Carbon Dioxide Treatment Revives Wellfield Performance in Collier County

Kirk Martin, Andrew McThenia, Pamela Libby, and Joshua Bauer

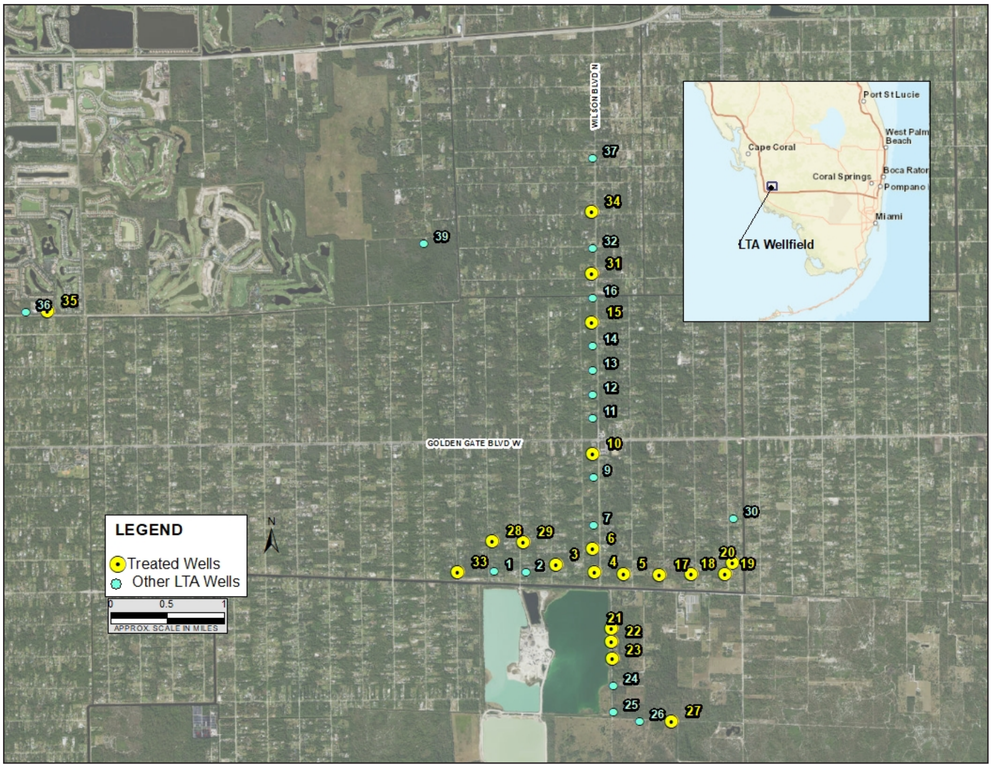

Figure 1. Aerial map showing wells rehabilitated in the Golden Gate Wellfield.

Figure 2. Carbon dioxide diffusing stone.

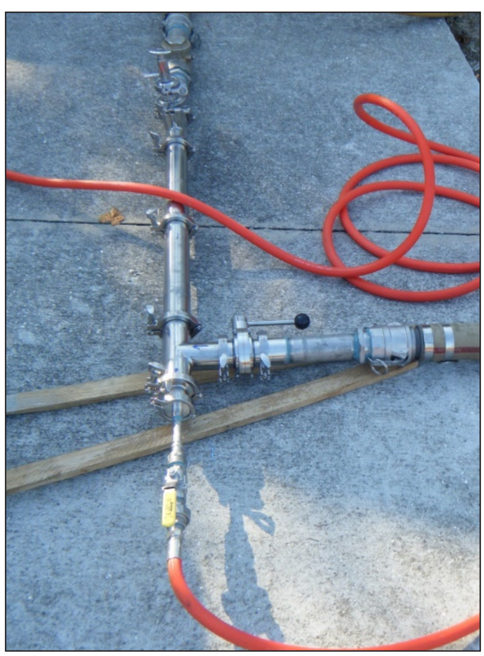

Figure 3. Carbon dioxide diffusion manifold.

