Improving the Performance of ASR Wells with CO_2 Injection

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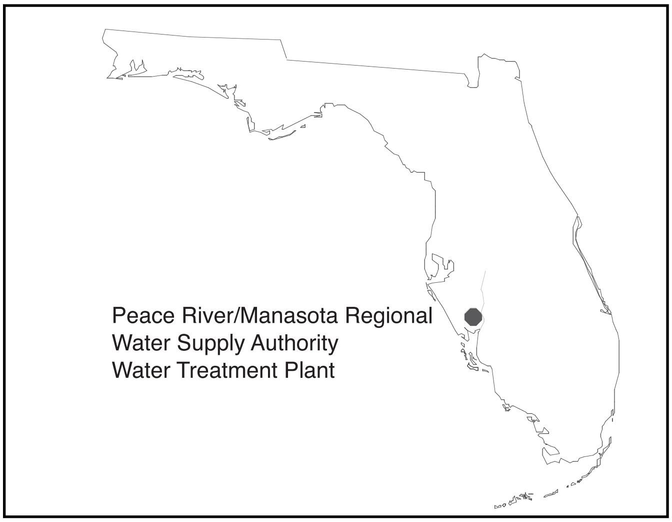

Figure 1. Location of Site.

The Peace River/Manasota Regional Water Supply Authority was formed to provide regional water supply to a four-county area of southwest Florida (**Figure 1**). The authority recently completed an expansion of the Peace River Regional Water Supply Facility to meet water-supply contracts totaling 18 million gallons per day (mgd) to three of the four member counties. The facility relies on surface water from the Peace River, a variable water source with flows ranging from billions of gallons per day to periods of almost no flow. As a result of limits imposed by the authority's water-use permit, there are times when the facility is unable to divert any water from the river and must rely on storage to meet contract obligations.

The main component of storage is an aquifer storage and recovery (ASR) system. This system relies on injection wells to store finished water at times when raw water can be diverted and treated at rates in excess of the daily demand. Water is recovered from these same wells to meet demand during periods of low river flow when diversion is prohibited.

The facility expansion, completed in 2002, included an expansion of the conventional water-treatment process from 12 to 24 mgd, an increase in the installed capacity of the river pumps from 24 to 36 mgd, and construction of 12 new 1.0-mgd ASR wells, bringing the total number of wells serving the facility to 21.

The plant is permitted to withdraw raw water from the Peace River about nine months per year on average. At these times, water is pumped from the river to a 625-million-gallon, off-stream, raw-water reservoir. Raw water is subsequently pumped to the water-treatment plant, where it is treated using a conventional coagulation process.

Following treatment, the water is pumped to clear-water storage. Surplus treated water remaining after delivery of contract water is injected into the ASR wells. The plant is unable to divert water from the river an average of about three months per year. At these times, water is recovered from the ASR wells for delivery. The facility layout is shown in **Figure 2**.

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ASR Well Performance

The ASR wells are designed for injection and recovery rates of about 1 mgd per well. At these rates, the facility has a theoretical capacity to store or recover water at a nominal rate of about 21 mgd with all wells operational. As a practical matter, the ASR wells need the capacity to store water at a rate equal to the difference between treatment-plant capacity (24 mgd) and the daily demand for water, currently averaging about 12 mgd.

Design and construction of the ASR wells was carefully planned to avoid penetrating highly permeable zones where losses of stored water would be high, and

