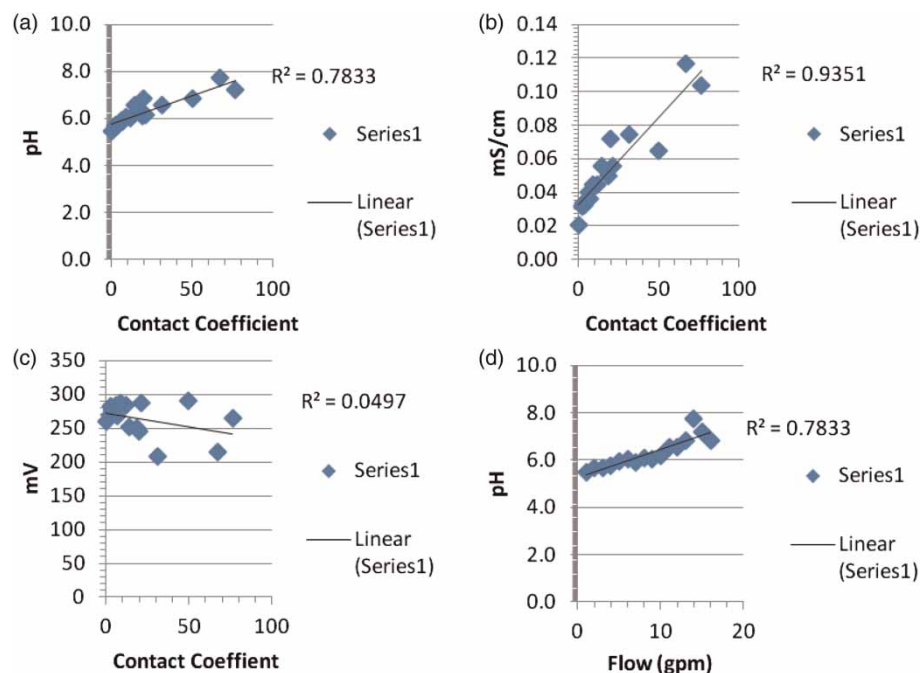However lime alone does not add any carbonate alkalinity, only OH. The lime did reduce the ORP by two-thirds.

Figure 4 │ (a) pH versus contact coefficient for kiln dust, (b) conductivity versus contact coefficient for kiln dust, (c) ORP versus contact coefficient for kiln dust, (d) pH versus flow for kiln dust.
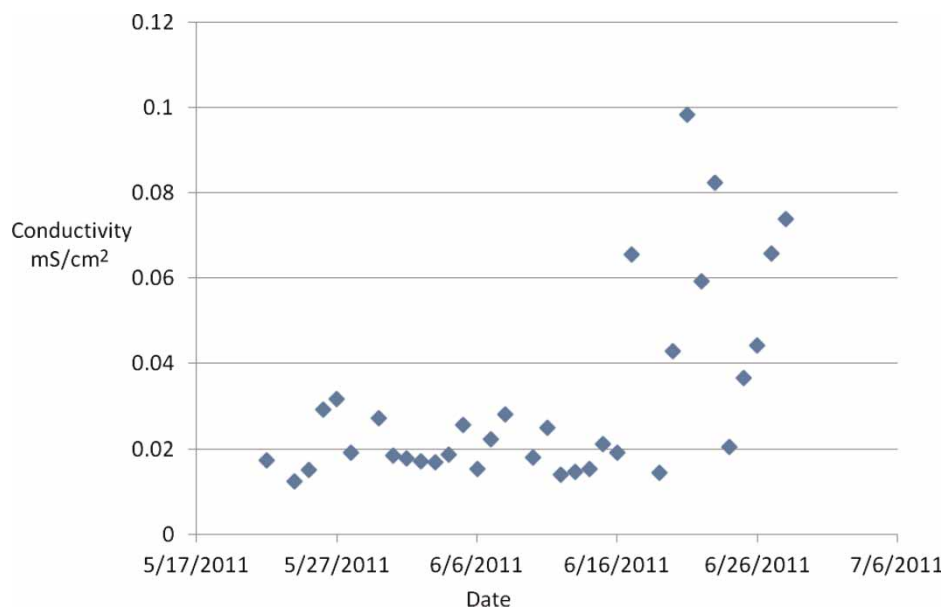

Figure 5 │ Results of conductivity for lime addition.