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Collier County (county) produces water from four separate groundwater sources: two that are fresh and two that are brackish. As part of an effort to optimize the utilization of fresh water sources, the county implemented a phased program of well rehabilitation to improve capacity of the Lower Tamiami Aquifer (LTA) wellfield. A unique carbon dioxide (CO_2) treatment process was developed for the wellfield that resulted in well yield improvements ranging up to 625 percent. During the initial rehabilitation phase, treatment methods using hydrochloric acid (HCl) and CO_2 were compared, with no significant difference in results. Because well rehabilitation using CO_2 as the reagent is inherently safer and less expensive than using stronger acids, the use of HCl was removed from subsequent phases of the rehabilitation program.

The CO_2 method involves an inline diffusion of CO_2 into raw feed water from the wellfield transmission system to create carbonic acid. The injected acid solution reacts to dissolve carbonate minerals in the well bore. Upon completion of the injection phase, water flow is reversed by airlifting and agitation to remove water saturated with dissolved carbonate material and any loosened residue from the formation. Wellfield capacity has been increased by close to 10 mil gal per day (mgd) from treatment of 20 LTA production wells. Additional applications of CO_2 acidification are being contracted as part of a regular budgeted maintenance program.

Background

Water Science Associates was contracted by Collier County Public Utilities to design and oversee rehabilitation treatments of 20 LTA production wells in the Collier County Golden Gate Wellfield. The treatment techniques included

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Figure 4. Carbon dioxide injection tanks
and raw water main connection.

Figure 5. Acid header assembly at wellhead.

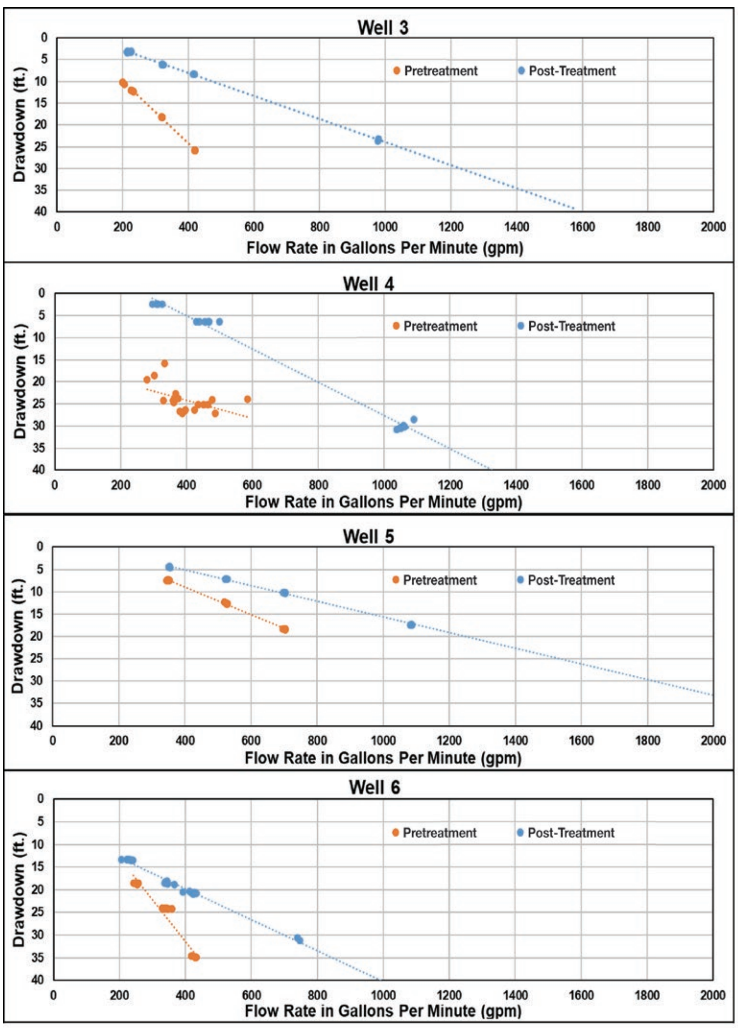

Figure 6. Plots of pumping rates versus drawdown
for wells 3, 4, 5, and 6.