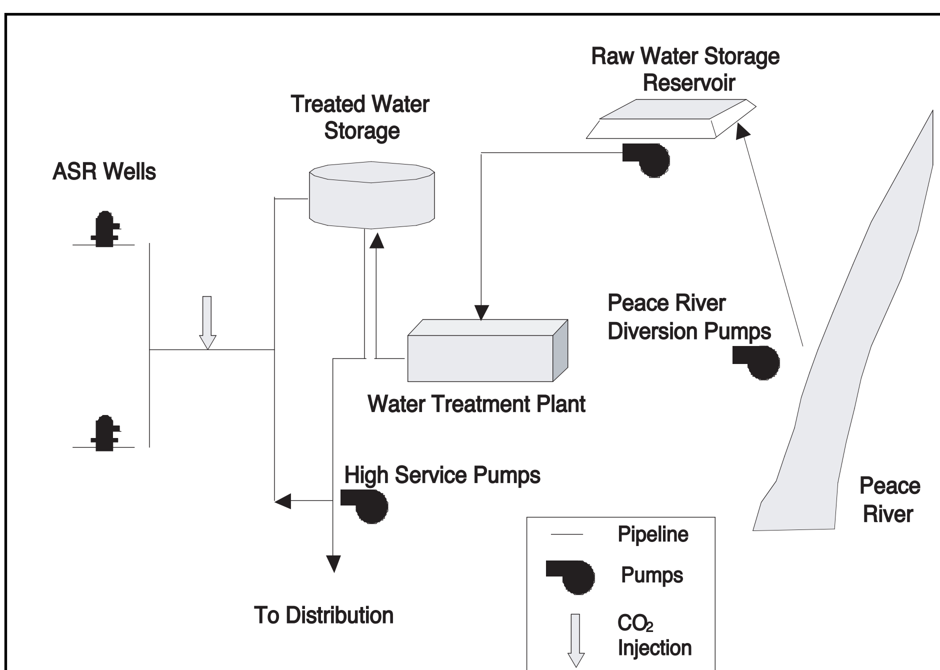

Figure 2. Facility Layout.

Figure 3. Refrigerated bulk CO_2 storage.

favored well completion in relatively thin intervals having lower, more uniform permeability. As a consequence, although recovery capacity met the project objectives, the injection capacity of several of the wells constructed as part of the expansion fell below design objectives.

There was also a progressive decline in injectivity of several of the wells during the initial storage cycle. This gradual "plugging" is a likely consequence of the chemistry of the water being injected. The pH of the finished water is adjusted in a final step of the treatment process such that there is a slight tendency toward a precipitating condition.

Prior investigations at the Peace River site wellfield showed that recovery efficiency (the ratio of the volume of water recovered at a given quality to the total volume of water stored) was highest where the wells were installed in a symmetrical pattern. Prior investigations also indicated improved recovery efficiency for operations where storage and recovery of water was somewhat balanced among wells. This could be accomplished more easily if the performance of the wells were uniform.

Static-water levels in the wellfield are about 12 feet above ground surface, or about five pounds per square inch (psi) wellhead pressure. The limiting condition for well performance occurs when the wells are in an injection mode, when injection pressures are limited to the prevailing pipeline pressure of about 70 psi (162 feet).

Given a target injection capacity of about 700 gallons per minute (gpm), a minimum specific injectivity (defined herein as the volume rate of injection in gpm per foot of water-level increase during injection) of about five gpm per foot was targeted. Eight wells exhibited specific injectivity near or below the target value during the initial storage cycle. Nonetheless, the CO_2 was delivered to all wells in the wellfield as part of the initial testing.

Well Stimulation Program

Sodium hydroxide (caustic soda), a strong alkaline compound, is used to modify the pH of water in the treatment process at the Peace River Facility. Sodium hydroxide is added at three locations in the treatment process before the treated water is distributed to the water supply authority's customers or routed to the ASR wells for storage. The authority targets a finished-water pH in the range of 7.2 to 8.5. On average, the pH of the finished water is about 8.2.

Given the average chemistry of the finished water, a pH of 8.2 yields a saturation index near zero, indicating that the water is stable or has a slight tendency to deposit calcium carbonate. This condition is desirable in terms of utility pipelines and service facilities because it affords protection against internal corrosion. Unfortunately, this same tendency to precipitate calcium carbonate may be responsible for loss of injection capacity in the ASR wells by causing a plugging of the wells at the face of the wellbore.

There were a number of factors that suggested use of carbon dioxide (CO_2) for stimulating well performance:

1. Its use had already been successfully demonstrated at the site on an existing well.
2. It is relatively safe and easy to handle.
3. It was anticipated that a reduction in pH of the finished water by 0.5 to 1.0 pH units with CO_2 would reverse the tendency toward plugging the wells.
4. As an acid, there are no unwanted salt ions like chloride or sulfate associated with adding CO_2.

Carbon dioxide is effective for pH adjustment because it alters the carbonate species equilibrium. The addition of carbon dioxide produces a weak acid. Although as a weak acid, it takes a much larger relative dose of carbon dioxide to effect a pH change than would result from the addition of a hard mineral acid such as sulfuric or hydrochloric acid, there are few risks in handling the material and no issues related to disposing spent byproducts, as is the case with the mineral acids.