Option 2 – Stability results of the using limestone

Results indicated that the pH goals (>7) were met under all conditions (see Figure 8). Flow rates varied from 0.5 to

2.5 gpm/sf (0.05–0.25 L min^{-1} m^{-2}), of surface area, averaging 1.6 gpm/sf (0.16 L min^{-1} m^{-2}), which is similar to a standard sand filter at a water plant. At the goal pH, the conductivity was 0.10 μm cm^{-2} (see Figure 9). Figure 10

Figure 6 │ Results for pH with lime addition.

Figure 7 │ pH and conductivity. For a goal of pH > 7, conductivity needed to be above 0.045 mS cm^{-2}.

shows the correlation between conductivity and pH. Based on this conductivity, approximately 70 mg L^{-1} of the limestone was dissolved, which translates to 1.75 tons/d (800 kg d^{-1}) at 6 MGD (272 L s^{-1}) of flow. This translates to under US \$40/d. Washed limestone is needed and would need to be placed in the filter on an ongoing basis.
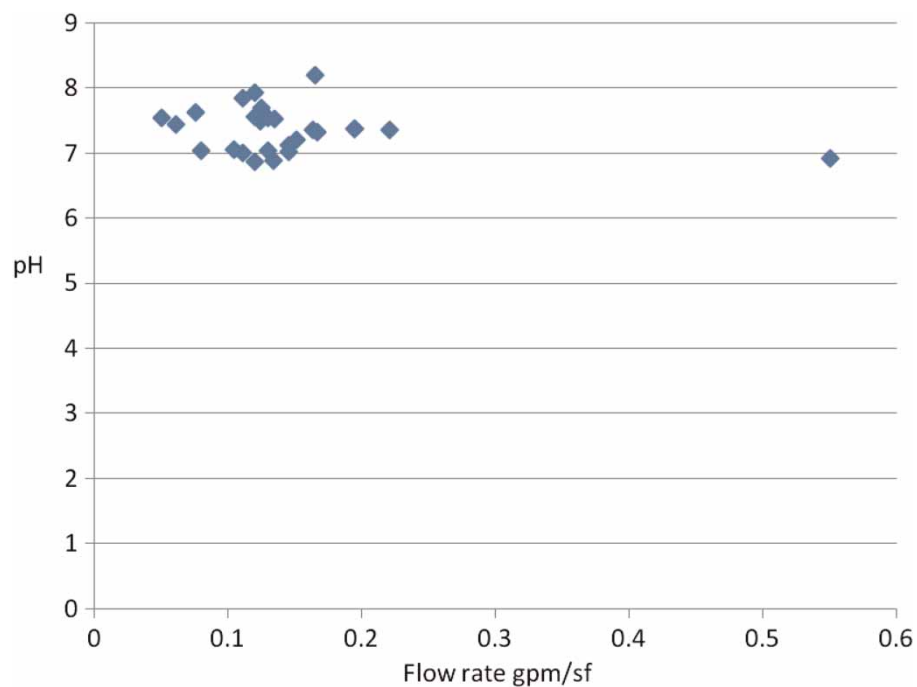
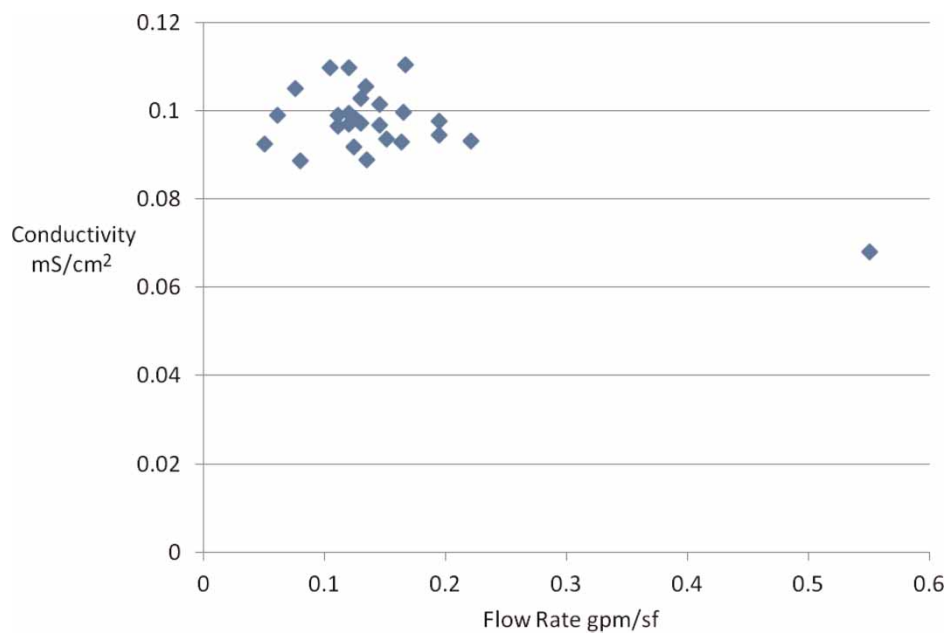**Figure 8** │ Results for pH given limestone contact at various flow rates.