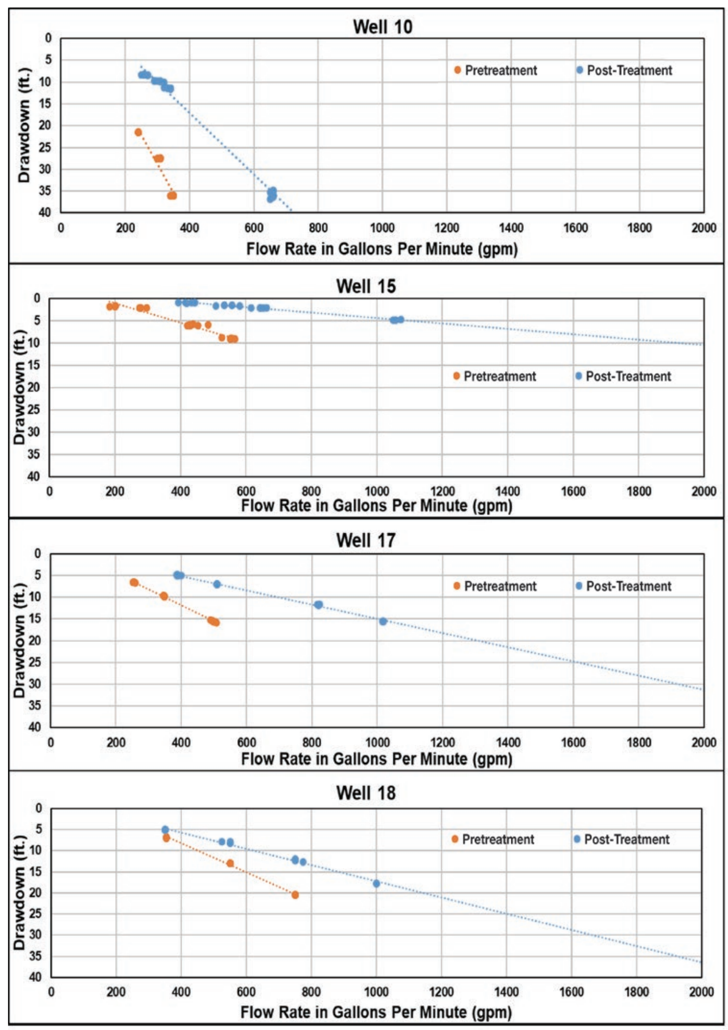

Figure 7. Plots of pumping rates versus drawdown
for wells 10, 15, 17, and 18.