A pilot injection test was conducted over a six-day period in September 2002. The goal was to test the response of the ASR wells to a pH adjustment between 0.5 and 1.0 pH units. Initial estimates of CO_2 requirements indicated a dosing rate of less than 10 milligrams per liter carbon dioxide.

The pilot testing involved treating the entire flow stream delivered to the ASR wellfield, an average of about 8 mgd. Accordingly, initial estimates indicated a need for CO_2 to be supplied at a rate of less than 25 pounds per hour. Liquid CO_2 was delivered and stored on site in a 19-ton refrigerated tanker truck.

The main considerations in selecting a location for setup of the CO_2 injection facilities involved the following:

1. Security – it was desirable to install the temporary facilities at a location that would permit easy surveillance and protection.
2. Convenience – to allow ready access for measurements and adjustments, and to allow rapid shutdown of the system in the event of a loss of power.
3. Mixing and reaction time – the injection point was selected to allow for complete mixing of the CO_2 prior to its arrival at the ASR wells. There is approximately one mile of piping between the injection point and the ASR wellfield. While this distance was judged to provide ample opportunity for mixing and reaction time, there was some concern over the excessive feedback time of nearly one hour between the site of injection and the point at which pH in the treated stream is measured.

The equipment installed for pilot testing provided the means for metering and adjusting CO_2 injection; however, the dose of CO_2 required was so small that it was difficult to precisely meter and control it with the equipment provided. It proved easier to adjust CO_2 injection rates according to pH measurements at the wellfield as a way to maintain pH values in the range of 6.9 to 7.6.

An existing air-release/vacuum valve on

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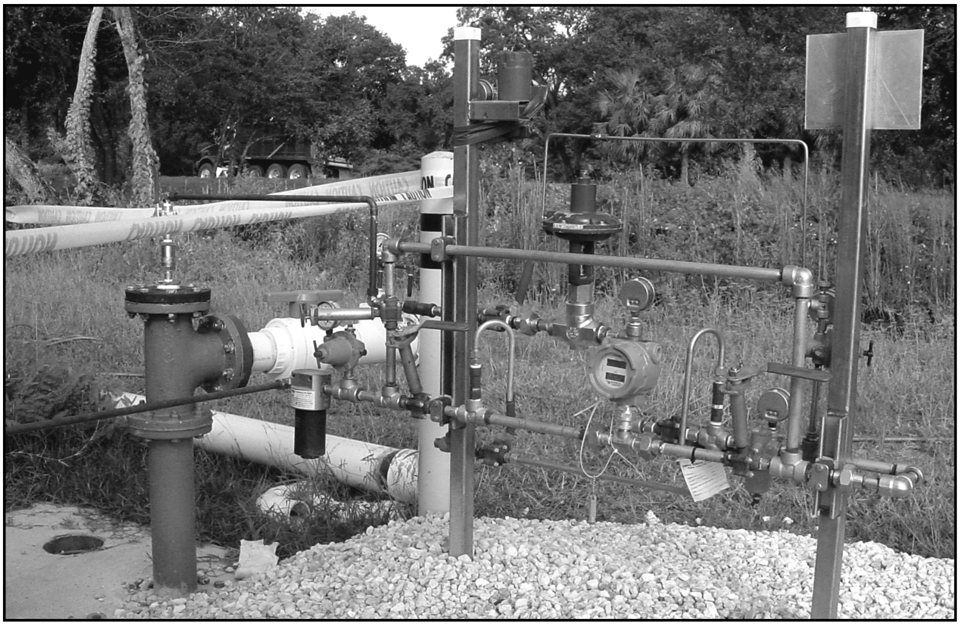

Figure 4. Piping for CO_2 injection.

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the supply line to the ASR wellfield was removed and replaced with a tapped blind flange. A custom-made injector was inserted into the tap and the CO_2 was fed at a controlled rate. A special injector fabricated by the supplier of the CO_2 was used to promote mixing and efficient transfer of CO_2 gas to the water. The refrigerated CO_2 storage tank used during testing is shown in **Figure 3**. The piping for injection of CO_2 into the pipeline feeding the ASR wellfield is shown in **Figure 4**.