Figure 9 │ Results for conductivity given limestone contact at various flow rates.

Option 3 – Stability results of the using kiln dust

The kiln dust filter configuration was the same as the limestone filter. At flow rates of 0.05–0.66 gpm (0.005–0.7 L min^{-1} m^{-2}),

the pH was consistently above 6.7 (see Figure 11). The water run through the kiln dust was generally around 0.060 mS/cm^{-2} (see Figure 12). Results indicated that the pH goals (>7) were met under all conditions (see Figure 13). Flow rates varied
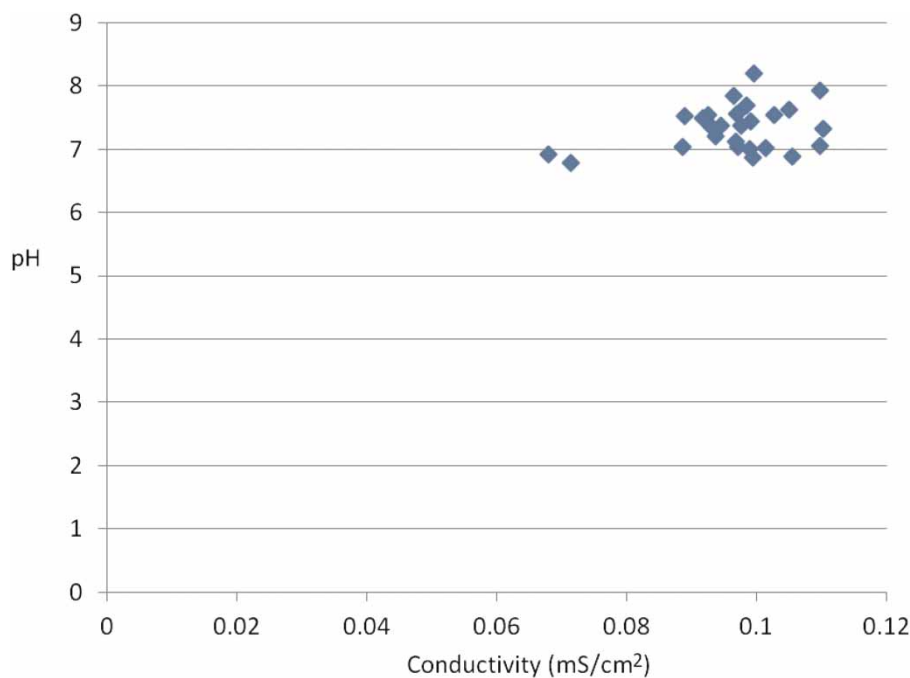
Figure 10 | pH versus conductivity for limestone filter. Both pH and conductivity goals were easily reached.
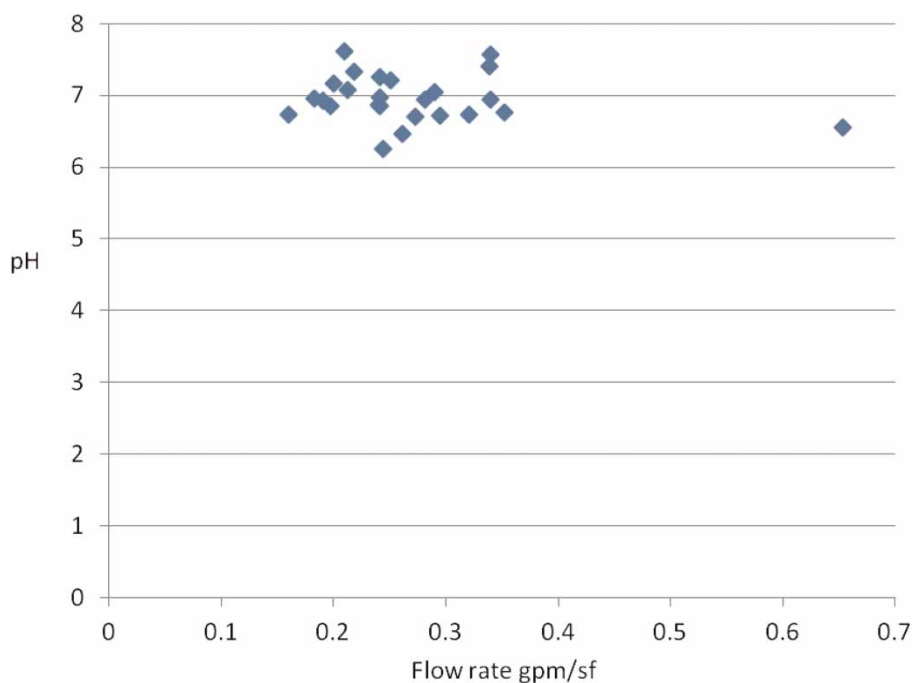