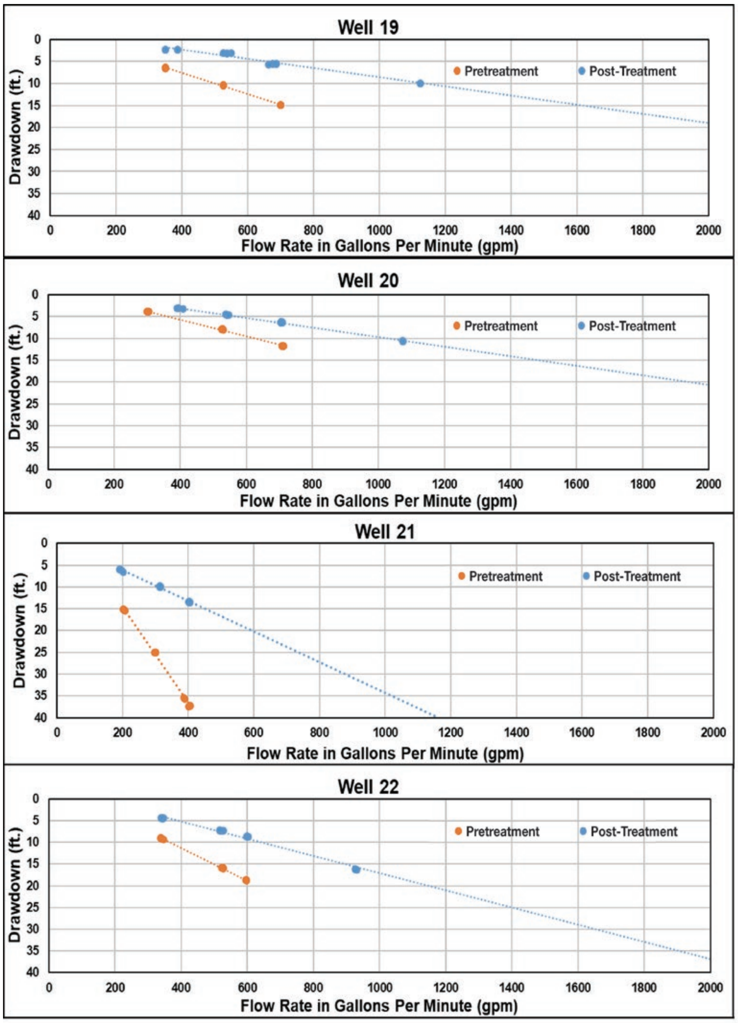

Figure 8. Plots of pumping rates versus drawdown for wells 19, 20, 21, and 22.

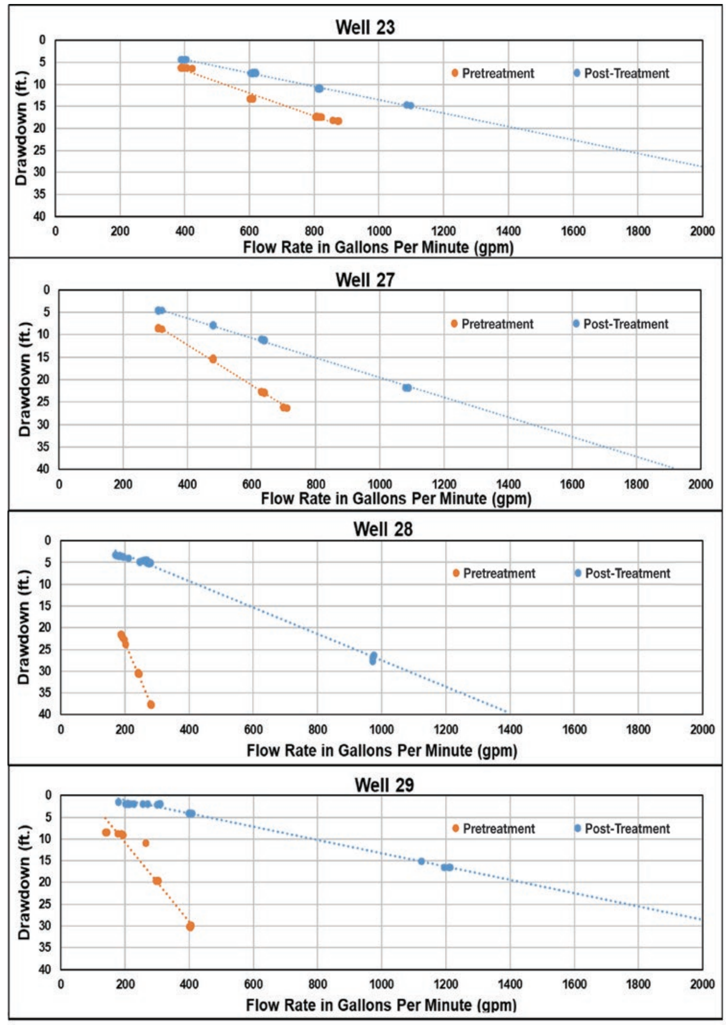

Figure 9. Plots of pumping rates versus drawdown for wells 23, 27, 28, and 29.

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injection of either a solution of HCl acid or injection of dissolved CO_2 gas. The process was conducted in three phases, with some experimentation applied in the first phase and adaptive lessons learned applied in each subsequent phase. Plans and specifications were prepared, and Wells and Water Systems, a water well contracting firm, was hired to perform the specified work. Figure 1 shows the locations of the treated wells within the Golden Gate Wellfield.

Step-Drawdown Testing

Prior to any rehabilitation treatment, a pretreatment step-drawdown test was conducted on each well to establish baseline-specific capacity values. During the initial step-drawdown testing, each well was pumped at three separate and increasing rates for a period of approximately 30 minutes per step. After the completion of acid treatment and development, a post-treatment step-drawdown test was conducted at approximately the same step rates and step durations as the initial test for comparison purposes. At the end of the post-treatment specific capacity test, an additional rate step was performed at the highest safe capacity of the pump and well.