Results of the CO_2 Injection Program

The pilot injection test was conducted over a six-day period in September 2002. Eleven of the 12 new wells were involved in the testing. One well had not yet been equipped with permanent pumping equipment and was not included. The pH during the test period ranged from 6.9 to 7.6, compared with a typical finished-water pH of 8.2. The total volume of water injected during this period was about 55 million gallons. Total CO_2 used during the 144 hours of testing is estimated to be about 3,000 pounds.

Specific injectivity, the ratio of the rate of injection in gpm to the water-level buildup in feet, was used as a measure of well performance. Excluding three wells whose specific injectivity exceeded design goals at the start of the pilot injection testing, average injectivity of wells prior to CO_2 injection was 2.2 gpm/ft, while the average injectivity following CO_2 injection was 4.5 gpm/ft, representing an improvement in well performance of over 100 percent.

Figure 5 shows the change in specific injectivity over time, beginning before the start of CO_2 injection. Excluded from this figure are the three wells whose injectivity values were initially high and tended to obscure changes in the remaining eight wells, and also the well not included in the testing because it was not equipped with permanent pumping equipment.

Specific injectivity can be seen to decay in the days following the conclusion of the injection period. Injectivity has remained somewhat stable since the initial testing, although it will likely continue to decrease over time.

The authority is currently evaluating several alternatives for addressing the tendency for gradual well plugging during water-storage cycles. Among the alternatives are permanent facilities for automated injection of CO_2 and bypassing the caustic soda addition with a portion of the flows intended for storage in the ASR wellfield. The rate of flow of the bypass stream would be regulated to maintain pH targets for water delivered exclusively to ASR storage.

Summary

Carbon dioxide injection was highly effective in improving the performance of ASR wells in an environment where plugging appears to be related to carbonate precipitation in the wellbore. Well performance was increased over the short term by over 100 percent. The mechanism for well improvement is likely related to the shift in carbonate species equilibrium associated with a change in pH brought about by the CO_2 injection.

The use of CO_2 has advantages over the more conventional use of hard acids like hydrochloric or sulfuric acid for well stimulation. It is much safer and easier to handle. It is a weaker acid and does not have the potential to damage the formation if over-applied. It does not add chloride or sulfate to the water being treated. It was found that a relatively small adjustment of pH was needed to effect a positive improvement in injectivity.

There is a tendency for resumed plugging and decline in well performance. The Peace River/ Manasota Regional Water Supply Authority is currently investigating permanent installation of a CO_2 injection system for maintaining and improving performance of their ASR wells.

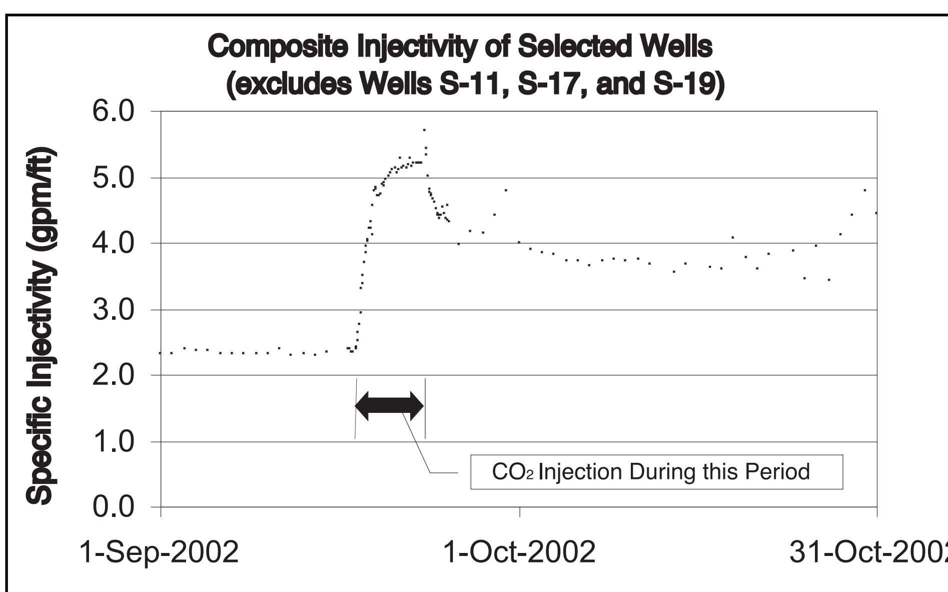

Figure 5. Graph showing well performance through the pilot testing period (selected wells excluded from analysis).