Figure 11 | Results for pH given kiln dust contact at various flow rates.

from 1 to 4 gpm/sf of surface area, averaging 3 gpm/sf, which is faster than a standard sand filter at a water plant. At the goal pH, the conductivity was 0.55 μm cm^{-2}. Based on this conductivity, approximately 40 mg L^{-1} of the kiln dust was dissolved, which translates to 1 ton/d at 6 MGD (272 L s^{-1}) of flow. This translates to under US \$100/d. Washed kiln dust is needed and would need to be placed in the filter on an ongoing basis. Kiln dust could be obtained for hauling costs only.
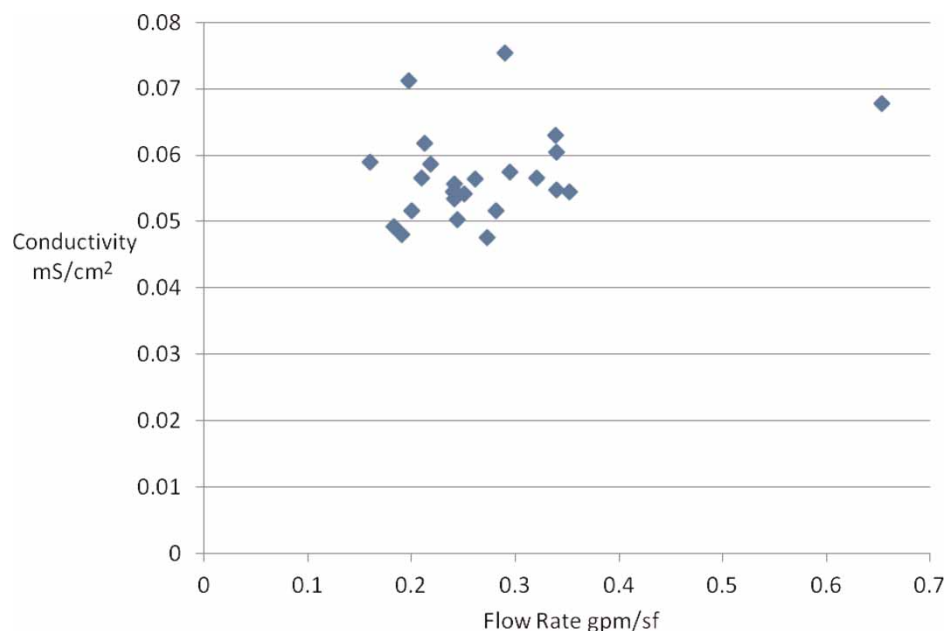
Figure 12 | Results for conductivity given kiln dust contact at various flow rates.
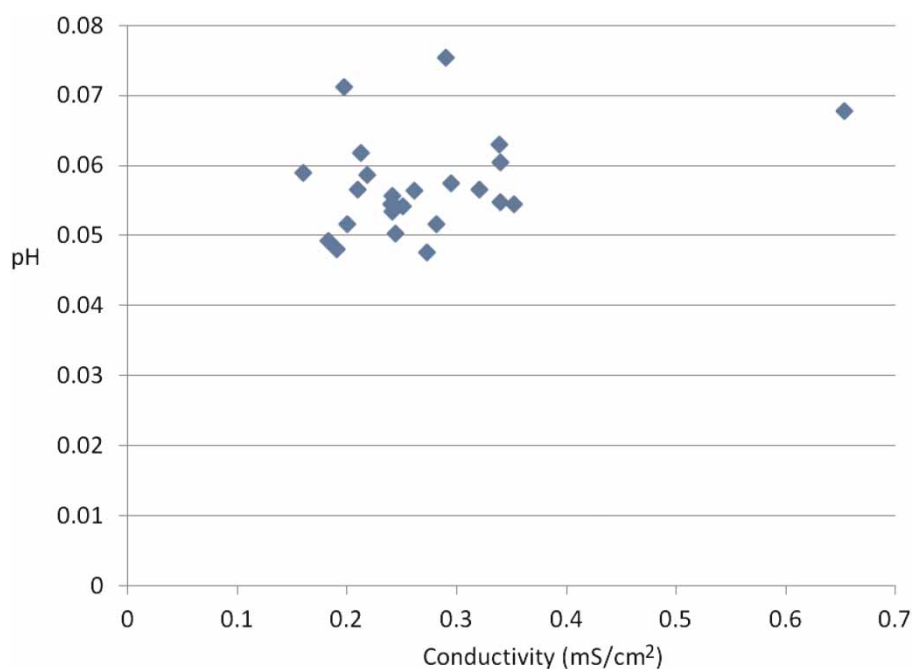