Static water level was measured prior to step-drawdown testing. After the start of pumping, water level readings and flow measurements were taken at five-minute intervals throughout the duration of the test. Existing flow control valves at each well were used to adjust the pumping rate for each step. Specific capacity was calculated by dividing the step flow rate in gal per minute (gpm) by the final drawdown at the end of the step calculated in feet below the static water level.

Carbon Dioxide Treatment Procedures

The CO_2 was used to treat the wells via diffusion of the CO_2 gas through a carbonation stone into a stream of raw feed water, with the resulting solution of dissolved carbon dioxide injected into the well through a tremie pipe. Once dissolved into the feed water, the formation of carbonic acid provides the acidic reagent needed to dissolve carbonate minerals in the borehole and surrounding formation. The feed water source consisted of raw water from the county's pressurized water line connected to the larger wellfield.

The food-grade CO_2 used in the treatment was delivered to each site in liquid form and transferred from a bulk tanker to fill multiple individual 450-lb capacity tanks onsite. The individual tanks were connected to each other in a series via a vaporizing system of regulated flow lines, which allowed continuous feeding of CO_2 though the diffusion stone into an injection manifold, where it was introduced to the raw feed water. The resulting blend was pumped down a tremie pipe set at varying depths, but generally within 20 ft of the bottom of the casing in each well.

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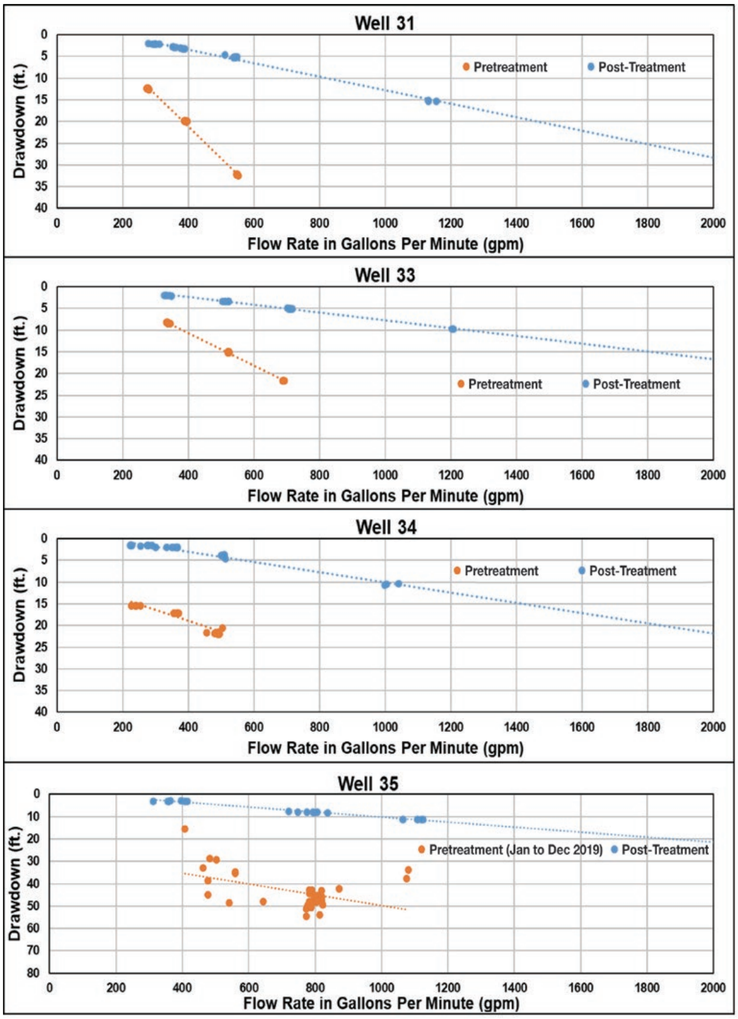

Figure 10. Plots of pumping rates versus drawdown for wells 31, 33, 34, and 35.

Table 1. Specific Capacity Comparison Summary

Well No.	PRETREATMENT			POST-TREATMENT			Percent Improvement
	Step 3 Avg. Flow Rate (gpm)	Drawdown (ft below static)	Specific Capacity (gpm/ft)	Comparable Flow Rate (gpm)	Drawdown (ft below static)	Specific Capacity (gpm/ft)	
3	420	25.8	16.3	416	8.3	50.0	**207%**
4	452	25.5	17.9	452	6.3	71.3	**297%**
5	702	18.3	38.4	701	10.2	68.5	**78%**
6	426	34.6	12.3	425	20.6	20.6	**68%**
10	346	36.1	9.6	336	11.4	29.5	**208%**
15	552	9.1	60.8	546	1.5	363.7	**498%**
17	500	15.5	32.3	509	7.0	73.0	**126%**
18	750	20.5	36.5	754	12.3	61.4	**68%**
19	700	15.0	46.8	678	5.6	121.1	**159%**
20	711	11.8	60.3	706	6.3	112.6	**87%**
21	399	37.3	10.7	403	13.5	29.9	**180%**
22	596	18.7	31.9	600	8.6	69.5	**118%**
23	812	17.4	46.6	815	10.9	74.9	**61%**
27	637	22.9	27.8	639	11.2	57.0	**105%**
28	282	37.5	7.5	277	5.1	54.5	**625%**
29	404	29.8	13.6	402	4.1	98.1	**623%**
31*	549	32.1	17.1	539	5.1	104.9	**514%**
33*	690	21.6	31.9	709	5.1	139.6	**338%**
34	486	22.0	22.1	507	4.6	109.7	**397%**
35	783	44.4	17.6	783	8.1	96.2	**445%**

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Treatment at each well consisted of injection of 4200 lb of CO_2 per well diffused inline into the raw water at a feed ratio of about 10 lb of CO_2 per 1,000 gal of water over a period of about 100 hours. A total volume of between 500,000 and 700,000 gal of raw water infused with CO_2 was injected into each well at rates that averaged between 60 and 80 gpm, depending on the raw water system pressure and flow. The contractor adjusted the water flow and gas feed rates to maintain the pH of the solution entering the well. The pH was measured downstream from the mixing point immediately prior to injection on an hourly basis and was recorded by the contractor, along with the flow rate. The time required for injection ranged between 100 and 140 hours, depending on the feed pressure from the raw water supply system. Figures 2 through 5 show the CO_2 diffusing stone and vaporization manifold system used for injecting CO_2 into each well.

Airlift Development and Disinfection

After completion of each acidification procedure, airlift development was performed on the well by pumping compressed air down a 2.375-in.-diameter tremie pipe installed to a depth of approximately 100 ft using a 375 cu-ft-per-minute (cfm) air compressor. Airlifting was alternated with periodic short (five-minute) idle periods for the water levels to partially recover.

This airlift surge method is intended to physically agitate and remove particulate matter from the well by reversing the direction of flow into and out of the open borehole. The idle periods allow the water in the casing to fall back into the well, with the resulting pressure and reversed flow suspending solids that can then be removed during the next airlift cycle. The airlift development was performed over a period of approximately eight hours for each well. Prior to reinstallation of the well pumps, each well was chlorinated using sodium hypochlorite. After the pumps were reinstalled and a minimum contact time of 24 hours had elapsed, the wells were purged of residual disinfectant prior to the post-treatment step-drawdown testing. Bacteriological clearance sampling was performed by the county prior to returning each well to service.

Specific Capacity Improvement Evaluation

Pretreatment step-drawdown tests were performed on all wells prior to acid treatment. The testing included three steps, with the step 1 rates established at approximately 50 percent of the estimated maximum pumping rate for each well, step 2 rates at approximately 75 percent of the estimated maximum pumping rate for each well, and step 3 rates at the estimated maximum pumping rate for each well. Figures 6 through 10 contain graphs of pumping rates versus drawdown for each step test performed.