Figure 13 | pH versus conductivity for kiln dust analysis. Both pH and conductivity goals were easily reached.

The potential for metal leaching from kiln dust or limestone

Kiln dust and limestone have the potential to leach metals, therefore two additional tests were conducted. Concern was for the potential for mobilization of arsenic, or the release of other heavy metals like cadmium, chromium, mercury and lead from the kiln dust, which often has high heavy metals concentrations. A series of three replicate water samples were taken for the lime, limestone and kiln dust

Table 3 | Results of water quality post-stabilization

Parameter	LS1 µg L^{-1}	LS2 µg L^{-1}	LS3 µg L^{-1}	CKD1 µg L^{-1}	CKD2 µg L^{-1}	CKD3 µg L^{-1}	SP5-1 µg L^{-1}	SP5-2 µg L^{-1}	SP5-3 µg L^{-1}
Arsenic	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	ND	ND	3.85	ND	4.21
Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silica	ND	ND	ND	ND	ND	ND	ND	ND	ND
Selenium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mercury	ND	0.047	ND	ND	ND	ND	0.065	ND	ND
Phosphorus	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND: not detected.

finished water. Table 3 shows that the results for arsenic, cadmium, chromium, lead, phosphorus, silica, selenium and silver were all non-detectable at the µg L^{-1} level. In two samples, minor amounts of mercury were present, but these quantities did not exceed regulatory standards. In two cases barium also was present. These were leached from the limestone. The kiln dust, despite having significant metals content, did not leach metals.

CONCLUSIONS

Solving the potential for under-saturation of reverse osmosis treated water needs to be addressed to protect piping and treatment facilities. While potable water supplies might use a variety of chemicals, the expense of these chemicals is not justified for aquifer recharge. A less costly, easier to operate and safer solution was sought. This project determined that limestone and kiln dust could meet the goals of pH adjustment, hardness and alkalinity easily at limited cost. Table 4 outlines the options and goals. For an aquifer injection project, using the limestone from the formation to stabilize the water prior to injection makes sense. The concept would work in a manner similar to a filter. Table 4 outlines the NaOH solution currently employed compared to the options investigated here. As can been seen, these solutions accomplish the goals of balancing water supplies more readily that caustic soda alone.

Table 4 | Summary of options considered for stabilization of water

Goal	NaOH	Lime	Limestone	Kiln dust
pH adjustment	Met	Met	Met	Met
Hardness added	No	Yes	Yes	Yes
Alkalinity added	No	No	Yes	Yes
Est. capital cost	Low	Medium	Medium	Medium
Operational ease	Easy	Medium	Easy	Easy
Operational cost	Medium	Medium	Low	Low
Standard practice	Yes	No	No	No
Metals?	No	No	No	Possible
Material needed/d	3.5 tons	1 ton	1.75 tons	1 ton

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