Post-treatment step-drawdown pumping rates were determined for steps 1 through 3 to best match those rates used during the pretreatment testing for each well to provide a direct comparison of well performance improvement. At the end of post-treatment step-drawdown testing, an additional fourth step rate was included at the improved maximum capacity of the pump to evaluate the potential productivity of each well. The performance improvements to each well were evaluated at the step 3 pumping rate, which was the highest common rate used during both pretreatment and post-treatment tests.

The percentage improvements in specific capacity at step 3 ranged from 60 to over 600 percent, with the average improvement being around 260 percent. The average pumping rates, drawdowns, and specific capacities of each well during step 3 are summarized in Table 1, and graphical comparisons of pretreatment and post-treatment drawdown are provided in Figure 11.

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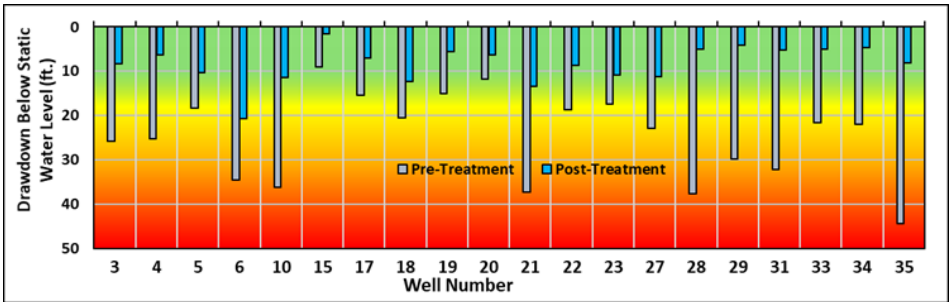

Figure 11. Pretreatment versus post-treatment drawdowns at step 3.

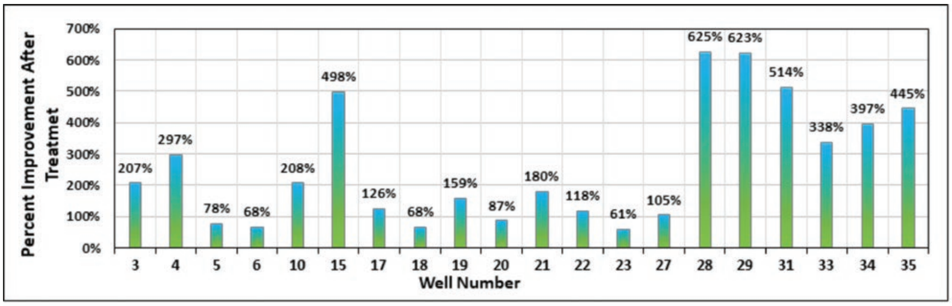

Figure 12. Percentage specific capacity improvement at step 3.

Table 2. Summary of Pretreatment and Post-Treatment Maximum Pumping Rates

Well No.	PRETREATMENT	POST-TREATMENT
	Average Max Flow Rate (gpm)	Average Max Test Rate (gpm)
3	420	976
4	452	1052
5	702	1085
6	426	743
10	346	657
15	552	1059
17	500	1017
18	750	1000
19	700	1125
20	711	1074
21	399	730
22	596	928
23	812	1092
27	637	1087
28	282	974
29	404	1207
31	549	1139
33	690	1206
34	486	1014
35	783	1102
SUM	11196	20267
COMBINED INCREASE OVER PRETREATMENT		9071

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The percent improvement in yield at step 3 is shown in Figure 12. The combined pumping rate improvements for treatment of 20 wells equates to a total increase of about 7,000 gpm, or about 10 mgd on a 24-hour pumping basis (Table 2).

Summary

The CO_2 acid treatment method has proven to provide a safe and cost-effective means to make significant improvements in well yield in the county's LTA wellfield. The setup and process is relatively simple, and to a large degree, self-performing, once the system is set up on an individual production well. While the process can be completed without removal of the production pump, the vigorous and high-capacity post-treatment development with air provides greater yield improvements over pump development, and therefore, a higher rate of return on the county's investment in the process.

The county has now started budgeting for regular CO_2 maintenance within its annual operations budget to allow for continued improvements and a more reliable system year to year.